Vesicular Basalt Provisioning Practices Among the Prehistoric Hohokam of the Salt-Gila Basin, Southern Arizona

by

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ABSTRACT

This study evaluates five different hypotheses potentially accounting for the prehistoric movement of vesicular basalt during the Hohokam occupation of the Salt-Gila Basin (ca. A.D. 700-1450): 1) direct procurement; 2) direct exchange; 3) down-the-line exchange; 4) market exchange; and 5) elite-controlled exchange. The plausibility of each hypothesis is assessed by examining the relative frequency of different vesicular basalt source types at sites as related to the geographic distance from their source; intra-site variance in vesicular basalt source type diversity; inter-site variance in vesicular basalt source type diversity; and temporal specificity and continuity in source preference. The study sample is comprised of 484 vesicular basalt artifacts recovered from nine Hohokam sites: Casa Grande, Gila Crossing, the Hospital Site, La Plaza, Las Colinas, Los Hornos, Lower Santan, Pueblo Grande, and Upper Santan. Geographic provenance data for artifacts are generated by comparing their chemical composition to a geochemical reference database composed of more than 700 vesicular basalt raw material samples from 17 different source areas in the Salt-Gila Basin. Geochemical data for both artifact and raw material samples were collected using a portable X-ray fluorescence spectrometer and a newly developed sampling procedure that provides an efficient, reliable, and nondestructive means of analysis.

The results of the hypothesis testing found that direct procurement is a possible material provisioning practice for perhaps only a small number of households in the Salt-Gila Basin; specifically those located less than 10 km from a vesicular basalt outcrop. Direct exchange is also an unlikely explanation, though it cannot be rejected outright. The other exchange hypotheses, down-the-line, market, and elite-controlled exchange, as defined in this study, are all rejected as possible explanations. From these results, a new model of Hohokam vesicular basalt provisioning practices is developed for future testing. This model posits that vesicular basalt groundstone tools were produced by specialists in a handful of locations during both the Preclassic and Classic periods, and that finished tools were acquired through workshop procurement or local distributers. The implications of these findings for understanding the organization of Hohokam domestic and political economies are also discussed.

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CHAPTER 1: INTRODUCTION TO RESEARCH PROBLEM AND OVERVIEW OF THE STUDY

It is the year A.D. 1000. The setting is a large indigenous village in a place that would later become the sprawling metropolis of Phoenix, Arizona. A group of women are hard at work grinding dry maize kernels into a fine meal with large stone tools. Behind them, smoke from a hearth seeps from the roof of a dome-shaped waddle-and-daub structure, their home. Elsewhere, other members of the village are conducting various tasks, including painting pottery, weaving textiles, hauling fire wood, constructing additional dwellings, and returning from a successful deer hunt. Just beyond the village, fields of corn, beans, and squash are being fed with water diverted by hand-made irrigation ditches. Further afield, a large precipitous mountain range extends from the desert floor, overlooking the small village and its surrounding fields. Altogether, it is a quintessential image of the prehistoric Hohokam people who made their living along the Salt and Gila Rivers of the Sonoran Desert in southern Arizona (Figure 1.1).

Something is out of place in the image, though. Something so mundane, that it does not cross the mind of most people who see it. In fact, most archaeologists who study the Hohokam don’t even think much about it. The item, or rather items, of interest are the grinding stones. These tools are not out of place in the village scene per se, as grinding stones are extremely abundant at Hohokam archaeological sites. They are also known to have been regularly used by the descendents of the Hohokam, the Akimel O’odham, who still live in the area to this day. However, the stones are not in their natural context. Hohokam grinding implements were often manufactured from vesicular basalt, a dark

Figure 1.1. Depiction of a Prehistoric Hohokam Village (courtesy of Scott Seibel, artist, and used with permission of Friends of the San Pedro River)

gray to black igneous rock that is well known for its porous or bubbly texture. Intriguingly, though, vesicular basalt is not naturally abundant in the Phoenix area, being relegated to portions of a handful of bedrock outcrops. Thus, the stone had to be transported some distance before use in Hohokam households.

Given the disparity between the natural availability of vesicular basalt and its frequency in archaeological contexts, the question easily arises: how did the women in the village scene acquire the volcanic stone? Did they or their husbands procure it themselves by travelling to the geological source of the material, extracting it, and then hauling it back without the aid of beasts-of-burden? Or did they receive it from a relative or close friend who lived near the source and manufactured grinding tools to exchange as gifts during social events? Perhaps the family obtained the stone from trading partners in an adjacent village, who in turn received the stone from someone else located closer to the source. There is also a possibility that the family acquired vesicular basalt grinding tools from a stranger during market-like gatherings that occurred every now and again during communal ceremonies in their own village. Another thought is that the stone was brought to the site and then redistributed to the family by an unrelated, elite-member of their village who had increased access to exchange partners living in communities located near vesicular basalt outcrops. Is there another explanation?

The research presented in this dissertation seeks to determine the primary means by which Hohokam households acquired vesicular basalt used in groundstone tool production. This is no simple task. If it was, then one of the many preeminent Hohokam archaeologists who have worked in the region over the last century would surely have figured it out by now. So what is it that limits archaeologists from fully understanding this topic? Well, first, it is not possible to get a full answer from the Akimel O'odham ethnographic record. These accounts mainly note that the stone was "from the surrounding hills" and provide no specific information about the acquisition process (e.g., Russell 1908:109). Additionally, by the time the first ethnographers reached the area, the Akimel O'odham had already acquired several Euroamerican goods that might have affected the need for vesicular basalt and possibly also the nature of its acquisition, including metal kitchen wares, wagons and carts, beasts-of-burden, and new food resources and technologies (e.g., canned goods). The appropriation of river water by

Euroamerican settlers in late nineteenth and the ensuing negative impacts on Akimel O'odham agriculture may have also reduced the demand for vesicular basalt grinding stones. Thus, even if it were known, historical vesicular basalt provisioning practices are likely not applicable to the prehistoric Hohokam.

A second reason for the poor understanding of Hohokam vesicular basalt provisioning practices is the absence of an efficient and reliable analytical method for determining the geographic origin of groundstone. The ability to tie archaeological provenience (i.e., where an artifact is recovered) with natural provenance (i.e., where it originates in nature) is known in the archaeological community as "sourcing". Sourcing studies are important for reconstructing the organization of prehistoric material transfers because certain acquisition and distribution practices will lead to temporal or spatial patterns in artifact provenance data that archaeologists can detect. Thus, by not having a proper method for determining the origin of vesicular basalt, it is not possible to create provenance datasets that are useful for evaluating different ideas on how Hohokam households acquired vesicular basalt.

If the primary objective of this study is to determine how the Hohokam provisioned themselves with vesicular basalt groundstone tools, then a secondary goal of this research must be the development of an efficient and reliable sourcing methodology. Again, this is not an easy task. The effort ultimately involved improving my understanding of basic atomic physics, delving into the complex geological history of the Basin and Range territory in southern Arizona, experimenting with recent advances in portable X-ray spectrometers, and personally trekking across miles of mountainous terrain to collect and haul back hundreds of vesicular basalt samples for compositional analysis. I believe, thankfully, that these efforts have paid off. The result is a capable analytical technique for sourcing vesicular basalt groundstone artifacts and, consequently, an improved understanding of Hohokam groundstone material procurement and distribution practices. This dissertation details the background, hypothesis, methods, results, and conclusions of the research effort.

The Hohokam and Vesicular Basalt Groundstone

The cultural focus of this study is the prehistoric Hohokam of southern Arizona (Figure 1.2). The name Hohokam derives from the Akimel O'odham word *Huhugam*, which is often translated as "those who have gone before" and is used by the O'odham when referring to all of their ancestors. Archaeologists use the term Hohokam as a label for a prehistoric cultural complex that once existed in the O'odham territory from approximately A.D. 1-1450. Definitive material characteristics of the Hohokam include large-scale irrigation works, organized settlement complexes, communal ballcourts and platform mounds, a suite of finely-crafted goods such as figurines and palettes, exotic imports, and a cremation burial ritual (Bayman 2001; Crown and Judge 1991; Doyel 1991a; Haury 1976; Gumerman 1991; Fish 1989; Fish and Fish 2008; Gladwin et al. 1937). Researchers have also found evidence suggesting that the Hohokam developed a highly specialized and integrated regional economy (Abbott 2000, 2009; Abbott et al. 2007a; Abbott et al. 2007b; Crown 1991; Doyel 1991b; Kelly 2013; Watts 2013), a shared ritual ideology (Doyel 1991a; Wilcox 1987; Wilcox and Sternberg 1983), and

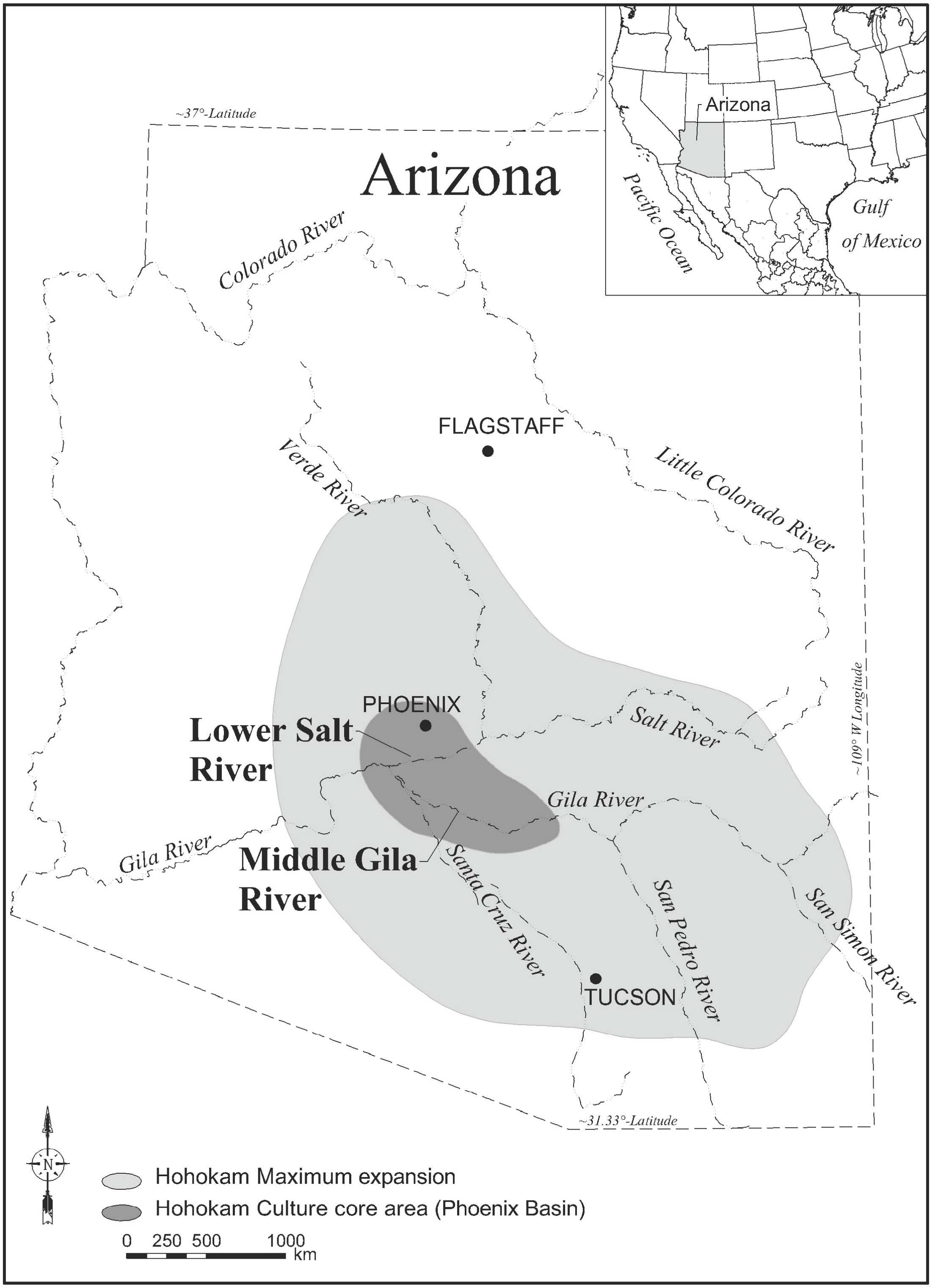

Figure 1.2. Map of Arizona Showing the Hohokam Cultural Territory.

complex social and political relations (Abbott et al. 2006; Doyel 1987, 1991a; Fish and Fish 1991, 2000; Gregory 1987; Gregory and Nials 1985; Howard 2006; Wilcox 1991).

The heartland or "core" of the Hohokam culture tradition was the Salt-Gila Basin (Figure 1.3), where the prehistoric "desert farmers and craftsman" thrived for over one thousand years (Haury 1976). The long-term success of the Hohokam was rooted in a solid agrarian economy. Throughout the Preclassic (Colonial and Sedentary periods; ca A.D. 700-1150), they constructed and maintained a vast network of canals alongside the Salt and Gila Rivers (Cable and Doyel 1985; Doyel 1991a; Gregory 1994; Howard 1987; 2006; Howard and Huckleberry 1991; Woodson 2010, 2013). These canals were used to divert river water into irrigated fields of corn, beans, and squash. Select wild resources, including chenopod, amaranth, pigweed, and globemallow, were also likely encouraged and exploited along the water control features (Gasser 1981; Gasser and Kwiatkowski 1991:437). By the end of the Classic period (ca. A.D. 1150-1450), the irrigation infrastructure had cumulated into one of the largest and most sophisticated systems in prehistoric North America. One scholar, Jerry Howard, estimates that the irrigation system comprised hundreds of kilometers of main and distribution canals and permitted the cultivation of tens of thousands of hectares (Howard, J. 1993, 2006; see also Woodson 2010, 2013).

A heavy reliance on domesticated crops and other cultivars by the Hohokam necessitated the use of grinding tools, namely stone manos (i.e., hand stones) and metates (i.e., mealing stones). These tools were needed by households to process plant parts into edible forms prior to consumption (Adams 1989, 1999; Eddy 1964; Greenwald 1990;

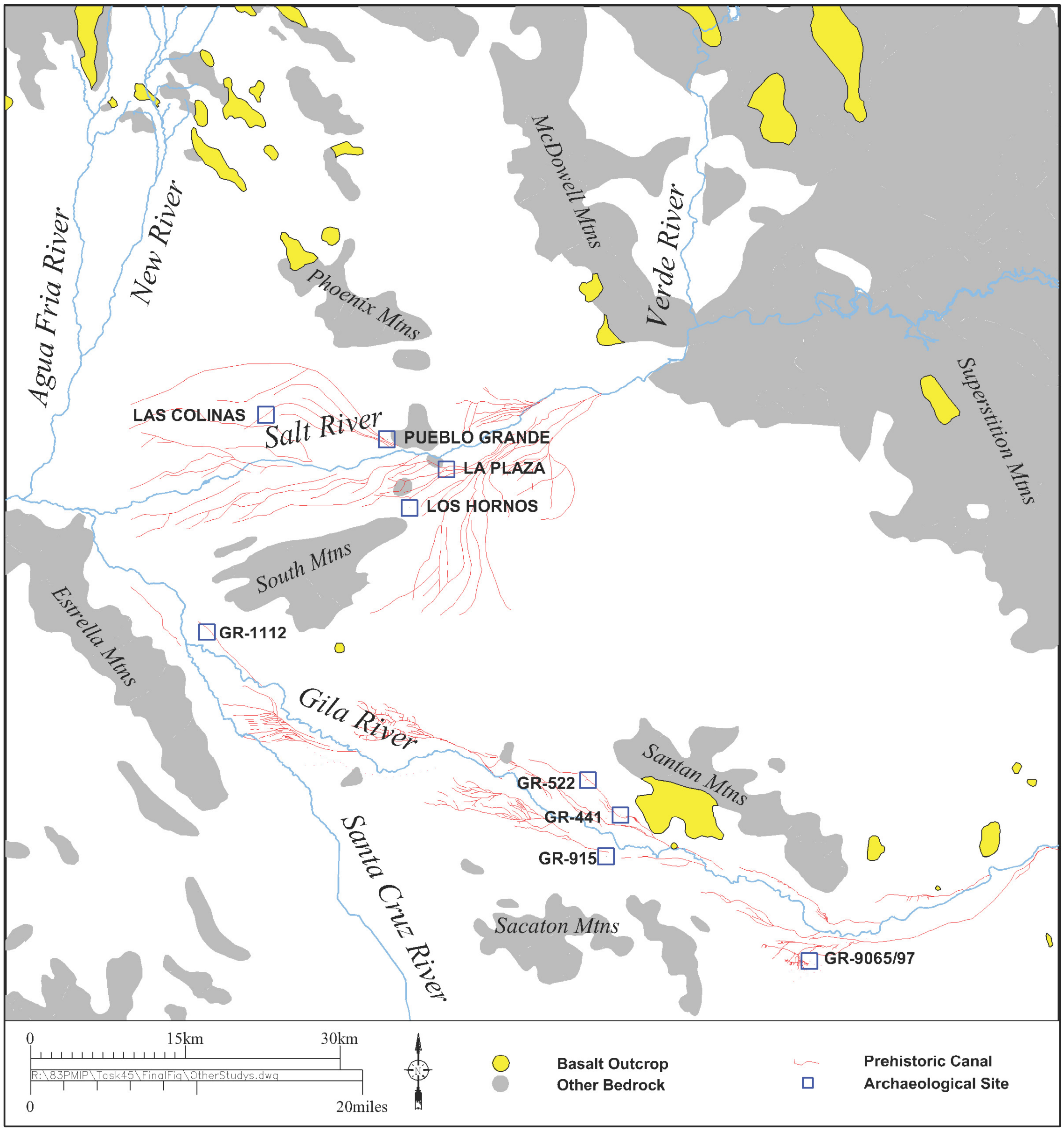

Figure 1.3. Map of Irrigation Networks and Relevant Villages within the Hohokam Core Area.

Mauldin 1993; Russell 1908). Hohokam manos are traditionally divided into one-handed and two-handed types (Gladwin et al. 1937; Haury 1945, 1976). One-handed manos are oblate spheroids that are usually manufactured with very minimal effort from conveniently sized river cobbles (Figure 1.4). Two-handed manos are ovate to tabular in shape and are typically formed from bedrock talus (Figure 1.5; Schlanger 1991; Stone 1994a). Hohokam metates are also subdivided using morphological criteria into slab, basin, and trough forms. “Slab metates lack definable shoulders, whereas basin metates consist of concave grinding surface surrounded on all sides by an informal shoulder, and trough metates consists of rectangular grinding surfaces flanked on two sides by definable shoulders” (Figures 1.6–1.8; Stone 1994a:14). Both manos and metates are classified by archaeologists as groundstone tools because the stone is ground into its current shape during initial production and through subsequent use.

Figure 1.4. Hohokam One-handed, Ovoid Manos

Figure 1.5. Hohokam Two-handed Rectangular Manos

Figure 1.6. Hohokam Granite Slab Metate.

Figure 1.7. Hohokam Andesite Basin Metate.

Figure 1.8. Hohokam Vesicular Basalt Trough Metate.

The importance of groundstone tools to the agrarian farmers of the Salt-Gila Basin has long been recognized by archaeologists working in the region (e.g., Gladwin and Gladwin 1929; Gladwin et al. 1937; Haury 1945, 1976). Emil Haury (1976:281), for instance, stated that the metate was "highly prized" and the most enduring element of the Hohokam cultural complex. A similar sentiment was given by ethnographer Frank Russell (1908:95) in his account of the Akimel O'odham, when he said that the "metate admits no wooden substitute, and without it the full food value of maize could not have been utilized…" As perhaps the most important subsistence tool to indigenous populations in the region, it is no surprise that groundstone tools are one of the most abundant archaeological artifacts in the Hohokam cultural territory (Haury 1976; Russell 1908).As an example, intensive archaeological excavations at the core Hohokam village of Pueblo Grande led to the recovery of more than three thousand groundstone tool fragments (Stone 1994a), while the recovery of projectile points, bifaces, and knives totaled just over a few hundred artifacts combined (Peterson 1994).

A cursory examination of groundstone tool collections from Hohokam sites in the Salt-Gila Basin also reveals that the majority of prehistoric groundstone tools were manufactured from vesicular basalt (defined in this study to include any textured intermediate-mafic [i.e., andesite-basaltic] stone (see Bostwick and Burton 1993). For instance, the igneous stone accounts for 79 percent (n=43/56) of the excavated groundstone sample at the site of Grand Canal Ruins in the lower Salt River valley (Mitchell 1989), and 76 percent (n=111/146) of the recovered assemblage at the village of Upper Santan in the middle Gila Valley (Woodson and Loendorf 2014). Project records further reveal that the Hohokam typically used vesicular basalt specifically for the production of two-handed tabular-shaped manos and trough metates (see Stone 1994b). These two tools were likely components of a single tool complex, since maximum grinding potential is fulfilled when a mano that fits border-to-border within the metate troughs is moved in a reciprocal motion (Adams 1999:482).

The Hohokam may have preferred the use of vesicular basalt in groundstone tool manufacture for several reasons. First, basalt is a relatively dense stone. As such, the material can effectively grind plant parts without wearing away too quickly or introducing grit into the food that is being processed (Adams 1999; Greenwald 1990; Hayden 1987; Horsfall 1987). Second, natural cavities in the rock provide a rough surface that is ideal for shearing large-grained domesticates, such as corn, the mainstay of the Hohokam diet (Adams 1989, 1999; Mauldin 1993; Stone 1994b:68; Schneider 2002). Third, the vesicles allow the stone to maintain an effective grinding surface after repeated use, whereas other material types, such as granite, must be regularly roughened to maintain grinding efficiency (Greenwald 1990; Horsfall 1987). Lastly, basaltic material in the Salt-Gila Basin often features coarse-grained mineral inclusions (i.e., phenocrysts and xenocrysts) among a predominately fine-grained matrix. These inclusions further promote the shearing and self-renewing qualities of the rock surface by contributing to the heterogeneous texture (Hayden 1987; Horsfall 1987; Schneider 2002).

Although vesicular basalt was preferred by the Hohokam for groundstone manufacture, the stone was not readily available to most prehistoric households. Material large enough for the production of two-handed manos and trough metates is extremely uncommon in the lower Salt and middle Gila River channels, and is completely absent in the majority of the bedrock outcrops in the region (Drosendahl 1989; Kokalis 1971; Reynolds and Bartlett 2002; Reynolds and DeWitt 1991; Richard et al. 2000). Basaltic material of suitable size for groundstone tool production is found at only a dozen or so geologically discrete locations within the Hohokam core territory, including select portions of the Phoenix, McDowell, and Santan Mountain ranges; Lone Butte; and several outcrops near the town of Florence (Figure 1.9; Table 1.1). Additional material source areas are found beyond the irrigated core in an area referred to as the Hohokam periphery. Basalt outcrops in these areas include Adobe Mountain, West Wing Mountain, and the Deem, Hedgpeth and Union Hills to the north; the Vaiva Hills and Table Top Mountains to the south; and Robbins and Powers Buttes to the west (Anderson 1989; Bostwick and Burton 1993; Leighty 1997; Richard et al. 2000; Rubenstein et al. 1995; Wilson et al. 1963). Thus, as a preferred, but not naturally ubiquitous raw material, vesicular basalt was often transported some distance before Hohokam households could use it.

Five different hypotheses potentially explain how the Hohokam moved such large quantities of vesicular basalt from quarry and manufacturing locales to habitation sites. First, it is possible that individuals acquired the material by procuring it themselves directly from the closest available source area (Euler 1989; Stone 1994a, 2003). This explanation is known as the *direct procurement* model. Second, it is possible that individuals obtained the textured stone through reciprocal exchange relations with close kin or trade partners (Bruder 1982, 1983a; Doyel 1985a; Marshall2007; Mitchell 1989).

This theory is termed the *direct exchange* model. Third, raw material and, more likely, finished tools may have been moved over large distances via multiple reciprocities through *down-the-line exchange*. Fourth, groundstone tools may have been produced by specialists and then acquired by consumer households through some variant of *market*

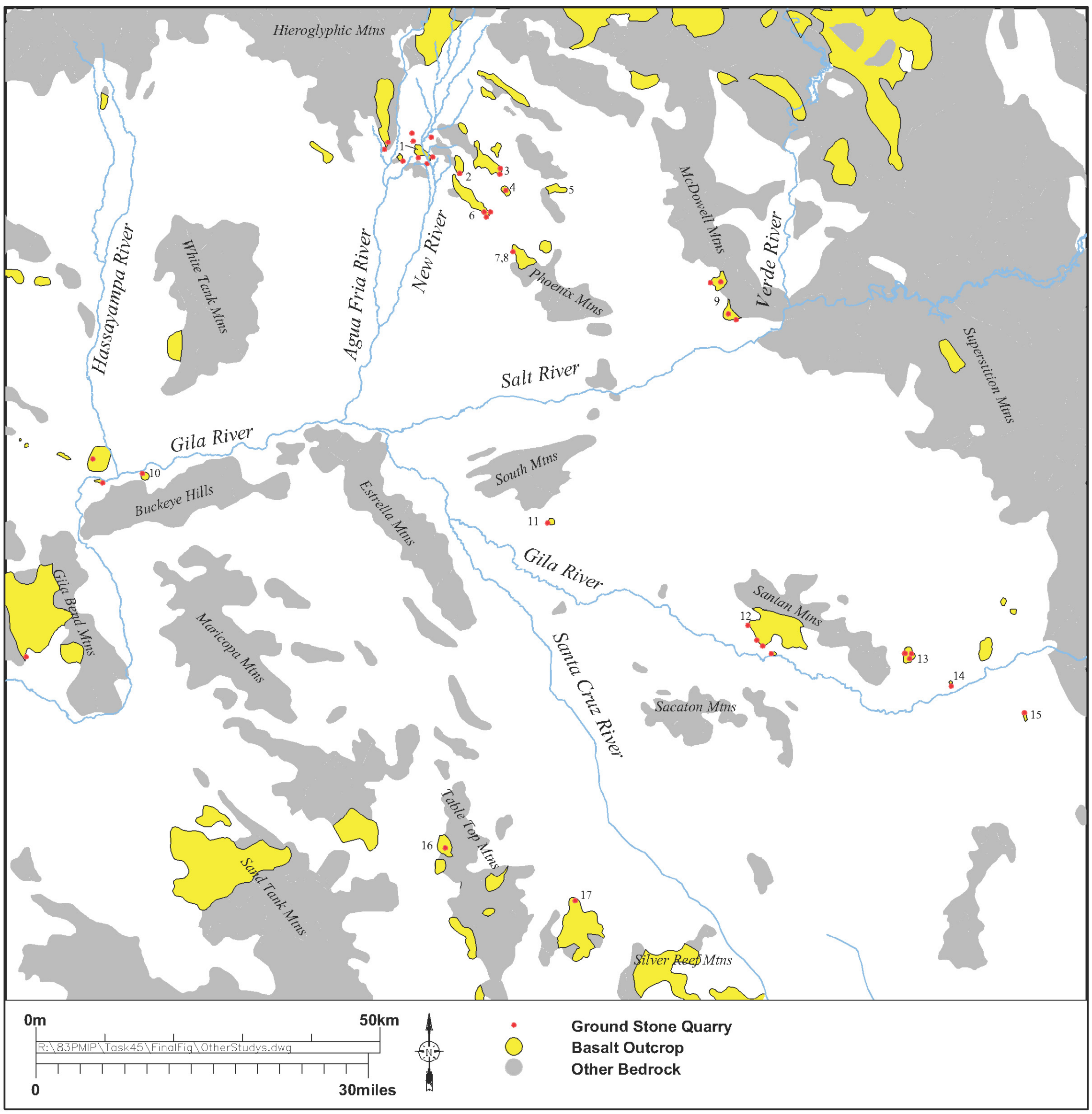

Figure 1.9. Map of the Salt-Gila Basin Showing Vesicular Basalt Outcrops and Prehistoric Hohokam Quarry Sites (see Table 1.1 for key to numbered locations).

Table 1.1. Vesicular Basalt Outcrops Reference Table

Source No.	Source Area Name	Source No.	Source Area Name
1	West Wing Mtn	10	Robbins Butte
2	Ludden Mtn	11	Lone Butte
3	Deem Hills	12	Santan Mtns
4	Adobe Mtn	13	Florence Cinder Mine
5	Union Hills	14	Poston Butte
6	Hedgpeth Hills	15	Picture Rocks
7	Moon Hill	16	Table Top Mtn
8	Shaw Butte	17	Vaiva Hills
9	McDowell Mtns		

exchange (Abbott 2009, 2010; Abbott et al. 2001; Abbott et al. 2007a; Abbott et al. 2007b; Doyel 1985a; Watts 2013). Lastly, Hohokam households may have acquired the stone from local elites who managed the distribution of the material for their own personal gain (Bayman 1994, 1995, 2002; Doyel 1985a, 1991a, 1991b; Teague 1984). This explanation is referred to as *elite-controlled exchange*. Notably, there is probably no one-size fits all explanation, as vesicular basalt provisioning practices are anticipated to vary depending on the proximity of a households to material source locations and other culture-historical factors.

Previous attempts have been made to determine which hypothesis (or hypotheses) best accounts for the prehistoric movement of vesicular basalt in the Salt-Gila Basin. The principal analytical method employed in these studies has been geographic provenance analysis (i.e., sourcing), which seeks to identify the spatial origin of groundstone artifacts through an evaluation of their physical or geochemical composition and, subsequently, to interpret any meaningful patterns among the resultant provenance dataset. Analytical techniques previously used to characterize the composition of vesicular basalt artifacts include microscopic petrography, macroscopic petrography, and geochemical assays (e.g., Bostwick and Burton 1993; Doyel 1985a; Marshall 2007; Rubenstein et al. 1995; Stone 1994a; 2003). Although use of these techniques has shed some insight on Hohokam vesicular basalt movements (see Stone 1994a, 2003), they remain largely ineffective due to instrumental and methodological limitations in the characterization of raw material sources and artifacts. The lack of an effective analytical technique has stalled Hohokam provenance studies by preventing the creation of a large representative source database useful for evaluating provenance classifications for single groundstone artifacts. This situation also means that there is not a valid method for producing large artifact provenance datasets that are needed for evaluating different hypotheses concerning Hohokam vesicular basalt provisioning practices.

Research Objectives

Given the present state of Hohokam vesicular basalt provenance research, the objective of this study is both methodological and substantive. The methodological objective is to develop a practical and reliable analytical technique for determining the geographic origin of vesicular basalt used by the Hohokam for groundstone tool manufacture. Substantively, the objective is to better understand the primary means by which prehistoric Hohokam households acquired vesicular basalt during the Preclassic and Classic. This second goal is achieved by applying the newly developed analytical method to produce a large vesicular basalt provenance dataset useful for evaluating the five different hypotheses potentially accounting for the movement of the textured stone from quarry locations to household contexts.

Development of Portable X-ray Fluorescence Spectroscopy for Hohokam Vesicular Basalt Provenance Analysis

This study seeks to develop the utility of portable X-ray fluorescence spectrometry (PXRF) for assessing the geographic provenance of Hohokam vesicular basalt groundstone artifacts. Compared to other compositional analysis techniques, PXRF has a number of practical advantages for the intended task. First, the technique does not require the modification of specimens prior to or during analysis. Second, PXRF is inexpensive compared to most other analytical instruments (Shackley 2008; 2011). The affordability and nondestructive nature of PXRF permits the efficient analysis of a larger number of samples, thus yielding a more robust and potentially more meaningful provenance and archaeological datasets. Third, PXRF instruments, like the one that is used in this study, are available as hand-held devices. The ability to place handheld analyzers in any position during analysis helps to avoid sample size limitations commonplace to most laboratory and desktop instruments, a major concern in the study of large and heavy groundstone artifacts. Finally, the ability to transport the device to curatorial facilities circumvents possible legal and financial complications arising from obtaining artifacts on loan and transporting them to other locations for study.

Although there are several practical benefits of using PXRF for this research, there are two analytical limitations related to the nondestructive analysis of unmodified vesicular basalt samples that first need to be addressed. First, one of the primary challenges in analyzing unmodified samples is generating a reliable (i.e., precise and accurate) geochemical measurement. Irregular sample morphology, irregular surface texture, variable particle size, and geochemical variability affect the reliability of XRF through the physical phenomena of X-ray attenuation, absorption, interference, and enhancement (Davis et al. 2011; Forster et al. 2011; Jenkins 1999; Lachance and Claisse 1995; Lundblad et al. 2011; Potts et al. 1997; Shackley 2011). These phenomena can lead to a mischaracterization of sample chemistry by suppressing or over representing fluorescence X-rays from constituent elements. For example, denser particles within a specimen have the potential to attenuate or block fluorescent X-rays from escaping the sample, thereby resulting in an improper representation of sample chemistry (Jenkins 1999:145).

In order to improve the reliability of nondestructive PXRF for Hohokam vesicular basalt provenance analyses three experiments are conducted. The aim of these experiments is to determine: 1) the minimum analysis time necessary to yield a consistent geochemical measurement for a single-spot assay; 2) the minimum number of differently-placed assays needed to produce a consistent characterization of sample geochemistry; and 3) whether the minimum analysis requirements are able to generate accurate geochemical data. The results of these three experiments are used to develop an efficient and reliable PXRF data collection procedure for the nondestructive analysis of unmodified vesicular basalt raw material and artifact samples, thereby providing the means for developing a robust raw material reference and artifact source provenance databases.

A second main concern in using PXRF for this study is that the Provenance Postulate has not yet been satisfied for Hohokam vesicular basalt provenance analyses. The Provenance Postulate states that artifact sourcing is possible as long as there exists some qualitative or quantitative difference among the relevant source areas that exceeds in some manner the variation within them (Weigand et al. 1977:24). The basaltic outcrops in the Salt-Gila Basin were created from multiple, expansive, and long-term flow events (Leighty 1997). Temporal and spatial variability in these flows has resulted in substantial heterogeneity within a single source area, and subtle differences among adjacent exposures, potentially making artifact provenance assessments difficult, if not impossible. It is promising, though, that previous analyses have found geochemical variation among a handful (n=35) of samples from six material source areas exploited by the Hohokam (Marshall 2007; Rubenstein et al. 1995). However, a much larger sample of raw material from these and other source areas in the region is needed to adequately evaluate the Provenance Postulate for Hohokam vesicular basalt sourcing studies.

To determine if there is sufficient geochemical variation among the basaltic outcrops in the Salt-Gila Basin to permit sourcing analyses, the data collections procedures identified in the experiments described above will be used in the analysis of 738 raw material specimens from 17 locations known to be exploited prehistorically by the Hohokam. The scale of this analysis is far greater than any previous vesicular basalt sourcing study in the Hohokam region. It therefore provides the most comprehensive source reference database to date for evaluating the Provenance Postulate. Geochemical data that are generated in the analysis of this large sample will be evaluated for intra- and inter-group variability, as well as the feasibility of sourcing vesicular basalt used for groundstone manufacture. The results of these assessments will then be used to determine the geographic origin of vesicular basalt groundstone artifacts from archaeological sites, thereby permitting the creation of a provenance dataset useful for evaluating different hypotheses about Hohokam vesicular basalt provisioning strategies.

Eliminating Potential Hypotheses of Hohokam Vesicular Basalt Provisioning Practices

The substantive goal of this study is to better understand the means by which prehistoric Hohokam households in the Salt-Gila Basin obtained vesicular basalt raw material and finished groundstone tools. This objective is accomplished by evaluating the viability of the five different hypotheses that potentially explain the movement of the textured stone: direct procurement, direct exchange, down-the-line exchange, market exchange, and elite-controlled exchange. The plausibility of each of the five hypotheses is assessed by examining four variables: 1) the relative frequency of different vesicular basalt source types at sites as related to the geographic distance from their source; 2) intra-site variance in vesicular basalt source type diversity; 3) inter-site variance in vesicular basalt source type diversity; and 4) temporal specificity and continuity. Ethnographic and archaeological case studies suggest that different provisioning practices will generate vesicular basalt provenance data patterns within the archaeological record that are specific to one or more of the four variables. Therefore, by evaluating the four variables against the archaeological expectations associated with each provisioning practice, it will be possible to reject or find support for the research hypothesis.

Because vesicular basalt provisioning practices may have differed across space and time, the variable testing and hypothesis evaluation will involve a provenance analysis for vesicular basalt groundstone artifacts from nine Hohokam sites: Casa Grande (GR-9065, GR-9067), Gila Crossing (GR-1223), the Hospital Site (GR-915), La Plaza (AZ U:9:165 (ASM)), Las Colinas (AZ T:12:10 (ASM)), La Ciudad de los Hornos (AZ U:9:48 (ASM)), Lower Santan (GR-522), Pueblo Grande (AZ U:9:1 (ASM)), and Upper Santan (GR-441). All of these sites represent the remains of large Preclassic and/or Classic period Hohokam communities throughout the lower Salt and middle Gila River valleys (see Figure 1.3). A total of 484 vesicular basalt groundstone artifacts from these sites are subjected to geographic provenance analysis using the newly developed analytical methods for nondestructive PXRF. This large, spatially and temporally variable artifact provenance dataset will help to refine scholarly understandings of Hohokam vesicular basalt provisioning activities by providing the information necessary for evaluating the test predictions related to each of the four test variables. An improved understanding of Hohokam vesicular basalt provisioning practices is thus achieved by examining the test expectations at each site and rejecting as many of the proposed hypotheses as possible.

The site-by-site evaluation of the hypotheses may also provide insight on synchronic and diachronic patterns in vesicular basalt provisioning practices and, consequently, lead to a new model of Hohokam vesicular basalt movements that can be tested in future studies. For instance, it may be found that households located in one area of the Salt-Gila Basin followed one material provisioning practices, while others located elsewhere pursued another. Similarly, the findings may suggest that vesicular basalt acquisition practices differed between the Preclassic and Classic periods. When the findings for each site are considered in aggregate, the spatial and temporal trends could possibly result in a newer or more nuanced model of Hohokam groundstone acquisition and distribution trends.

Research Significance

The methodological and substantive objectives of this study have significant implications for Hohokam archaeology, broader anthropological theory, and archaeometric research in general. One important outcome of this study is that it will provide additional information on the organization of the Hohokam domestic economy. Several scholars have argued that the Preclassic domestic economy was comparatively complex and based on a high level of community interdependence (Abbott 2006, 2009, 2010; Abbott et al. 2001a; Abbott et al. 2007a; Abbott et al. 2007b; Crown 1991; Doyel 1991b; Kelly 2013; Watts 2013). For example, Abbott (2009) has shown that core Hohokam households were reliant on producers in just a handful of localities for the full complement of vessel types and wares during this temporal interval. Abbott's observation runs counter to the common conception that prehistoric agrarian communities in the American southwest were largely self-sufficient and autonomous (cf. Plog 1989, 1995). Does this traditional perception hold true for the manufacture of vesicular basalt groundstone tools, or was the production and distribution of these implements also embedded in a highly specialized and integrated regional economy?

The findings of this study will also provide information on the Hohokam Classic period domestic economy. Hohokam archaeologists denote the Preclassic to Classic period transition as a hinge-point in Hohokam cultural history (e.g., Doyel 1980, 2000). One marked shift between these two periods was the disintegration of the above noted regionally-integrated ceramic production and exchange economy and the establishment of local self-sufficiency (Abbott 2000, 2009, 2010). Additionally, some Hohokam scholars have argued that the production and distribution of some material goods was manipulated by a small segment of the population for their own political gain (Bayman 1995, 2002; Harry and Bayman 2000; McGuire and Howard 1987; Rice 1995, 1998; Rice et al 1998; Teague 1984). Did the production and distribution of vesicular basalt groundstone differ between the Preclassic and Classic periods? If so, did this change represent a shift from a highly-integrated specialist economy to one of local self-sufficiency or, alternatively, the usurpation of household tool production by unrelated self-interested aggrandizers? The results of this study may help us to understand the broader cultural context of the Hohokam Classic period, and the social and political significance of the Preclassic to Classic period transition.

The results of this study are also significant because they will provide an opportunity to comment on the importance of regionally-scarce but important resources in the political economy and sociocultural evolution. Based on archaeological, ethnographic, and historical records, Hayden (1987, 1995) argues that control over the production and distribution of basic but non-ubiquitous resources, including groundstone material, is a means by which certain individuals or groups can gain social and political clout. Furthermore, he argues that the cultural institutions that emerge to create or maintain this managerial position spur socially-stratified societies, political elites, and even complex regional centers (Hayden 1987:106). Hayden's (1987) hypothesis can be evaluated in the context of this study since vesicular basalt was also a regionally-scarce but important raw material to Hohokam households. Additionally, at least two core Hohokam communities were located near known groundstone quarries and therefore had the potential to control the distribution of groundstone material. This study may thus provide some information on whether or not the management of the textured stone helped aspiring individuals gain elevated status in the Hohokam area (i.e., the elite-controlled hypothesis), and in a broader sense, whether Hayden's (1987) hypothesis is a valid explanation for cultural change in the Salt-Gila Basin.

The methodological findings of this study are also significant. The development of an efficient, reliable, and nondestructive compositional analysis technique for vesicular basalt provenance studies means that this research is only the beginning (hopefully) of a new chapter in Hohokam archaeology. The development and adoption of other analytical techniques for obsidian and ceramic provenance research has unleashed a wealth of new information on Hohokam social, economic, political, and even ritual organizations. Notably, the information gleaned from the movement of obsidian and ceramic goods differs slightly due to nonlocal and local availability, respectively. As a local but regionally scarce raw material, vesicular basalt provenance analyses are expected to provide another complementary perspective on Hohokam cultural practices.

Finally, this study is significant because it adds increasing support for the use of nondestructive geochemical techniques for compositional analyses of heterogeneous materials. Nondestructive PXRF is known to be an effective analytical tool for fine-grained basalt provenance analyses in the Hawaiian Islands (i.e., Lundblad et al. 2008, 2011; Mills et al. 2008; Mintmier et al. 2012) and Oceania (Grave et al. 2012). However, nondestructive PXRF has not yet been applied in coarse-grained vesicular basalt provenance analyses. Researchers in Central and South America as well as the Near East continue to apply destructive analytical techniques to understand the movement of igneous stone. This study demonstrates that the use of an efficient and nondestructive analytical technique allows for the increased analysis of raw material and artifact samples, which in turn provides a more nuanced perspective on past material acquisition and distribution practices. Therefore, the analytical methods developed and employed in this study may provide others with a general outline for improving the productivity and results of geographic provenance studies in other parts of the world were basalt or other heterogeneous igneous stone is a culturally relevant material.

Dissertation Organization

The remainder of this document is organized into six chapters. The ensuing chapter, Chapter 2, provides an overview of previous investigations on vesicular basalt movements in the Hohokam territory. Its intent is to provide pertinent information on the advantages and disadvantages of analytical techniques previous employed to assess the geographic origin of vesicular basalt groundstone tools. It ends with a discussion on the analytical advances necessary to conduct valid vesicular basalt provenance analyses and, by extension, generate datasets useful for evaluating various explanations for vesicular basalt movements in the Hohokam territory.

Chapter 3 details the five hypotheses that potentially explain how the Hohokam moved vesicular basalt raw material and groundstone tools from quarry and manufacturing locales to habitation sites. These hypotheses are based on the early observations of vesicular basalt distribution patterns, as well as more recent understandings of the Hohokam domestic economy. The discussion in this chapter first presents a description and defense for each hypothesis. It then moves on to present the test variables and predictions that are used in this research study to evaluate the validity of each model.

Chapters 4 and 5 introduce the raw material and archaeological data sample used in this study. The raw material sample presented in Chapter 4 is composed of over 700 vesicular basalt specimens from 17 different basaltic outcrops with evidence of prehistoric quarrying and tool production activities. The strategy used to identify and sample each of these locations is discussed, followed by a detailed overview of the geological and archaeological research history associated with each contributing source area. The archaeological sample summarized in Chapter 5 consists of nearly 500 groundstone artifacts from nine Hohokam sites. A brief description of these sites and the archaeological contexts from which the groundstone samples derive is provided.

Chapter 6 discusses the analytical method of the research study. This chapter begins with a basic overview of XRF theory and method. It then moves to discuss the analytical advantages and disadvantages of the technique for Hohokam vesicular basalt provenance analyses. The chapter concludes with a presentation of the development and evaluation of the nondestructive chemical data collection and source provenance protocols that are used in the current analysis of vesicular basalt groundstone artifacts. The larger intent of this chapter is to demonstrate that nondestructive PXRF is a reliable and valid technique for vesicular basalt geographic provenance analyses in the Hohokam Salt-Gila Basin.

Chapter 7 presents the results of the vesicular basalt groundstone geographic provenance analysis and hypothesis testing. The artifact provenance results for each study site are discussed in relation to the four test variables. This discussion is then used to provide grounds for rejecting potential procurement practices at each site. Next, the results from all nine sample sites are considered together to evaluate the validity of the five research hypotheses. At the end of the chapter, the results of the hypothesis testing, which ultimately fail to identify one comprehensive vesicular basalt provisioning practice for the study region, and the available provenance data patterns are considered in tandem to develop a new model of groundstone acquisition and distribution for the Preclassic and Classic period Hohokam households.

In the final chapter of the dissertation, Chapter 8, the broader implications of the study are discussed. Attention is given to two particular topics. First, the significance of the research findings in relation to scholarly understandings of the Hohokam domestic economy is summarized. This section offers a new perspective on the organization of craft production along with its social and political implications during the Hohokam Preclassic and Classic periods. Second, the importance (or, more accurately, lack thereof) of regionally-scarce groundstone material in the Hohokam political economy and as an important commodity in cultural evolution is presented. Lastly, a few final remarks are made summarizing the findings and significance, both methodology and substantive, of the study.

In sum, this research culminates in a new understanding of how the group of Hohokam women who are the focus of Figure 1.1 acquired vesicular basalt grinding tools. It also provides some information on the broader social and political context within which these women and their families made a living, thereby offering another perspective on the nature of Hohokam economic and social organization during the Preclassic and Classic periods. Methodologically, this study demonstrates the efficacy of nondestructive PXRF for Hohokam vesicular basalt provenance analysis. It is anticipated that this study is the start of a new analytical tradition in Hohokam archaeology, with aspirations for standing alongside well-established ceramic and obsidian provenance studies. More broadly, the methods developed as part of this research speak to the possible utility of nondestructive provenance analyses for compositionally heterogeneous lithic materials in other regions of the world.

CHAPTER 2: PREVIOUS RESEARCH ON HOHOKAM VESICULAR BASALT PROVISIONING PRACTICES

For three decades, Hohokam archaeologists have been aware of the long-distance movement of vesicular basalt in the prehistoric Salt-Gila Basin (e.g., Bruder 1982, 1983a, 1983b). During this time, a few ideas emerged that attempt to explain the means by which the textured stone moved from quarry and manufacturing locals to habitation sites. Some of these ideas include direct procurement (Euler 1989; Stone 1994a), balanced reciprocity (Bruder 1982, 1983a; Doyel 1985a; Marshall 2007; Mitchell 1989), and some form of elite-controlled exchange (Doyel 1985a). These various theories were based upon and, in some cases evaluated by, the results of vesicular basalt groundstone provenance analysis. This approach involves, first, determining the geographic origin of lithic material by matching its physical or chemical composition to that of known raw material source areas (i.e., "sourcing") and, second, conducting an assessment of the result provenance dataset for meaningful patterns that reject or support the alternative hypotheses.

Previous analytical techniques utilized for Hohokam vesicular basalt provenance research include microscopic petrography, macroscopic petrography, and geochemical analysis. Although these techniques are all viable and their use has led to some insight on vesicular basalt movements in the study region, they are either underdeveloped or impractical for the analysis of large archaeological datasets (Fertelmes and Loendorf 2012; Marshall 2007; Rubenstein et al. 1995; Shackley 1994a, 1995). As a result, researchers have not been able to generate the large databases needed to evaluate the

Provenance Postulate for Hohokam vesicular basalt sourcing analyses, nor permit the analysis of large sample sets needed to evaluate the various theories concerning vesicular basalt procurement and distribution practices. This chapter provides an overview and critique of previous Hohokam vesicular basalt provenance analysis. Its intention is to provide a foundation for the research hypotheses used in this research study and also demonstrate the need for a new analytical methodology.

Previous Research Methods and Results

Microscopic Petrography

Vesicular basalt provenance analyses first became an interest in Hohokam archaeology in the 1980s, when archaeological research projects first identified prehistoric groundstone quarries and tool production sites among several basaltic outcrops (e.g., Adobe Mountain, Hedgpeth Hills, and West Wing Mountain) in the Hohokam northern periphery (Bruder 1982, 1983a, 1983b; Doyel and Elson 1985; Green 1989). Investigators for these projects were quick to postulate a possible link between these quarry sites and the basalt-rich groundstone assemblages in the irrigated lowlands. One of the first to comment on this issue was Simon Bruder (1982; 1983b), who as part of the Adobe Dam Project, noted that the absence of vesicular basalt outcrops in the lower Salt River Valley probably compelled the exchange of the textured stone from the Hedgpeth Hills and Adobe Mountain to households in the Hohokam core.

The existence of a vesicular basalt exchange network between the Hohokam core and periphery was first tested during the New River Authorized Dam Project (Doyel

1985a; Schaller 1985). A total of ten samples, including five specimens from a groundstone manufacturing site, Terrace Garden at the base of West Wing Mountain, and five groundstone fragments from the core village of Las Colinas, were converted into thin-section samples and examined with a polarizing microscope (Figure 2.1). Evaluation of specimen mineralogy under the scope revealed that the igneous material from West Wing Mountain is a rare type of volcanic rock that results from the mixing of rhyolitic and basaltic magma (Schaller 1985:779). The most distinctive characteristic of this unique material is large white quartz-crystal inclusions (Figure 2.2). Significantly, all five stone tools from Las Colinas exhibited the same mineral characteristics. The investigative team for the project concluded from the similarities that vesicular basalt from the West Wing Mountains was transported more than 30 km to Las Colinas (Doyel 1985a, 1985b).

Following the results of the petrographic study, Doyel (1985a, 1985b) speculated on the organization and structure of vesicular basalt exchanges between the New River drainage and lower Salt River Valley. His ideas largely stemmed from observations at the Terrace Garden site at the base of West Wing Mountain. This groundstone material quarry site exhibited several trails, a ceremonial ballcourt[1] – the only known court in the Hohokam territory without a permanent habitation area – and a high density of groundstone production debris, which he estimated was substantially greater than that which would be produced through local demand (Doyel 1985a:723; Hoffman and Doyel 1985:560). From this combination of features, Doyel (1985a:725) suggested the idea that

[1] The Terrace Garden ballcourt is a comparatively small ovate ring of dozens of basaltic rocks in an area that was cleared of natural boulder talus. It is therefore considerably different from the larger earthen-embankments typical of most Hohokam ballcourts.

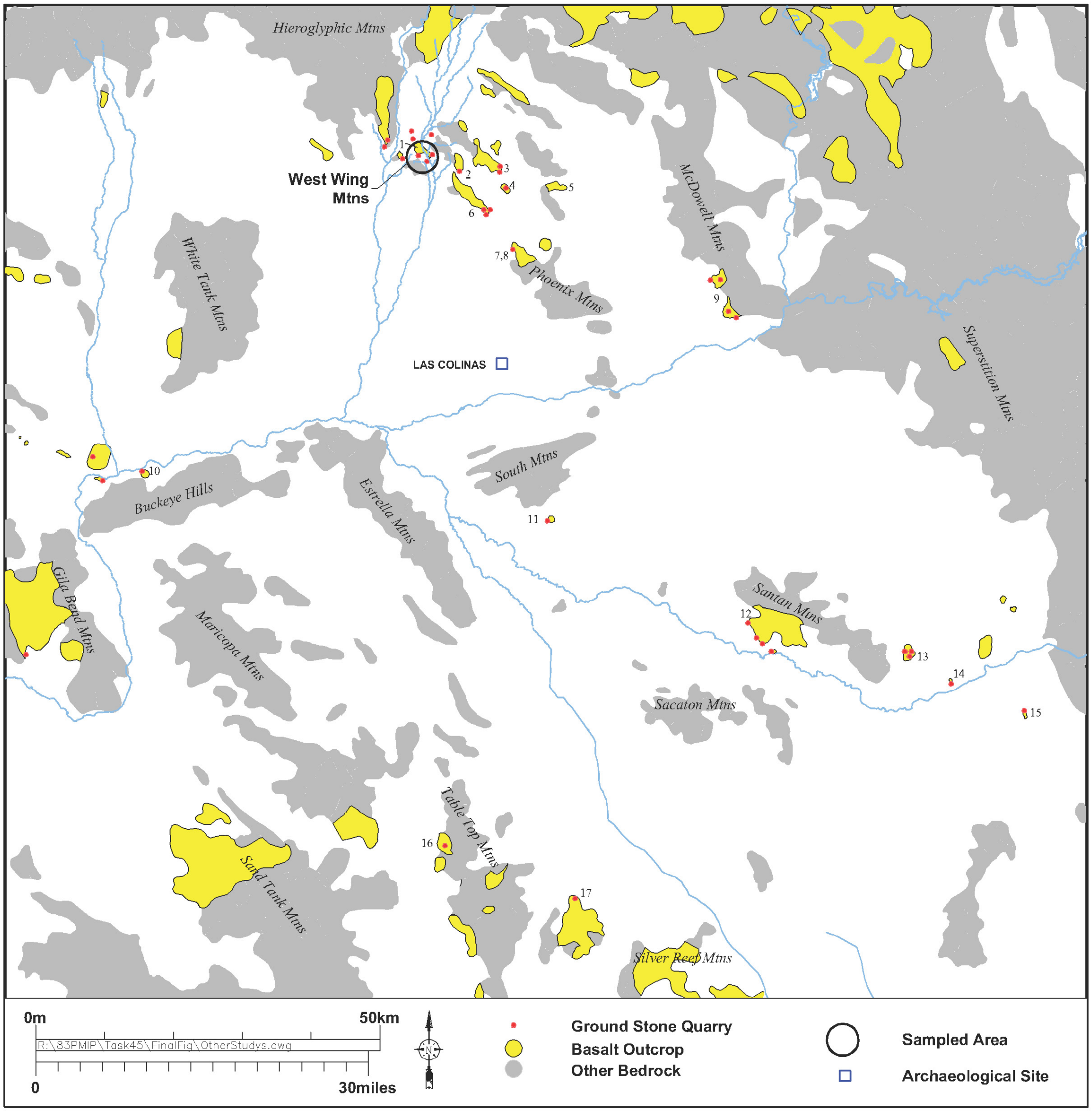

Figure 2.1. Map of Hohokam Sites and Vesicular Basalt Outcrops Included in the Petrographic-based Geographic Provenance Analysis for the New River Authorized Dam Project (see Table 1.1 for key to numbered locations).

Hohokam communities living near basaltic outcrops in the New River drainage specialized in the production of groundstone tools and exchanged their goods at ballcourt events with visitors from the lower Salt River Valley, who in return exchanged decorated pottery, shell jewelry, and other commodities. He proposed that the purpose of this exchange was primarily social and used to integrate populations in the New River drainage with those living in the lower Salt River Valley. However, Doyel was uncertain whether these exchanges were characterized by bilateral reciprocity among individual trade partnerships (i.e., direct exchange) or involved the pooling and redistribution of goods by managerial elites (i.e., elite-controlled exchange).

Figure 2.2. Example of Quartz-bearing Vesicular Basalt from West Wing Mountain

The identification of prehistoric groundstone quarries and tool production sites in the Hohokam northern periphery, along with mineralogical evidence for long-distance exchange, led to additional petrographic-based vesicular basalt provenance analyses. The petrographic approach was used in the evaluation of groundstone material from the sites of La Lomita Pequeña (Schaller 1988) and Grand Canal Ruins (Schaller 1989a) in the lower Salt River Valley, several sites in the middle Gila River Valley that were investigated for the Liberty-to-Coolidge Transmission Line Rebuild Project (Schaller 1987), and a handful of sites in the northern periphery associated with the Waddell Dam Project (Schaller 1989b). In each research project, the unique quartz-bearing rock from West Wing Mountain was identified. Other sets of mineralogically related artifacts were also observed under the microscope, but the geographic origin of these rocks could not be determined due to the absence of a comprehensive petrographic database for the Hohokam region.

The identification of multiple mineralogically distinct vesicular basalt groups in groundstone assemblages resulted in continued speculation about the nature of vesicular basalt transfers in the prehistoric Salt-Gila Basin. For example, investigators at Grand Canal Ruins suggested that large villages in the Hohokam core exchanged surplus agricultural products to communities in the northern periphery in return for groundstone tools (Mitchell 1989:465). The movement of groundstone material from this perspective was thus not socially-motivated as Doyel (1985a) supposed, but was instead embedded in a mutually-beneficial regional exchange system that involved community specialization and managerial elites.

Despite the growing potential of microscopic petrography for groundstone provenance research, Hohokam archaeologists soon became dissatisfied with the approach. Thin-section petrography is not conducive for archaeological research because it is both expensive and destructive. These two analytical requirements restrict the submission and analysis of large sample sets necessary for building the large datasets needed to confidently determine the origin of distinct mineralogical groups, as well as to evaluate models about the movement of groundstone in the Hohokam territory. As an example, the largest number of samples submitted for petrographic analyses from any one of the above-mentioned studies was 16 (Green 1989; Schaller 1989b). These 16 specimens were selected from a total of 481 groundstone artifacts exhibiting vesicular texture, or just three percent of the inventory. Small sample size limitations are partly the reason why early vesicular basalt provenance studies were not definitive in regards to models of material exchanges between the Hohokam core and periphery.

Microscopic petrography analysis also fell into disfavor because it was soon found that the technique was not as valid for provenance studies as initially thought. In the first petrographic study for the New River Authorized Dam Project, Schaller (1985:880) inferred from the available geologic maps at the time that, in addition to West Wing Mountain, the distinctive quartz-bearing basalt might be found in the Hieroglyphic Mountains, Calderwood Butte, Ludden Mountain, and a portion of the Union and Deem Hills. This geographic variability was acceptable at the time because all of these outcrops are located in the northern periphery. However, geological and archaeological researchers later confirmed the presence of quartz-bearing basalt at Adobe Mountain, Ludden Mountain, West Wing Mountain, Hedgpeth Hills and Deem Hills in the northern periphery, the McDowell Mountains in lower Salt River Valley, and also an outcrop in the middle Gila River Valley near Florence (Bostwick and Burton 1993; Holloway and Leighty 1997; Leighty and Holloway 1998; Leighty and Huckleberry 1998a; Lundin

2003). Therefore, the exact geographic provenance of quartz-bearing basalts in core area villages could have been from three very different regions, only one of which was the Hohokam northern periphery. The inability to determine even the general origin of groundstone material helped to curb the use of microscopic petrography for Hohokam vesicular basalt provenance analysis.

Thus, despite a promising start, the use of microscopic petrography for Hohokam vesicular basalt groundstone provenance analysis was abandoned due to its destructive nature, costly sample preparation requirements, and inability to determine even the general origin of material with "distinctive" mineral inclusions.

Macroscopic Petrography

While microscopic petrography was still being employed, Hohokam archaeologists began to sort vesicular basalt artifacts into very broad regional source groups based on "distinguishable" macroscopic mineral inclusions (e.g., Euler 1989). This approach was based on the findings of the microscopic method, which at first assumed that all basalts with large quartz inclusions derived from outcrops in the Hohokam northern periphery (Schaller 1985, 1987, 1988, 1989a, 1989b). Macroscopic petrography became the preferred sourcing method because it had the advantage of being nondestructive and inexpensive, thereby permitting the efficient creation of large provenance datasets. For example, use of the macroscopic method on a sample of groundstone from the Hohokam village of Las Colinas determined that 278 of the 663

(42%) vesicular basalt groundstone artifacts were manufactured using quartz-bearing basalt from the northern periphery (Euler 1989:86).

The generation of the large provenance dataset at Las Colinas permitted the first meaningful assessment of Hohokam vesicular basalt procurement and distribution practices. Temporal sorting of the Las Colinas sample, for instance, revealed that quartz-bearing basalt accounted for 25 percent of the assemblage during the early Sedentary period, 35 percent during the middle to late Sedentary, but was completely absent in the subsequent Classic periods (Euler 1989:86). Euler (1989) recognized that the decrease in northern materials at the start of the Classic period correlated well with the abandonment date for the New River drainage and, therefore supported Doyel's (1985a) idea of a social exchange between the Hohokam core and periphery. Intriguingly, though, Euler offered an alternative explanation. He noted that the basaltic outcrops of the northern periphery, such as West Wing Mountain, Adobe Mountain, and Hedgpeth Hills, were within a one-day's walk of Las Colinas. He then suggested that individuals from Las Colinas "might have been willing and able to traverse that short distance to acquire high-grade stone, particularly when a tool might receive several years of use" (Euler 1989:88). Euler (1989) also proposed a scenario in which vesicular basalt was procured directly by Hohokam core households during seasonal occupation of the New River drainage in the Preclassic period.

The usefulness of macroscopic petrography was further enhanced by Todd Bostwick and James Burton (1993). These two researchers undertook a comprehensive geological study of volcanic outcrops in the Hohokam culture territory with the intent of locating all potential groundstone material source areas. Their study employed petrographic and geochemical (back-scattered electron/energy dispersive electron microscopy) analytical techniques to help identify distinctive characteristics among the identified source areas that could be useful for archaeological provenance analyses. In the end, Bostwick and Burton (1993:360) examined approximately 50 raw material samples from 30 different volcanic outcrops in the lower Salt, lower Gila, middle Gila, New River, Verde, and Santa Cruz river drainages (Figure 2.3).

Bostwick and Burton's study resulted in three archaeologically relevant observations. First, field inspection of possible source areas led to the discovery of several prehistoric groundstone quarries. Newly documented quarry sites were located in the McDowell Mountains, Santan Mountains, Vaiva Hills, Picture Rocks, Cerro Prieto Mountains, and Gila Bend area (Bostwick and Burton 1993:365). Second, the two researchers reported they had identified a total of five compositionally- and spatially-discrete vesicular basalt regional source groups. These five regions were termed the "Phoenix Basin" (e.g., the Northern Periphery), the "middle Gila River", the "lower Gila River", the "Santa Rosa Wash", and the "Verde River" drainage (see Figure 2.3; Bostwick and Burton 1993:363). Third, and perhaps most importantly, the compositionally and spatially discrete groups could be differentiated using the unaided eye by looking for distinctive mineral inclusions (Bostwick and Burton 1993:368). For example, material from the Phoenix Basin group would feature large quartz xenocrysts (see Figure 2.1; the middle Gila group contained plagioclase phenocrysts (Figure 2.4; the

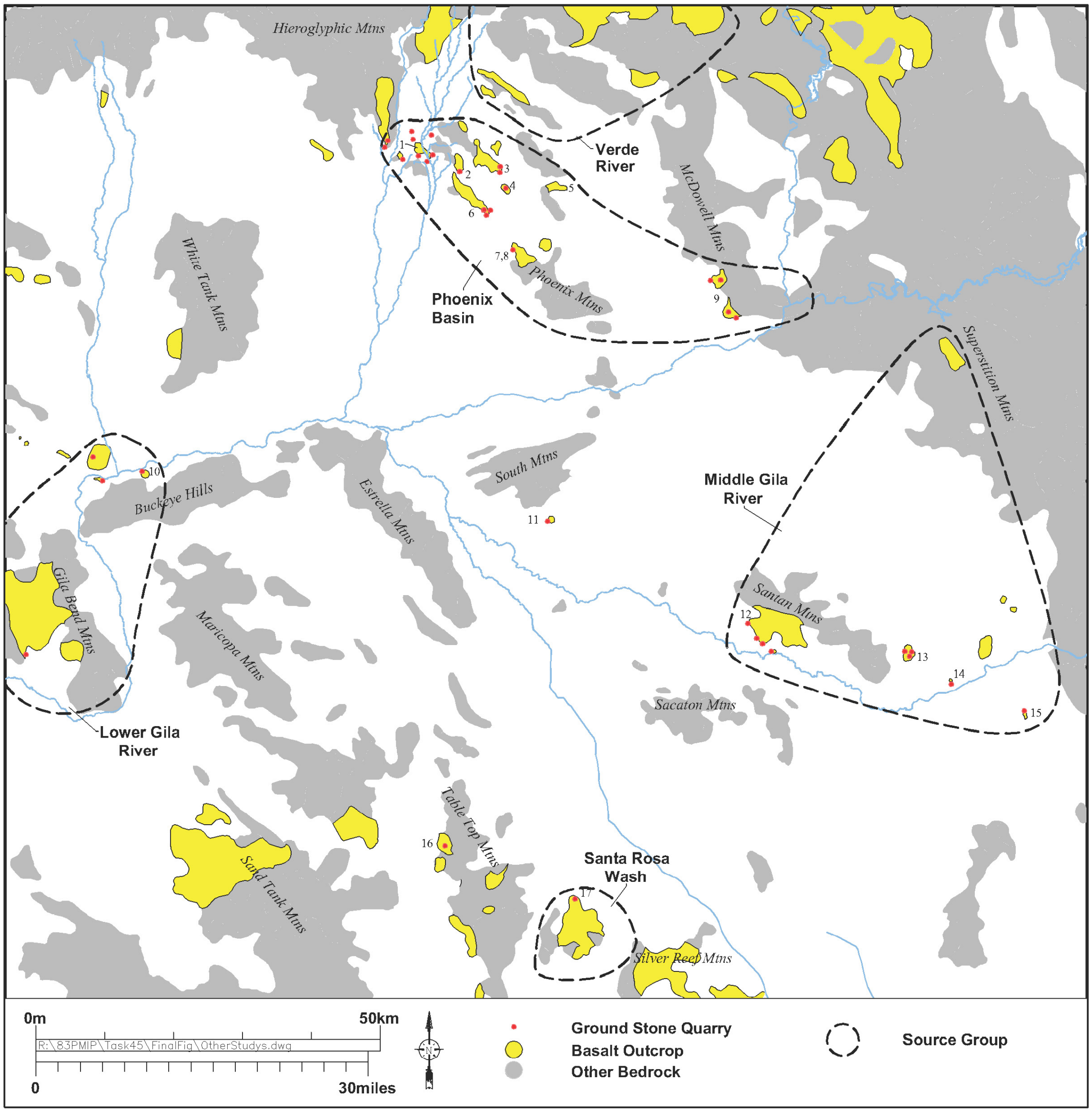

Figure 2.3. Map of Regional Vesicular Basalt Source Groups as Identified by Bostwick and Burton (1993; see Table 1.1 for key to numbered locations).

Santa Rosa Wash group contained large hornblende phenocrysts (Figure 2.5); and the lower Gila River and Verde River groups both contained abundant olivine phenocrysts (Bostwick and Burton 1993:363). Thus, archaeologist now had five spatially and

Figure 2.4. Vesicular Basalt from the Santan Mountains, Middle Gila River Valley Source Group

Figure 2.5. Vesicular Basalt from the Vaiva Hills, Santa Rosa Wash Source Group.

compositionally discrete groups (and potentially specific quarries) to which vesicular basalt groundstone artifacts could be traced.

Bostwick and Burton's (1993) findings were incorporated into subsequent Hohokam vesicular basalt provenance analyses (e.g., Rapp 1995; Stone 1994a). Perhaps the most effective use of the refined methodology was Stone's (1994a, 1994b, 2003) analysis of groundstone artifacts from the core village of Pueblo Grande. Archaeological excavations at this site resulted in the recovery of more than 500 vesicular basalt groundstone artifacts from Late Sedentary, Early Classic and Late Classic contexts (Stone 1994a:30). Stone identified the geographic origin for all of these artifacts as evidenced by their macroscopic mineralogical constitution. Subsequent evaluation of spatial and temporal patterning in the provenance data revealed that the site's inhabitants obtained vesicular material from the same regional source groups in roughly the same order of preference during all three temporal periods (Stone 1994a, 2003). Additionally, there was no evidence to suggest that any one particular habitation area had preferential access to the raw material in general or a specific source group in particular during either the Late Sedentary or Classic periods (Stone 1994a:30). The homogeneity in artifact and source distribution patterns across time and space at Pueblo Grande led Stone to suggest that the procurement of vesicular basalt was not affected by the broader socio-cultural changes of the Hohokam sequence, such as the collapse of the ballcourt network, the rise of platform mounds, or changing social relationships over time. Therefore, Stone (Stone 1994a:46, 2003) suggested that the acquisition of vesicular basalt was accomplished by individual households through direct procurement (Stone 1994a:46, 2003).

Despite the analytical success of the Pueblo Grande provenance study, Hohokam archaeologists began to question the utility of the macroscopic approach. To some, the method remained too subjective (e.g., Rubenstein et al. 1995; Schaller 1989b). A fitting example of its subjectivity was noted by Schaller (1989b:754), who recognized that archaeologists for the Waddell Dam project had misclassified the rock type and macroscopic mineralogy for eight of the 16 (50%) groundstone samples submitted for petrographic analysis. Surprisingly, he found the archaeologists were unaware that they had labeled a sample of quartz-bearing basalt, the only macroscopically distinctive mineral inclusion known at the time, as aphanitic andesite. The inability of archaeologists to correctly identify material type and macroscopic mineral inclusions led Schaller (1989b:754) to warn them that "hand specimen examination is usually insufficient to actually describe the petrographic characteristic of a volcanic rock."

The efficacy of the macroscopic approach is further questionable on three counts. First, Bostwick and Burton's (1993) typology identifies five different compositionally and spatially discrete basalt groups: Phoenix Basin, middle Gila River, lower Gila River, Santa Rosa Wash, and Verde River (Bostwick and Burton 1993:363). However, only three of these groups (Phoenix Basin, middle Gila River, and Santa Rosa Wash) can actually be distinguished by their macroscopic mineralogy, since vesicular basalt from the lower Gila River and the Verde River Valley groups both contain abundant olivine phenocrysts. Thus, the precise geographic origin of groundstone artifacts featuring olivine inclusions cannot be determined in hand, and microscopic or geochemical methods need to be employed to discern their origin (Bostwick and Burton 1993:364).

Second, macroscopic petrography is limited because it cannot differentiate material from different volcanic outcrops within each of the five regional source groups identified by Bostwick and Burton (1993). For as noted earlier, the quartz-bearing rocks of the Phoenix Basin group are actually found among at least eight geographically-discrete bedrock outcrops that are spread across an area of approximately 700 square miles. Poor spatial resolution among provenance datasets inhibits analysts from observing meaningful temporal or spatial variation in material acquisition trends. Perhaps the greatest consequence of this limitation is the inability to differentiate vesicular basalt from McDowell Mountain in the Hohokam core from material derived from outcrops in the Hohokam northern periphery (i.e., Adobe Mountain, Deem Hills, Hedgpeth Hills, and West Wing Mountain). The presence of large groundstone quarry sites at these outcrops makes the distinction of these locations particularly important for testing different ideas about vesicular basalt movements in the Hohokam territory.

Finally, the macroscopic method is also limited because it does not take into account mineralogical variation found within each source region. Bostwick and Burton (1993) stated that basalt from the Phoenix Basin group is characterized by large quartz inclusions. However, geologists before and after their study have identified at least three different primary flow events in the region (Chalk Canyon, Garfias Wash, and New River Formations), each with its own unique mineralogical constitution (Anderson 1989; Holloway and Leighty 1998; Jagiello 1987; Leighty 1997; Leighty and Holloway 1998; Leighty and Huckleberry 1998a). Some of these different geological events are even found within the same bedrock outcropping block tilting during the Basin and Range disturbance. For instance, the Deem and Hedgpeth Hills contain material from the older Chalk Canyon (i.e., “Hedgpeth Formation” – see Chapter 4) on its southern face and material from the younger New River formation on the north. Different periods of volcanism have also been found in the other four regional source groups identified by Bostwick and Burton (1993; see Leighty 1997 for a summary). The compositionally-discrete groups identified by Bostwick and Burton (1993) are, therefore, not as spatially discrete as suggested in their study.

In sum, macroscopic petrography offered an efficient and affordable alternative to the microscopic method. These two advantages allowed for the analysis of large volumes of groundstone material, as exemplified by the analyses at Las Colinas (Euler 1989) and Pueblo Grande (Stone 1994a, 2003). However, the macroscopic method is severely limited by its subjectivity, geographical imprecision, and inability to take into account intra-source mineralogical variability. These shortcomings eventually led to the disuse of macroscopic method for Hohokam vesicular basalt provenance analyses.

Geochemical Analysis

Unsatisfied with the efficacy of microscopic and macroscopic petrography, Hohokam archaeologists investigated the possibility of using geochemical analyses to determine the provenance of vesicular basalt groundstone material. Geochemical analyses offer the possibility of improved spatial resolution over mineralogical techniques because they can measure certain trace elements (e.g., strontium, rubidium, yttrium, zirconium, and niobium) in igneous materials that typically exhibit concentrations specific to volcanic flow events (Shackley 2008, 2011). From these data, it is often possible to differentiate material from spatially and temporally distinct basaltic outcrops, even when the general mineralogy of the stone is quite similar. Chemical-based analytical techniques, such as XRF, also offer the potential to be nondestructive and cost-efficient, two additional advantageous over mineral-based methods.

The first geochemical provenance analysis of vesicular basalt groundstone in Hohokam archaeology was conducted as a joint venture between the Alma School Road Project (Doyel et al. 1995) and the State Route 87 – McDowell Road to Shea Boulevard Project (Henderson and Abbott 1995). Raw material and artifact samples from both of the projects were submitted for XRF analysis (Shackley 1994, 1995a). The raw material sample included five specimens each from documented prehistoric Hohokam quarry sites at McDowell Mountain (AZ U:5:143 (ASM)), West Wing Mountains (McQuestion Quarry; AZ T:8:63 (ASU)), and the Phoenix Mountains (Moon Hill Quarry)(Figure 2.6). A total of 24 groundstone artifacts were analyzed from four different archaeological sites, including AZ U:9:14 (ASM); AZ U:9:95 (ASM), AZ U:9:97 (ASM), and AZ U:9:97 (ASM). In preparation for their analysis, a small flake (>10.0 x 10.0 x 3.0 millimeters) was removed from each specimen and washed in distilled water prior to analysis. Production of the sample flakes was necessary for this analysis because the complete groundstone artifact could not fit within the sample chamber of the desktop XRF used in the analysis (Tracor X-ray TX 6100).

The geochemical analyses revealed some interesting patterning among the resultant elemental data. Specifically, bivariate plots of rubidium and strontium elemental

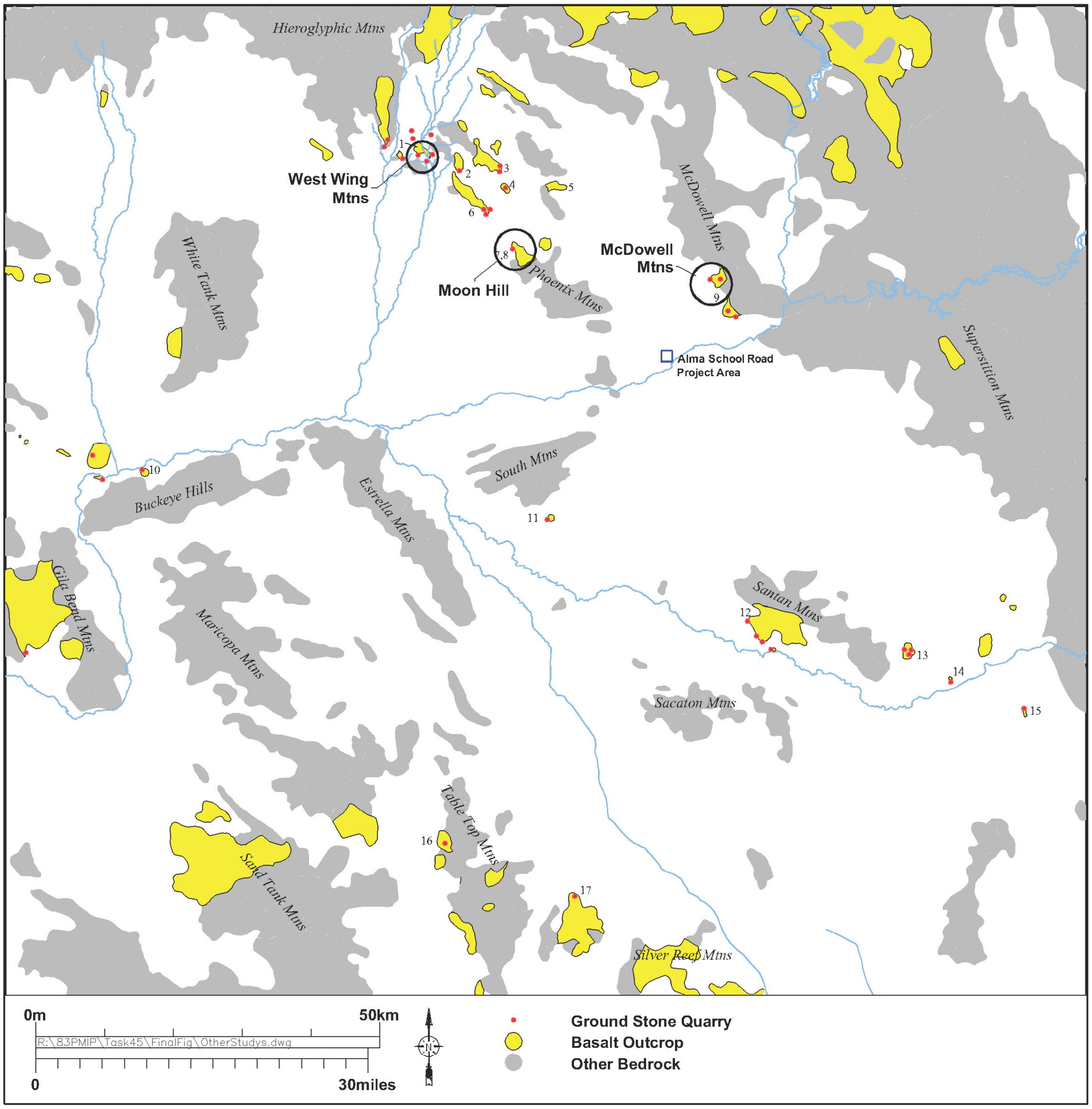

Figure 2.6. Map of Hohokam Sites and Vesicular Basalt Outcrops Included in the Geographic Provenance Analysis for the Alma School Road and State Route 87 – McDowell Road to Shea Boulevard Projects (see Table 1.1 for key to numbered locations).

concentrations, as well as rubidium and nickel concentrations, produced visible separation of the three raw material sample groups (Shackley 1994, 1995a; see also

Rubenstein et al. 1995). The researchers also used multivariate discriminant analyses to determine if any of the artifact samples were chemically similar to the raw material samples. The results of the statistical analysis suggested that about half of the artifacts were from the closest basaltic outcrop to the project area, McDowell Mountain (n=7). The other half of the sample was found to be chemically similar to the Moon Hill (n=4) and West Wing Mountain (n=4) source areas. Rubenstein and colleagues (1995:327) suggested that the presence of artifacts from these more distant locations indicated that the procurement of vesicular basalt groundstone tools may involve more complex factors than simple distance to source (i.e., direct procurement), adding that this is an issue that "is ripe for exploration through further investigations on the source of groundstone artifacts" (Rubenstein et al. 1995:328).

The next attempt to use geochemical analyses to determine the geographic provenance of vesicular basalt groundstone artifacts was undertaken during the Palo Verde Ruin Project (Hackbarth and Craig 2007; Marshall 20007). The raw material sample for this study included five specimens each from the prehistoric Hohokam quarries at Adobe Mountain (NA17236), Lone Butte (GR-671), the Hedgpeth Hills (AZ T:8:164 (ASM)) and West Wing Mountain (AZ T:8:19 (ASM); Terrace Garden Site; Figure 2.7). The artifact sample derived from the Hohokam village of Palo Verde Ruin in the northern periphery (n=10), as well as from the core sites of Grand Canal Ruins (n=7) and La Lomita Pequeña (n=8). As in the previous study, a small piece of each sample was chipped off its parent stone before placement in an XRF sample chamber. In addition, a flat sample surface was cut on each sample using a lapidary trim saw "in order to optimize the results of the analysis and reduce the potential effects of weathering and surface contamination" (Skinner 2000a, 2000b, 2001).

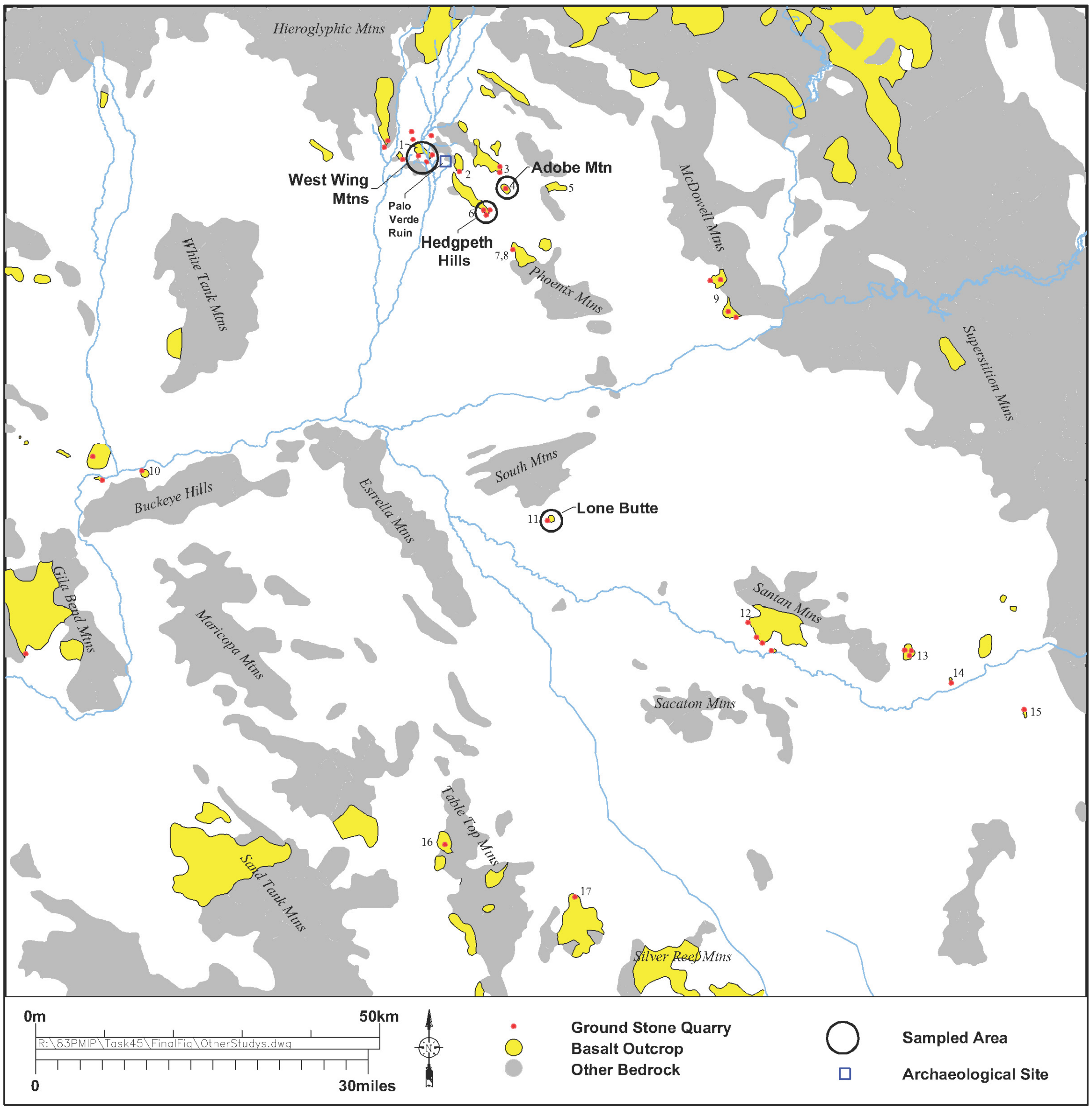

Figure 2.7. Map of Hohokam Sites and Vesicular Basalt Outcrops Included in the Geographic Provenance Analysis for the Palo Verde Ruin Project (see Table 1.1 for key to numbered locations).

The geochemical analyses for the Palo Verde Ruin project observed consistent geochemical variability among the four raw material sample groups when comparing bivariate plots of strontium and zirconium elemental concentrations. Skinner (2000a, 2000b, 2001) was also able to match some of the artifact samples to the raw material sample locations. For instance, six of the ten artifacts from Palo Verde Ruin appeared to belong to the proximate West Wing Mountain (n=3) and Adobe Mountain (n=3) quarries based on similar elemental concentrations. Marshall (2007) later conducted a multivariate statistical analysis of the elemental data provided by Skinner and provisionally assigned four of the samples from Palo Verde Ruin to the Hedgpeth Hills and one to Adobe Mountain. Additionally, Marshall suggested six of the samples from the core village sites derived from the Hedgpeth Hills and one sample was traced back to Adobe Mountain.

As part of a research synthesis, Marshall (2007) considered the meaning of his own provenance classifications within the context of demographic reconstructions for Palo Verde Ruin, the intensity of groundstone tool production and consumption in the New River Drainage, and the directionality of the previously identified vesicular basalt exchanges (Doyel 1985a, Euler 1989; Mitchell 1989). He surmised that the exchange of vesicular basalt from the northern periphery to the Hohokam core was not founded on economic interdependency, but rather social motivations (Marshall 2007:210). Particularly, he supported Doyel’s (1985a) hypothesis that vesicular basalt tools were exchanged for decorated pottery and shell jewelry transferred through bilateral exchange partnerships (Marshall 2007:210). Marshall’s main justification for this inference was that the estimated number of groundstone tools produced annually in the New River Drainage – about two to three per month (Marshall 2007:210) – was too low for a highly specialized, economically-motivated exchange system (i.e., market exchange, elite-controlled exchange, and even down-the-line exchange).

Skinner's analysis for the Palo Verde Ruin Project and Shackley's earlier research efforts advanced Hohokam groundstone provenance research in three key areas. First, their studies demonstrated that geochemical analysis by means of XRF can provide an efficient and objective method for characterizing basaltic material. Second, and more importantly, they found consistent geochemical variability among five of the known vesicular basalt groundstone quarry locations (Lone Butte, Hedgpeth Hills, McDowell Mountain, Moon Hill, and West Wing Mountain), thereby demonstrating the potential validity of the approach for groundstone material sourcing analyses. Third, geochemical analyses were able to distinguish between basaltic outcrops that were lumped together as a single source area under the mineralogical approaches. Specifically, Shackley (1994, 1995a) and Skinner's (2000a, 2000b, 2001) studies show predictable geochemical variation among four of the quartz-bearing basalt outcrops (i.e., Adobe Mountain, Hedgpeth Hills, McDowell Mountain, and West Wing Mountain). These improvements in the objectivity, validity, and spatial resolution of geochemical analyses compared to the petrographic approaches make XRF spectroscopy a potentially powerful analytical tool for Hohokam vesicular basalt provenance analyses.

Despite the initial positive findings, the use of desktop XRF for Hohokam vesicular basalt geographic provenance analysis has been slow to develop. One reason for the slow pace is practicality. The analysis of groundstone artifacts with laboratory-based desktop XRF instruments generally entails the long-distance transport of sample material. For example, previous analyses of vesicular basalt artifacts from the Hohokam area of southern Arizona were conducted at laboratories in northern California (Shackley 1994, 1995a) and Washington (Skinner 2000a, 2000b, 2001). Mailing large and heavy groundstone tools is cost prohibitive. Furthermore, it is impossible to fit large artifacts into the sample chambers of most desktop instruments. Past researchers have thus resorted to removing flakes from artifacts using a rock saw and then sending these smaller samples off for analysis. However, the destruction of cultural materials is not generally preferred in the archaeological and curatorial communities.

Another reason for the limited application of XRF in Hohokam vesicular basalt studies are the constraints associated with the nondestructive analysis of unmodified and geochemically heterogeneous specimens. Irregular sample morphology, irregular surface texture, variable particle size, and geochemical variability affect the reliability of XRF through the physical phenomena of X-ray attenuation, absorption, interference, and enhancement (Davis et al. 2011; Forster et al. 2011; Jenkins 1999; Lachance and Claisse 1995; Lundblad et al. 2011; Potts et al. 1997; Shackley 2011). For example, chemical heterogeneity is a concern in analysis because analytical instruments often only target a very small portion of a specimen. Consequently, differently placed assays on a single specimen will result in different chemical signatures. Shackley (1994, 1995a) was quite hesitant about his provenance assignments for the Alma School Road and State Route 87 – McDowell Road to Shea Boulevard Projects due to single specimen compositional variability. In his words, "the material submitted for analysis was not comprised of homogeneous substance, so internal variability is great. The five samples from each source cannot be expected to exhibit the range of variability for these sources and, from this, the chance for assignment to a known source when the source is really unknown was relatively great" (Shackley 1995a:43).

Analysts can mitigate the adverse effect of physical and geochemical variability on measurement reliability by modifying samples prior to analysis. Skinner (2000a, 2000b, 2001), for instance, mitigated the effects of irregular sample morphology and texture by sawing a flat sample surface. And though it was not done by either Shackley or Skinner, geochemical heterogeneity can be mitigated by pulverizing a sample into a fine-grained powders and then fusing it into glass. However, the destruction of artifact samples, no matter how small a piece, is neither cost-efficient nor preferred by the curatorial community. In fact the first question always asked by museum curators when I asked them permission to analyze Hohokam groundstone artifacts was, "is this a destructive analysis?" Using an analytical technique that is both comparatively expensive and destructive has the potential to limit sample size, which leads once again to smaller and less robust dataset for evaluating various hypotheses on material transfers.

A third analytical concern for geochemical provenance analyses is population heterogeneity. Basalt outcrops are often created by expansive and long-term eruptions. Different rates of flow and variable exposures to external elements can lead to different mineralogical, chemical, and textural properties across a single flow, but subtle variation among nearby flows (Brown 1967; McDonald 1967; Weisler 1997; Weisler and Sinton

1997). Consequently, a more complete understanding of the geochemical variability present among the basaltic formations in the Salt-Gila territory is required before analysts can adequately assess the Provenance Postulate for Hohokam sourcing studies and be more certain about provenance assignments for groundstone artifacts. This concern was brought to light by Shackley (1995a:G5), who wrote "*that without a good source standard library, all of these source assignments could be spurious*" (his emphasis). Unfortunately, without a practical, nondestructive, and reliable means of determining single-sample geochemistry, the construction of a large reference database will remain a difficult and expensive task.

Implications of Previous Research for Current Study

Over the last three decades, a handful of Hohokam archaeologists have devoted considerable attention to understanding the primary means by which Hohokam households acquired vesicular basalt for groundstone tool production. Unfortunately, there has been little advancement in our knowledge of this issue because the analytical approaches used by researchers are limited in their ability to produce useful provenance datasets. The first provenance technique to be used, microscopic petrography, initially produced promising results. However, it is destructive, costly, and is thus far limited in its ability to pinpoint the geographic origin of several mineralogically distinctive types of basalt. Macroscopic petrography, which offers the advantage of being extremely efficient and nondestructive, was deemed to be too subjective as a provenance method (Schaller 1989b). Its validity as a technique also came into question due to a more nuanced understanding of the volcanic history in the Salt-Gila Basin. Lastly, geochemical techniques, namely XRF spectroscopy, did not reach their full potential. These studies are stymied by analytical complications associated with single-specimen physical and geochemical variability, source population compositional heterogeneity, and the practical limitations of desktop instruments.

The absence of a practical and reliable geographic provenance method left Hohokam researchers with either small sample sets or equivocal provenance assignments. Consequently, there has been a general tepidness by analysts to critically evaluate different hypothesis regarding the prehistoric transfer of vesicular basalt in the Hohokam region. As a result, several ideas related to material procurement and distribution practices remain possible explanations. Also left unaddressed in previous analyses is the role that core Hohokam communities located next to vesicular basalt outcrops played in disseminating the material. Past studies focused considerable attention on the exchange relationship between the New River drainage and lower Salt River Valley (e.g., Bruder 1982, 1983a; Doyel 1985a; Mitchell 1989; Marshall 2007). However, the distribution of material from basaltic outcrops such as Moon Hill and McDowell Mountain in the lower Salt River Valley, or Lone Butte and Santan Mountain in the middle Gila River Valley has been largely unexplored.

In order to improve current understandings of prehistoric Hohokam vesicular basalt acquisition and distribution practices, two things are necessary. First, an efficient, practical, and reliable method for determining the provenance of vesicular basalt groundstone artifacts needs to be developed. The development of this method itself requires advancements in the analytical techniques used for determining the composition of unmodified basalt specimens and also the creation of a sufficiently representative source area database that is useful for identifying the geographic provenance of analyzed materials. Second, a much larger artifact sample that is composed of several archaeological assemblages needs to be analyzed. Given various differences in the distance between Hohokam communities and basalt source areas, as well as the temporal depth of the Hohokam cultural tradition, there is likely to be synchronic and diachronic variation in vesicular basalt acquisition practices. Thus, a larger sample will provide a more complete understanding of the structure and organization of Hohokam vesicular basalt exchanges through time. Together, an improved analytical methodology and a larger archaeological sample will provide the means to evaluate the merit of different hypotheses concerning the movement of vesicular basalt from natural to cultural contexts in the prehistoric Salt-Gila Basin.

CHAPTER 3: CURRENT HYPOTHESES FOR HOHOKAM VESICULAR BASALT PROVISIONING PRACTICES AND TEST EXPECTATIONS

This study evaluates the plausibility of five different hypotheses that potentially explain the movement of the textured stone from natural outcrops to household contexts during the Hohokam Preclassic and Classic periods. Three of the five hypotheses are explanations that have been previously suggested by Hohokam scholars: direct procurement, direct exchange, and down-the-line exchange (Doyel 1985a; Euler 1989; Marshall 2007; Mitchell 1989; Stone 1994a, 2003). Two other distributional hypotheses, market (Abbott 2006, 2009, 2010; Abbott et al. 2007a; Abbott et al. 2007b; Watts 2013) and elite-controlled exchange (Bayman 1994, 1995, 2002; McGuire 1985; McGuire and Howard 1987; Rice 1995; Teague 1984) are also evaluated. These exchange models have been previously proposed for the movement of other craft items during the Hohokam Preclassic and Classic periods, respectively. Thus, it is possible they explain the movement of vesicular basalt during these times as well.

The plausibility of each of the five hypotheses is assessed by examining four variables: 1) the relative frequency of different vesicular basalt types at sites as related to the geographic distance from their source; 2) intra-site variance in vesicular basalt type diversity; 3) inter-site variance in vesicular basalt type diversity; and 4) temporal specificity and continuity. Ethnographic and archaeological case studies suggest that different provisioning practices will generate vesicular basalt provenance data patterns within the archaeological record that are specific to one or more of the four variables. If the test expectations for a certain hypothesis are not fulfilled, then it will be rejected as a possible vesicular basalt provisioning practice. The series of relationships among the test hypotheses and variables are summarized in Table 3.1 and discussed in more detail in this chapter.

It is also important to note that the five hypotheses evaluated in this study are not an exhaustive list of possible Hohokam vesicular basalt provisioning practices. Nor are they mutually exclusive, as households in different sites may have pursued various provisioning practices according to local circumstance. Nonetheless, testing these five hypotheses will improve current understandings of vesicular basalt movements in the Hohokam territory by helping to eliminate one or more of the potential hypotheses. Additionally, by assessing the merit of each exchange model on a site-by-site basis, a more nuanced understanding of household provisioning practices through time and space in the Hohokam area will be developed. For instance, it might be found that certain sites adhered to the same material provisioning practices during both the Preclassic and Classic periods, while another site used different strategies during different times. The site-by-site analysis will therefore provide a glimpse on the potential factors influencing Hohokam vesicular basalt acquisition practices.

Hypotheses

Direct Procurement

The direct procurement model states that the primary consumer of lithic material is the one who travels to the source, collects the stone, and then brings it back to their

Table 3.1. Summary of Hypotheses and Test Expectations

Hypothesis	Site Level Source Frequency	Intra-Site Source Diversity Variance	Inter-Site Source Diversity Variance	Temporal Specificity/Continuity
Direct Procurement	Reliance on Closest Source Area	Homogeneity	-	-
Direct Exchange	Absence of Reliance on Closest Source Area and Absence of Distance-Decay Trend	Heterogeneity	-	-
Down-the-line Exchange	Distance-Decay Trend	Homogeneity	-	-
Market Exchange	Absence of Reliance on Closest Source Area and Absence of Distance-Decay Trend	Homogeneity	Homogeneity	Preclassic (middle Sacaton) / No Continuity
Elite-Controlled Exchange	Absence of Reliance on Closest Source Area and Absence of Distance-Decay Trend	Homogeneity	-	Classic / No Continuity

own home. Direct procurement is certainly a plausible explanation for the movement of vesicular basalt in the study area. Ethnographic and historical accounts from throughout the New World reveal that individuals often traveled considerable distances, without beasts-of-burden, to acquire material for groundstone production from specific locations (Binford 1979; Hayden 1987; Huckell 1986; Schneider 1996, 2002; Schneider and Altschul 2000: Schneider and LaPorta 2008). For instance, the Quechan people of the lower Colorado River valley in southwestern Arizona walked more than 48 km to procure suitable material (Schneider 2002:391). Likewise, tool makers in the Mayan Highlands of Guatemala traveled 12 km to reach source locations (Hayden 1987:21). Several vesicular basalt outcrops would have been well within this range for most Hohokam living along the middle Gila and lower Salt Rivers (see Figure 1.3). Thus, it is certainly possible that Hohokam households were "willing and able" to travel to vesicular basalt outcrops and quarry groundstone material themselves (Euler 1989:88).

Direct Exchange

Direct exchange possibly explains the movement of vesicular basalt in the Salt-Gila Basin. This hypothesis states that raw materials and craft items are transferred between individuals without the assistance of intermediaries (Kooyman 2000:138). Direct exchange relationships are typically founded on kinship or marriage ties that are common within settlements and between neighboring communities. Thus, these exchanges are characterized by general or balanced reciprocity (Sahlins 1972). However, direct exchange may also involve the transfer of goods over greater distances through the establishment of fictive kin relationships between unrelated persons (Earle 2002:241). Long distance trade among coequals is a typical household provisioning strategy in traditional societies when certain goods or materials are not readily available due to natural environmental variability (Braun and Plog 1982; Ford 1982; Halstead and O'Shea 1989; Rautman 1993; Sahlins 1972; Spielmann 1986, 1991; Stark 1991, 1992; Wiessner 1977, 1982).

There is good reason to suggest that vesicular basalt was distributed through direct exchange within the Hohokam core area. A handful of vesicular basalt outcrops with evidence of prehistoric quarrying and groundstone tool production are present in the irrigated lowlands. Two relevant outcrops in this regard include the Santan Mountains, which are adjacent to the primary village of Upper Santan in the middle Gila River Valley, and the McDowell Mountains near the Scottsdale irrigation system (see Figure 1.3). However, most core households were located some distance from these source areas. A large proportion of the Hohokam population may therefore have chosen to acquire vesicular basalt through relatives or trade partners that lived in communities located closer to material source areas. For example, households in the middle Gila River valley may have transacted with individuals at Upper Santan. Similarly, individuals in the lower Salt River Valley may have exchanged directly for groundstone material and tools with Hohokam groups located near the McDowell Mountain source area. Such material exchanges may have helped households to reinforce critical social and economic relations (Graves 1991; Sahlins 1972).

The direct exchange of vesicular basalt may have also occurred between the Hohokam core and periphery. Archaeologists have found empirical evidence that material from basaltic outcrops north of the lower Salt River Valley, such as the Hedgpeth Hills and West Wing Mountains, was consumed by core area households (Doyel 1985a; Schaller 1985, 1988, 1989a, 1989b). It is suggested that in return for vesicular basalt, peripheral households received shell jewelry, decorated pottery, ritual paraphernalia, and perhaps even subsistence products from the core (Abbott 2010; Crown 1991; Doyel 1985a:717, 1991b; Mitchell 1989). The direct exchange of goods and commodities between these two portions of the Hohokam region may have served to reinforce marriage or alliance networks, guard against periodic resource shortfalls, or provide access to differently available resources and culturally significant craft items (Braun and Plog 1982; Halstead and O'Shea 1989; Rautman 1993; Spielmann 1986; Stark 1991, 1992; Wiessner 1977, 1982). Due to the potential of the direct exchange model for explaining prehistoric distributions of vesicular basalt in the Hohokam territory, both at the local and regional scales, it is included in the current set of research hypotheses.

Down-the-Line Exchange

Down-the-line exchange is defined as the long-distance movement of goods through multiple intermediate and spatially succinct exchanges (Kooyman 2000:138). These small-scale exchanges are often reciprocal in nature and mediated between neighboring groups. As such, down-the-line exchange is a powerful explanation for material movements in traditional societies since it minimizes transportation costs for households, while also serving to reinforce social and economic relations between neighboring groups. Notably, though, down-the-line exchange is structurally different than direct exchange. In down-the-line exchange, each intermediary consumes a portion of the total supply that they receive before passing it on, resulting in a decline in the frequency or volume of a good or material across space (Renfrew 1977; Sahlins 1972). Conversely, the direct exchange model involves spatially equitable and nondirectional exchange relations. Thus, down-the-line exchange can be perceived as a linear network of nodes (i.e., exchange partners) that serves to transmit material unidirectionally from a production center to consumers in several different locations.

The down-the-line exchange model potentially accounts for the transfer of vesicular basalt in the Hohokam core area. As noted above, two large vesicular basalt outcrops within the irrigated lowlands, the McDowell and Santan Mountains, are located near the Salt and Gila Rivers, respectively. The proximate location of these two vesicular basalt source areas, when combined with the linear orientation of Hohokam irrigation communities, may have provided an ideal context for the development of down-the-line exchange. For example, it is feasible that households at Upper Santan acquired vesicular basalt from the nearby Santan Mountains (and produced finished tools) and then moved the raw material or finished tools to their neighbors "down-canal" at the village of Lower Santan, who in turn passed the goods down to other settlements along the same canal system. Likewise, it is possible that vesicular basalt from the McDowell Mountains was acquired by households in the Scottsdale Canal System, then exchanged to households at Pueblo Grande at the head of Canal System 2 to the west, who then moved it westward to communities at the tail end of Canal System 2, such as Las Colinas.

At a regional level, vesicular basalt may have also moved from the Hohokam periphery into the core area via down-the-line exchange. Connecting the irrigated lowlands with the uplands are multiple north-south drainages, including the Agua Fria River, New River, Verde River, and Cave Creek (see Figure 1.9). Hohokam communities were distributed along all of these drainages at different extents and scales during the Preclassic and Classic periods (Bruder 1983a; Doyel and Elson 1985; Hackbarth et al. 2002; Marshall and Shaw 2002; McQuestion and Gibson 1987). It is possible, then, that vesicular basalt was transferred southward from the Hohokam periphery to core households not through direct exchange relationships, but rather through multiple spatially succinct reciprocal exchanges situated along the water courses. Similarly designed exchange networks may have helped move vesicular basalt from the western periphery (e.g., Robbins and Powers Buttes) up the lower Gila River and into the

Hohokam core, as well as material or tools from source areas located south near the Santa Cruz River (e.g., Vaiva Hills).

A possible challenge to the down-the-line model for vesicular basalt distributions is a perceived low supply of manos and metates. Due to predictable attrition in the supply of implements at sequential nodes within a unidirectional exchange network, a substantial number of groundstone tools must be manufactured at the head of a network in order for a portion of them to reach the end of the network. Presently, though, there is skepticism about the intensity of groundstone manufacture in the Hohokam region. Using figures from Doyel's (1985a) study of groundstone manufacture at Terrace Garden, Marshall (2007) estimated that the annual number of metates traded out of the New River area was between 18 and 30 metates per year, or two to three a month. He concluded from this calculation that the production of groundstone tools, though highly visible archaeologically, may not have been that intense at any given time (Marshall 2007:210). If these estimates for groundstone manufacture are accurate, then it is unlikely that the production of vesicular basalt grinding tools was great enough to allow for movement of groundstone implements through several exchange nodes.

However, a comprehensive analysis of Hohokam groundstone manufacture within the Hohokam region has yet to be conducted. In particularly, production estimates do not exist for the larger quarries in the Hohokam core area, such as those found among the McDowell and Santan Mountains. Furthermore, the total number of prehistoric vesicular basalt quarry sites continues to increase as archaeological research in the Salt-Gila Basin accumulates. Thus, an accurate assessment about the intensity of groundstone tool production within the Hohokam region is lacking. Therefore, down-the-line exchange remains a tenable hypothesis.

Market Exchange

A fourth mechanism potentially responsible for the movement of vesicular basalt is market exchange. This distribution method involves the transaction of specialist produced goods at a location (e.g., marketplace or workshop) where the sellers of a particular commodity meet with potential buyers (Polanyi 1957; Pryor 1977; Sahlins 1972). Market exchange is a potential explanation for the distribution of goods since it confers important advantages for both producers and consumers. For producers (and/or distributers) who wish to profit from their effort, markets are ideal because they minimize transportation costs while simultaneously increasing purchasing opportunity by assembling multiple buyers in one place (Alden 1982; Belshaw 1965). Similarly, market exchange can be advantageous for consumers because it has the potential to concentrate many different types of goods or services in one place, thereby minimizing their own production efforts, transportation costs, and need for maintaining several different local and nonlocal exchange relationships (Carrasco 1983).

Hohokam researchers have recently found evidence to suggest that some form of market exchange may have existed for much of the Hohokam Preclassic (A.D. ca 500-1070) (Abbott 2009; Watts 2013). A recent investigation of Hohokam ceramic production and distribution patterns has even found evidence suggesting that concentrated production specialists were present even as early as the Pioneer period (Abbott 2009; Watts 2013:201). The organization of the specialist-based economy evolved and eventually reached its zenith during the middle Sedentary (A.D. 1000-1070). Analysis of ceramic production and distribution patterns from this short interval reveal that specialists in just five communities were responsible for manufacturing virtually all of the pottery vessels that were utilized by nearly every household in the Salt-Gila Basin (Abbott 2000, 2009, 2010). It has been argued that a market exchange economy was functionally necessary to distribute the large supply of specially-produced pottery to the broader consumer population throughout the Hohokam core area (Abbott 2006; 2010; Abbott et al. 2001, 2007a, 2007b).

Abbott and his colleagues (Abbott 2000, 2006, 2009; Abbott et al. 2001, 2007a, 2007b, 2010) have further suggested that these marketplaces occurred sequentially in different villages in conjunction with social and ritual events held at Hohokam ballcourts. These festivals would have aggregated large crowds from near and far under a single shared ideology, thereby providing an ideal social context for the barter and exchange of goods among socially-distant persons. For supporters of Hohokam marketplace exchange, the simultaneous collapse of specialized ceramic production and the demise of ballcourt ritualism in the late Sedentary period (A.D. 1070-1100) is no coincidence.

However, more recent evidence has come to light suggesting ballcourt festivals and marketplaces were not inextricably linked. Using simulation models to account for observed ceramic production and distribution patterns, Watts (2013) found evidence that some variant of market exchange was present during the Hohokam Pioneer, Colonial, and early and middle Sedentary periods. Thus, while the demise of the Hohokam market economy and ballcourt festival occurred simultaneously, and that it is certainly possible that goods and commodities were exchanged at ballcourt events, the rise of these two cultural institutions was not simultaneous, indicating that they did not develop in tandem. Watts (2013:202) suggests in lieu of the periodic marketplace theory, that workshop procurement – in which households acquired goods from producers in select locations – and shopkeeper merchandise – in which middlemen distributed goods acquired wholesale from producers – were present during much of the Hohokam Preclassic.

It is possible that some variant of Hohokam market exchange, whether it was marketplace exchange, workshop procurement, or local distributers, facilitated the distribution of vesicular basalt during part of the Hohokam Preclassic. One indirect line of supporting evidence for this idea is the relatively scarce distribution of vesicular basalt outcrops within the Hohokam core territory (see Figure 1.3). The limited availability of desirable groundstone material may have allowed for the concentrated production of groundstone tools at communities located adjacent to material source areas. Following Watts (2013), it is possible that Hohokam households in need of groundstone tools traveled to these production locales and retrieved finished goods themselves or, alternatively, acquired it through a local distributer in their own village who himself acquired several finished implements.

It is still also possible that vesicular basalt was exchanged at periodic marketplaces associated with ballcourt events. An important connection between Hohokam ballcourts and vesicular basalt exchange is evident at the Terrace Garden site. This site, which is situated at the footsteps of West Wing Mountain in the northern periphery, features a ceremonial ballcourt, a network of prehistoric trails, and approximately 100,000 square meters of groundstone manufacturing debris (Doyel 1985a:721). Remarkably, though, the site does not contain a permanent habitation. In fact, Terrace Garden is the only known Hohokam ballcourt that is not associated with a year-round occupation (Doyel 1985a; Doyel et al. 1985). This unique combination of archaeological features and evidence of groundstone manufacture is strong support for the idea that this ballcourt (and perhaps others) served a specialized function focused on the production and distribution of groundstone tools (Doyel 1985a).

A notable challenge to the market exchange model for vesicular basalt distributions is a perceived lack of a regular supply and frequent demand for manos and metates. In order for a good to enter into a market economy, there must first be a relatively continuous and stable supply of and demand for the product (Belshaw 1965; Polanyi 1957; Pryor 1977; Yang 2003). Vesicular basalt groundstone implements have a particularly long use life, on the order of 15-20 years for metates (Aschmann 1949:685; Hayden 1987:15). The use life of manos is shorter due simply to their smaller size, but still spans multiple years. The longevity of mano and metates may have stemmed regular and substantial demand for groundstone tools. And as noted above there is skepticism about the intensity of groundstone manufacture and supply rates (Marshall (2007). Together, the longevity of vesicular basalt grinding tools and the dearth of evidence in favor of intensive tool production suggest the possibility that the supply and demand of vesicular basalt in the Hohokam region was not great enough to compel its inclusion in a market exchange economy.

However, ethnographic accounts and archaeological data suggest that even if the demand for vesicular basalt grinding tools is not great at any one time, it is consistent. In 1936, two months of ethnographic observations at a traditional market in Quezaltenango, Guatemala, a town of approximately of 20,000 inhabitants at the time, revealed an average daily influx of 15 metates and 48 manos[2] (McBryde 1947). A constant demand for groundstone tools in traditional societies is attributed to at least two factors other than limited resource availability and basic material attrition. First, the establishment of a new household would entail obtaining a new set of manos and metates (Huckell 1986). Second, funerary customs may have reduced supplies and therefore added to the demand. The occurrence of groundstone tools in both male and female burials at several excavated sites in the Salt-Gila Basin (i.e., Schilz et al. 2011; Effland 1990; Gregory et al. 1989; Mitchell 1992, 1994a; Mitchell et al. 1994) suggests that some groundstone tools were not bequeathed and that surviving relatives needed to obtain new grinding tools. In considering these and other unknown factors that promote material demand, it is possible that the need for vesicular basalt groundstone tools was large enough to sustain its

[2] The figures reported by McBryde (1947) indicate that the number of groundstone tools imported by Quezaltenango in a year is greater than its population. Although this estimate is perhaps too high, the point remains valid that groundstone demand is greater than one would typically expect for traditional societies.

inclusion in a market-like economy. This study provides the first assessment of the market exchange hypothesis for the movement of vesicular basalt groundstone in the Salt-Gila Basin.

Elite-Controlled Exchange

A fifth possible explanation that accounts for the movement of vesicular basalt in the Hohokam territory is elite-controlled exchange. This distribution model posits that the long-distance movement of goods and materials was embedded in a web of regional exchange relations managed by a few elite members in each Hohokam village. The idea is based on an abundance of ethnographic and historical data which have found that individual aggrandizers are present in many traditional societies and that these persons attempt to gain or sustain their elevated social status by manipulating the distribution of high-value goods or other material resources that are important to local households for social reproduction and ritual participation (Blanton et al. 1996; Brumfiel and Earle 1987; Earle 1987, 1997, 2002; Friedman and Rowlands 1977; Hayden 1995, 1996; Helms 1992; Malinowski 1920, 1921, 1922; Santley 1984; Strathern 1969, 1978; Wiessner 2002). Control over the distribution of important goods and materials translates to elevated status because it provides a tangible means for establishing social and economic obligations with other individuals who are in need of those items (Blanton et al. 1996:4). This inequitable and centralized economic system is often permitted to exist by the greater populace due to the establishment of a shared ritual ideology that guarantees, at least in abstract, that followers will receive a fair share of the available goods (Spielmann 2002; Stanish 2003).

Similar to market exchange, elite-controlled exchange requires a stable supply and demand to persist. Though, contrary to market exchange, this economic balance is created through social and political manipulation. Thus, craft specialization and community interdependence are not the result of environmental and demographic conditions, but rather are created by leaders as a means of strengthening political control (Brumfiel and Earle 1987; Earle 2002). Currently, there is no evidence suggesting that Preclassic Hohokam society featured elite-sponsored groundstone tool production. Over a century of archaeological research in the region has not yielded one example of large caches of vesicular basalt raw material or finished groundstone tools, which would be expected if the production of groundstone implements was highly concentrated and organized under the auspices of elites. Additionally, there is little evidence in mortuary or settlement patterns for ranked status difference among individuals or communities, respectively, during this time (Doyel 1987; 1991a; McGuire 1992; Wilcox and Sternberg 1983; see Bayman 1995 and Harry and Bayman 2000 for a different perspective based in the Tucson Basin).

However, there is a possibility that Classic period platform mounds were centers from which Hohokam elites managed local and extra-local distribution networks (Bayman 1994, 1995, 2002; Doyel 1991a, 1991b; Howard 1985; McGuire 1985; McGuire and Howard 1987; Rice 1995, 1998; Rice et al 1998; Teague 1984). Several studies have found evidence that platform-mound sites accumulated greater quantities of nonlocal goods than nonplatform-mound sites (i.e., Bayman 1994, 1995, 2002; Fertelmes et al. 2012; Harry and Bayman 2000; McGuire and Howard 1987; Teague 1984). For example, the platform mound community at Marana contained greater concentrations of high-valued goods, including obsidian, marine shell ornaments, and decorated pottery, than surrounding villages (Bayman 2002; Harry and Bayman 2000). Additionally, vesicular basalt nonlocal obsidian frequencies at the site of Las Colinas were nearly eight times greater in the mound precinct than in the surrounding habitation areas (Fertelmes et al. 2012). Importantly, though, the levels of exotic materials at platform-mound centers are well below those expected for a centralized managerial-control system typical of chiefly redistributive economy (Rice et al.1998). Thus, while economic and political authority probably became more centralized around the platform mound during the Classic period, the manipulation of the Hohokam economy by elites was comparatively minimal and emphasized group rather than individual welfare (Elson and Abbott 2000; Fish and Fish 2000; Harry and Bayman 2000). It is possible, then, that local acquisition and distribution of vesicular basalt groundstone tools was overseen by a small segment of Hohokam society.

Test Variables

The validity of the five hypotheses described above is assessed by examining four measurable variables: 1) the relative frequency of different vesicular basalt types at sites as related to the geographic distance from their source; 2) intra-site variance in vesicular basalt type diversity; 3) inter-site variance in vesicular basalt type diversity; and 4) temporal specificity and continuity. Each hypothesis has specific vesicular basalt provenance data-patterning expectations for each of these variables based on observations from other archaeological and ethnographic case studies. Before delving into the particular expectations for each hypothesis, the following paragraphs define each variable and how they will be measured in this study.

Relative Source Frequency and Geographic Distance

The first variable that will be assessed during the hypothesis testing is the relative frequency of various vesicular basalt types in a site sample as related to their geographic distance from the geographic source area. The distance between a site and a vesicular basalt source area is considered in this study to be the linear interval from the center of the excavated portion of the site, where vesicular basalt groundstone samples were recovered, and the nearest documented groundstone quarry at a vesicular basalt outcrop. Straight line distances were deemed appropriate for this study since there is minimal topographic relief in the Salt-Gila Basin. One primary exception, though, is South Mountain, which separates the lower Salt River Valley from the middle Gila River (see Figure 1.3). The distance between some sample sites and vesicular basalt source areas therefore did take this geological feature into account by using the shortest path required to circumvent the mountain as the site-to-source distance.

The relationship between source frequency and geographic distance to source will be evaluated in two ways. First, the frequency of the most proximate source area in a site assemblage is evaluated. Assessing whether or not a site relied primarily on the closest available source area involves sorting the relative frequency of each vesicular basalt source area represented in a site sample by increasing site-to-source distance. If more than 70 percent of the vesicular basalt is traced to the nearest available source location, then it will be inferred that the site procured vesicular basalt primarily from this source area. The second pattern of interest is a distance-decay trend in relative source frequency for vesicular basalt groundstone samples. The existence of this data trend is confirmed using a Spearman's rank-order correlation test. This non-parametric test generates a statistic (Spearman's r) that describes the strength, direction, and significance of the association between two variables. Here, the variables of interest are relative source frequency and the site-to-source distance for each of the represented source areas in a site sample (note: source areas that are absent in a sample will not be included in the analysis). Test results that indicate the relationship is negative, strong, and significant ($r_s \leq -0.60$; $p \leq 0.05$) will be considered a distance-decay relationship.

Intra-site Source Diversity Variance

Variance in the diversity of vesicular basalt source types among different contexts within a single settlement can also provide insight on Hohokam material movements. Following others (e.g., Dunnell 1989; Garraty 2009; Kintigh 1984, 1989; McCartney and

Glass 1990), diversity is regarded as a combination of the interrelated concepts of richness and evenness. Richness is the number of different kinds or classes in a sample. Evenness is the relative frequency of each kind in a sample. Both richness and evenness can provide some expression on the variability within or between sample sets. For example, samples that are comparatively rich (e.g., a large number of kinds) or even (e.g., similar proportions of different kinds) are considered diverse. In contrast, samples that have a low number of kinds, or an abundance of just one of several possible kinds, are not diverse.

Statistics sensitive to both richness and evenness are referred to as measures of heterogeneity (McCartney and Glass 1990:522). Intuitively, heterogeneity is regarded as something that is highly variable in nature. It is opposite to homogeneity, which describes something that is uniform. In statistics, though, heterogeneity means something slightly different. It is the difference in the variable composition between one sample unit and a hypothetical standard, the latter of which often is determined using the overall proportion of each variable among all sample groups or even the total population (Garraty 2009:160). Heterogeneity thus describes the variation in the diversity (both richness and evenness) between sample groups, and not necessarily within a single group. If two different sample groups exhibit dissimilar proportions of different kinds, then there is heterogeneity. However, if two sample groups exhibit similar proportions of the same kinds, then there is homogeneity.

Archaeologists (borrowing from ecologists) have developed several approaches for measuring diversity in quantitative terms (see McCartney and Glass 1990). A more useful and therefore employed statistic for measuring diversity among archaeological datasets is the Brainerd-Robinson (BR) coefficient of similarity (Kintigh 2002; Peeples 2011). This statistic was developed for the specific purpose of comparing different archaeological collections in terms of the proportions of different represented types (i.e., diversity). A BR coefficient is the sum of the differences between the variable percentages for all types shared between sample groups (or an artificial, idealized dataset) subtracted by 200. This calculation generates an integer between 0 and 200, in which 200 is perfect homogeneity and 0 is perfect heterogeneity. The BR test is further useful because, by following procedures developed by DeBoer and others (1996) and Peeples (2011), it can be run parallel with a Monte Carlo simulation that calculates the probability of obtaining a BR similarity value less than or equal to the actual value by chance. This supplementary test determines whether the observed differences within or between sites are statistically significant or the result of the low sample numbers. For instance, imagine that a BR test comparing vesicular basalt provenance data between two different household groups at a site generates a similarity score of 100. If the Monte Carlo simulation indicates that this score is statistically significant, then the intra-site diversity pattern will be described as heterogeneous. If the simulation finds the score to not be significant, then the intra-site diversity pattern will be described as not heterogeneous (i.e., homogenous).

The BR coefficient of similarity and parallel Monte Carlo simulation will be used to assess intra-site variance in vesicular basalt source type diversity. Variance, or heterogeneity, in the consumption of source areas among different segments of a site will be considered present if two or more social units (i.e., household groups) exhibit a significantly low BR score when compared with one another. Conversely, if the BR test fails to find a significantly low coefficient of similarity among any of the social units, then intra-site diversity will be considered homogenous.

Inter-site Source Diversity Variance

The third variable that will be evaluated is inter-site variance in vesicular basalt type diversity. This variable examines whether or not separate Hohokam villages consumed similar proportions of material from different vesicular basalt source areas. Similar to intra-site diversity, inter-site diversity can be described as being either homogenous or heterogeneous in character. Inter-site homogeneity refers to similar degrees of diversity among sites (i.e., the same source areas were consumed to roughly the same extent at each site). In contrast, inter-site heterogeneity means that there is substantial difference in source area consumption. Assessing the diversity of vesicular basalt source type across multiple sites in a region will be used specifically to test the market exchange hypothesis only since this explanation expects there to be considerable homogeneity in vesicular basalt source types at different sites due to the existence of an extensive and shared exchange system (see discussion below). The other hypotheses do not assume that all Hohokam communities are engaged in the same vesicular basalt provisioning system. Therefore, it is not necessary to evaluate inter-site source diversity variance for these models (see Table 3.1).

Inter-site vesicular basalt type diversity will also be evaluated using a BR test for similarity. An important qualification to note at this point, though, is that while a BR test can efficiently determine if there are significant differences in source diversity between multiple pairs of sample units, it cannot assess the diversity of the dataset as a whole. In other words, the BR test cannot tell if significant differences between one or two sample groups in a collection of 10 sample groups constitutes heterogeneity for the entire dataset. Such a problem is not of considerable importance when assessing intra-site diversity because a significant difference between just two sample units is sufficient for supporting or rejecting the different vesicular basalt provisioning models (see discussion below). However, at the regional level, the limitation of the BR test is a concern because the irregular spatial distribution of sample sites with respect to vesicular basalt source areas potentially affects the uniformity of provisioning practices. It is not possible to replace the BR evaluation with other tests, such as Chi-square or Fisher's exact test, due to what turned out to be very low variable counts (n=<5) and a large number of types (n>6). Thus, whole sample heterogeneity is defined in this study as one-quarter of the paired samples with a BR value of 100 or less and/or is significantly different.

Temporal Specificity and Continuity

The final variable investigated as part of the hypothesis testing is temporal specificity for the Preclassic and Classic periods. Hohokam chronological intervals can serve as test variables because various vesicular basalt procurement practices are only applicable during certain time periods. This expectation is based on several archaeological studies that have found evidence of a market economy only during the Preclassic period, when ballcourt festivals provided an ideal context for the gathering of large crowds of people (Abbott 2006, 2009, 2010; Abbott et al. 2001, Abbott et al. 2007a; Abbott et al. 2007b; Van Keuren et al. 1997). Likewise, data supportive of elite-controlled exchange exists only during the Classic period, when a small group of individuals potentially oversaw ritual activities conducted at platform mounds (Bayman 1994, 1995, 2002; Doyel 1991a; Fertelmes et al. 2012; Rice et al. 1998; Teague 1984). As a result, the market exchange hypothesis and its associated data patterning expectations are applicable only to Preclassic households, while the elite-controlled exchange model is a suitable hypothesis only during the Classic period.

The Preclassic and Classic periods can also serve as test variables because various vesicular basalt procurement practices may have differed between the two periods. For example, households within a single settlement may have acquired groundstone material primarily through direct procurement during one temporal phase, but obtained stone through direct exchange in another. Additionally, if certain Hohokam cultural institutions (e.g., ballcourt and platform mounds) did support marketplace or elite-controlled exchange, then their rise and fall should compel substantial changes in vesicular basalt procurement practices and, therefore, vesicular basalt source provenance data patterning through time. The presence of temporal variability in vesicular basalt procurement practices between the Preclassic and Classic periods will be assessed by using Spearman's rank-order correlation to test for temporal continuity in vesicular basalt source area preference over time. R_s outputs that reveal a strong and significant positive association ($r_s \geq 0.60$; $p \leq 0.05$) in source provenance data through time indicate that material from the same source areas were acquired in the same order of preference during both temporal intervals of investigation (i.e., temporal continuity). Conversely, correlations that do not exhibit a strong and significant correlation suggest that there was a change in source preference over time.

Test Expectations

The primary objective of this study is to reject potential hypotheses accounting for the movement of vesicular basalt during the Hohokam Preclassic and Classic periods in the Salt-Gila Basin (see Table 3.1). The validity of each hypothesis is evaluated by assessing vesicular basalt provenance data patterns as they pertain to the four aforementioned test variables. Each material provisioning practice is expected to be associated with specific archaeological data patterns for one or more of the test variables based on observations from other ethnographic and archaeological case studies. Two different provisioning practices may yield similar patterns for a single test variable, but no two hypotheses share the same set of expectations. Therefore, the complete evaluation of vesicular basalt data patterns among all four variables provides a method for evaluating the validity of each hypothesis. The following paragraphs review the test expectations for the five vesicular basalt provisioning models.

Direct Procurement

The direct procurement model is rejected if a site does not acquire the majority of its vesicular basalt from the nearest available source area. This test expectation is based on the Law of Monotonic Decrement (Renfrew 1977), which states that in the absence of a preferred exchange partner (e.g., direct exchange) or highly organized exchange system (e.g., market exchange, elite-controlled exchange), the frequency or abundance of an exchanged commodity across space will decrease steadily and predictably (Hodder 1974; Hodder and Orton 1976; Kooyman 2000; Renfrew 1977:72; Renfrew et al. 1968a, 1968b; Torrence 1986). As such, the nearest lithic source area to a community is expected to be the most frequent at the site. Reliance on the closest material source area is considered satisfied in this study if 70 percent or more of the vesicular basalt in a site sample derives from the nearest available source area. Thus, the direct procurement model is deemed a viable explanation for material movements if 70 percent or more of the vesicular basalt in a site sample derives from the closest available source area. Conversely, this material provisioning model will be rejected if less than 70 percent of the vesicular basalt is from the nearest source area.

The direct procurement model may also be rejected if there is significant heterogeneity in the diversity of vesicular basalt source types among spatially distinct household groups within a single site. If different household groups within a village are all directly procuring vesicular basalt from the nearest available source area, then there should be little to no variation in consumption patterns within a village. In contrast, intra-site variation in source diversity suggests that different procurement practices are being pursued within a village, meaning direct procurement is likely not the predominant groundstone material provisioning practice. Therefore, if a BR test reveals that there is significant variation in the diversity of vesicular basalt source types among at least one household unit within a village, then the direct procurement model will be rejected.

Direct Exchange

The direct exchange model is rejected if a site acquires the vast majority of its vesicular basalt from the nearest available source area, or if there is a distance-decay relationship in relative source frequency. Ethnographic and archaeological evidence indicates that direct exchange relations are usually based on social relationships, such as close kin or affines (Earle 2002; Sahlins 1972; Wiessner 1977, 1982). The spatial extent of these relations is not necessarily bounded by geographical distance. In fact, direct exchange between households or communities usually develops as a means to overcome spatial or temporal variability in resource availability (Braun and Plog 1982; Ford 1982; Halstead and O'Shea 1989; Rautman 1993; Spielmann 1986, 1991; Stark 1991, 1992;

Wiessner 1977, 1982). Therefore, if the majority of vesicular basalt in a site sample is from the closest available source area, or there is a strong and significant ($r_s \leq -0.60$; $p \leq 0.05$) correlation in relative source frequency and geographic distance, then the data patterning suggests that geographic distance is a more important variable than social relations in the movement of vesicular basalt. However, if there is no association between relative source type frequency and geographic distance from the village, then support for the direct exchange model will persist.

The direct exchange model will also be rejected if there is a homogenous distribution of vesicular basalt source types within a site. Substantial differences in source type diversity is expected across a site because each social unit is engaged in its own exchange relations, and since these exchange partners were typically based on kin or fictive kin ties, these relationships will differ for each social unit (Earle 2002; Peterson et al. 1997 Sahlins 1972). The existence of various exchange relations leads to the acquisition of material from multiple source areas, which then typically remains spatially segregated into discrete consumer units. In contrast, other material provisioning practices tend to produce homogenous intra-site distributions of different vesicular basalt source types (see discussion under Market Exchange and Elite-Controlled Exchange in this chapter). Therefore, if a BR test produces a significantly low similarity score between two or more household units within a site, then the direct exchange model will be supported. Conversely, if the statistical test fails to find a significant difference in vesicular basalt acquisition trends between any two household units within a site, then support for the direct exchange model will be absent.

Down-the-Line Exchange

The down-the-line exchange model is rejected if the relative frequency of different vesicular basalt source types in a site sample does not exhibit a strong and significant distance-decay relationship. This expectation is based on the assumption that each node in a linear exchange network consumes a portion of the total supply that they receive before passing it on to the next node (Renfrew 1977; Sahlins 1972). Hohokam sites had the potential to receive material from several different vesicular basalt source areas given the presence of multiple outcrops in the region. Therefore, if groundstone material was moving through down-the-line exchange, and the volume of material available from a specific source area at a site is negatively correlated with the distance between the site and source area, then the relative frequency of source areas in a site sample should exhibit a distance-decay relationship. The presence of a strong and significant distance-decay trend in the relative frequency of different vesicular basalt source types at a site thus provides support for the down-the-line exchange model. Conversely, if geographic distance has no relationship with the relative frequency of different source types in a site sample, then the movement of materials through linear exchange networks is likely not operating, and the down-the-line exchange model can be rejected.

The down-the-line hypothesis will also be rejected if there is significant heterogeneity in intra-site vesicular basalt diversity patterning. This expectation results from the fact that in a linear exchange network that serves to transmit a finished good from a single producer to several different consumers through multiple intermediaries, the richness and evenness of different lithic source types will be related to their distance from each site. The predicable order of source availability for a single site therefore acts to suppress measurable intra-site variation in lithic provenance data as all households will have access to the same general pool of resources (i.e., odds are that each household will get material from the first and/or second closest source area). Therefore, if a BR test finds significant variation in the diversity of vesicular basalt source areas between one or more household groups within a site, then the down-the-line exchange model is rejected as a viable explanation. However, if the test finds that different household units have access to the same pool of resources, then there is support for the material provisioning model.

Market Exchange

The market exchange model is rejected if a Preclassic site acquires the majority (>70%) of its vesicular basalt from the nearest available source area, or if there is a distance-decay relationship in relative source frequency. If most Hohokam households chose to obtain finished vesicular basalt groundstone tools from producers residing in a handful of villages, rather than taking the effort to procure material directly from the nearest available source area themselves, then there should be no evidence of reliance on the closest available source area. A distance-decay relationship will also be lacking in the relative frequency of different vesicular basalt source types since the link between producer and consumer is not interrupted by middlemen who consume a portion of the supply. One important exception to these assumptions, though, is for communities located in close proximity (< 1 km) to a vesicular basalt quarry (e.g., Upper Santan). In these cases, the sheer abundance of material from the closest source area may be due to the role the local community played in producing a vast quantity of vesicular basalt groundstone tools for market or down-the-line exchange.

The market exchange model will also be rejected if there is a heterogeneous distribution of vesicular basalt source types within or among Preclassic sites. As discussed earlier, a market economy is expected to produce similar assemblages within single sites and throughout a region because the production of craft items is highly specialized and their distribution is independent of social and political relations (Garraty 2009; Hirth 1998). Additionally, if periodic marketplaces associated with Hohokam ballcourt festivals were responsible for the movement of goods throughout the Hohokam region as some scholars have proposed (Abbott 2006, 2009, 2010; Abbott et al. 2001; Abbott et al. 2007a; Abbott et al. 2007b), then most Hohokam households would have equal opportunity to acquire goods from the same set of producers. Thus, if a BR test comparing various Preclassic site assemblages finds significant homogeneity in source provenance data between two or more sample groups within or between sites, then the market hypothesis is supported. Conversely, if this same test does expose substantial variation between two or more sample units, then the market exchange hypothesis will be rejected.

Lastly, the market exchange hypothesis expects temporal variation in vesicular basalt procurement practices through time. This expectation is based on the fact that several Hohokam scholars have found evidence of a market-style economy only during the Hohokam Preclassic (Abbott 2006, 2009, 2010; Abbott et al. 2001; Abbott et al. 2007a; Abbott et al. 2007b; Kelly 2013; Van Keuren et al. 1997; Watts 2013). It has also been argued that this market economy dissolved rapidly in the late Sedentary period (Abbott 2009, 2010). If vesicular basalt was moved through a market exchange economy during the Preclassic, then the demise of Hohokam markets in the late Sedentary is expected to have compelled substantial changes in household material acquisition practices by the start of the Classic period. Thus, the market exchange hypothesis can be rejected if a Spearman's rank-order correlation finds a strong and significant positive relationship ($r_s \geq 0.60$; $p \leq 0.05$) in the relative frequency of different vesicular basalt types between the Preclassic and Classic periods. If this same test fails to identify a strong and significant positive relationship, then support for the market-exchange hypothesis will persist.

Elite-Controlled Exchange

The elite-controlled exchange hypothesis will be rejected if a Classic period site acquires the majority (>70%) of its vesicular basalt from the nearest available source area, or if there is a distance-decay relationship in relative source frequency. An abundance of ethnographic and archaeological evidence suggests that the acquisition and redistribution of nonlocal goods is a critical aspect of centralized exchange systems (Blanton et al. 1996; Brumfiel and Earle 1987; Earle 1977, 1987, 1997, 2002; Hayden 1995, 1996; Wiessner 2002). Additionally, as part of a power seeking strategy, elite members of a society will maintain exchange contacts with elites in several locations. Therefore, if the movement of vesicular basalt is part of an elite-controlled exchange economy, then geographic provenance data from Classic period sites should show no relationship between relative source area frequency and distance to source. If such a relationship is present, then the data will suggest instead that geographic distance is an important variable in the vesicular basalt movements. In this case, the elite-controlled exchange model will be rejected.

The elite-controlled exchange model can also be rejected if there is significant heterogeneity in vesicular basalt source type diversity among separate social units within a single village. Intra-site homogeneity in vesicular basalt distribution is expected since village elites tend to first pool material from several source areas before redistributing it to others in their community. Similar to marketplace exchange, the pooling of materials in a central place serves to mix material from various source areas, thereby giving each household equal access to several different source areas (Pires-Ferreira 1976; Pires-Ferreira and Flannery 176; Torrence 1986). Shared access to multiple vesicular basalt source areas means that no social unit at a site will have disproportionate access to a particular source or set of sources. Thus, the elite-controlled exchange hypothesis is supported if a BR test finds significant homogeneity in source type among discrete social units within a single Classic period village. However, if the statistical test does find substantial variation between two or more social units, then the material provisioning model can be rejected.

Lastly, the elite-controlled exchange hypothesis can be rejected if there is not temporal variation in vesicular basalt procurement practices through time. Hohokam scholars have only found evidence of a centralized economy at Classic period platform mound sites (Bayman 1994, 1995, 2002; Fertelmes et al. 2012; Teague 1984). For instance, Fertelmes and others (2012) found a significantly disproportionate amount of nonlocal obsidian at the Las Colinas platform mound compared to the surrounding residential areas, suggesting that the inhabitants of the former area had increased access to the volcanic glass. Evidence of disproportionate access to goods is lacking during the earlier Preclassic period (Fertelmes et al. 2012; Teague 1984). Thus, if an elite-controlled exchange economy did emerge during the Classic period, and the movement of vesicular basalt was managed by elites, then there should be evidence of a shift in vesicular basalt procurement and distribution patterns between the Preclassic and Classic periods. The elite-controlled exchange hypothesis can therefore be rejected if a rank-order correlation finds a strong and significant positive association ($r_s \geq 0.60$; $p \leq 0.05$) in the relative frequency of different vesicular basalt types between the Preclassic and Classic periods.

If this same test fails to identify a strong and significant positive relationship, then support for the material provisioning hypothesis will remain.

It is noted that some models of elite-controlled exchange expect considerable homogeneity in vesicular basalt provenance data. However, this expectation is mostly applicable in parts of the world where elite authority is extremely pronounced and institutionalized as part of a regional political-economy (e.g., Blanton et al. 1996; D'Altroy 1992; D'Altroy and Earle 1985; Earle 1997; Elson and Sherman 2007; Patterson and Gaily 1987; Santley 1984). Available evidence from the Hohokam culture sphere does not support such a model. Hohokam scholars have found evidence that compared to the Preclassic, the Classic period was a time of decreased social and potentially political interactions within the Hohokam core area (Abbott 2003a, 2003b, 2006; 2009; Crown 1991; Doyel 1991a). Furthermore, ethnographic observations from similar small to middle-range societies indicate that elite exchanges tend to be highly competitive faction-building strategies (Cobb 1993, 1996; Earle 2002; Hayden 1995, 1996; Helms 1992; Spielmann 2002). These two perspectives together suggest that Classic period elites did not develop or maintain a regional distributional system, but were perhaps instead competitors. From this vantage, then, the exchange of vesicular basalt during the Classic period is not expected to have been orchestrated at the regional level between cooperating elites. Therefore, a shared regional distribution system is neither expected nor tested for in the elite-controlled exchange model.

Summary

Five provisioning models that potentially explain the manner by which Hohokam households acquired vesicular basalt groundstone are tested as part of this study. These five models are: 1) direct procurement; 2) direct exchange; 3) down-the-line exchange; 4) market exchange; and 5) elite-controlled exchange. Again, these models are not mutually exclusive, meaning that multiple procurement and distribution practices may have existed simultaneously within and among Hohokam settlements. Some degree of spatial and temporal variability in procurement practices is in fact expected due to the nonubiquitous distribution of vesicular basalt in the Salt-Gila Basin and potentially shifting social and political relations among Hohokam communities. It is also reiterated that the proposed hypotheses are not an exhaustive list of possibilities. Other explanations not directly considered in this study may potentially account for the material movements. Moreover, unique Hohokam cultural practices and institutions (e.g., ballcourt and platform ceremonies) may potentially put a slight twist on these rather general material acquisition models. Therefore, an improved understanding of Hohokam vesicular basalt provisioning practices will be achieved by rejecting as many of the hypotheses as possible and, if feasible, creating a new model from the observed data patterning.

CHAPTER 4: VESICULAR BASALT SOURCE SAMPLE

A large sample of vesicular basalt from natural and cultural deposits is required to for this study. The raw material sample, which includes stone from various volcanic formations in the region, is essential for constructing a geochemical reference library that is useful for determining the provenance of vesicular basalt groundstone artifacts. The archaeological sample is composed of vesicular basalt artifacts from several spatially and temporally distinct Hohokam site assemblages. Provenance data from this diverse sample set is required to assess the plausibility of each research hypothesis. This chapter details the sampling strategy and composition of the raw material. The archaeological sample is the focus of the following chapter.

Raw Material Sample Plan

Identifying the geographic provenance of Hohokam vesicular basalt groundstone is in large part dependent on the creation of a geochemical database that represents the available procurement areas in the Salt-Gila Basin. The nature of raw material sample is critical because it will provide the basis for all subsequent analyses, interpretations, and inferences (Beardsley and Goles 2001; Richardson 1993; Shackley 2008). Its magnitude in sourcing studies was not underestimated by Beardsley and Goles (2001:587), who wrote that field sampling "is the first step in a long series of analytical procedures and interpretations that ultimately culminate in the identification of geological deposits which served as raw material sources."

Despite its importance, there is no standard protocol for developing a regional geochemical database. Its production and composition will depend on many factors, not the least of which include the topic of the research question, the spatial scale of the study region, the physical character of the raw material, and the geological history of the research area. Because these factors will vary across study areas, scholars advise researchers against adhering to a predetermined sampling plan and instead offer general guidelines designed to improve the representativeness and, therefore, the quality of the raw material sample overall (e.g., Beardsley and Goles 2001; Rapp 1985; Shackley 2005, 2008; Size 1987; Tykot 2003; Weisler 1993; Weisler and Sinton 1997). A review of various database creation projects suggests there are two important rules: first, identify all relevant target populations (i.e., geological source areas that would have supported archaeological quarries in the past) and, second obtain a sample population that is sufficiently representative of each target population (Beardsley and Goles 2001; Mintmier et al. 2012; Shackley1995b; 2005, 2008; Sinton and Sinoto 1997; Size 1987; Weisler 1990, 1993, 1997, 1998).

Identifying Target Populations

The first step in constructing a representative geochemical database for a geographic provenance analysis is to identify the primary and secondary distribution of all relevant target populations (Mintmier et al. 2012; Shackley 1995b, 2005, 2008; Tykot 2003:63; Weisler 1990, 1993). The objective of this study is to ascertain the origin of vesicular basalt used in Hohokam groundstone tool manufacture. Thus, the target population is defined as any deposit of vesicular basalt in the Salt-Gila Basin. Potential primary source deposits for this study thus consist of any intermediate-mafic (i.e., andesitic-basalt) volcanic formation. Felsic (i.e., rhyolitic) bedrock outcrops, such as Tempe Butte, Twin Buttes, and Superstition Mountains, were not considered because the material is not preferred for groundstone manufacture. Secondary source areas include drainages or terraces that contain tailings from the primary intermediate-bedrock formations.

A review of geological maps and documents resulted in the identification of approximately 35 spatially discrete bedrock exposures in the Hohokam core territory that constitute a primary source deposit (see Figure 1.9; Table 4.1).These select formations represent the remains of Cenozoic era volcanic flow events that date to the early Miocene (23-17 mya), middle Miocene (17-12 mya), and late Miocene (15-5 mya) epochs. The extrusive deposits of the early Miocene are primarily the result of andesitic eruptions. These events led to the formation of the better known Chalk Canyon (ca. 23-15 mya), Garfias Wash (ca. 20-17 mya), and quartz-bearing basalt "Hedgpeth" (ca. 20-15 mya) formations that are now visible in the mountains north of the modern Phoenix area[3]. Middle Miocene material is correlative with Hickey (i.e., New River) Basalt (ca. 16-9 mya). This dark basaltic rock is often found superimposed atop the early andesitic deposits on several of the tilted fault-block remnants in the Salt-Gila Basin, including the Hieroglyphic Mountains, Hedgpeth Hills, Deem Hills, Shaw Butte, and Middle Mountain

[3] The so called "Hedgpeth" formation is likely a subcomponent of the Chalk Canyon formation (see Jagiello 1987; Leighty 1997). However, due to its unique nature and notoriety in Hohokam vesicular basalt provenance research, it is given its own label in this document.

Table 4.1. List of Basalt Outcrops in the Study Region

Region	Source Area	Documented Quarry	Sampled
Lower Salt River Valley	Lookout Mountain	No	No
	McDowell Mtn	YES	YES
	Moon Hill	YES	YES
	Shaw Butte	No	YES
Middle Gila River Valley	Black Hills	No	No
	Dozer Hill	No	No
	Florence Cinder Mine	YES	YES
	Hunt Highway Buttes	No	No
	Lone Butte	YES	YES
	Picture Rock	YES	YES
	Poston Butte	YES	YES
	Santan Mtns	YES	YES
	Walker Butte	No	No
Northern Periphery	Adobe Mtn	YES	YES
	Agua Fria River Terrace	YES	No
	Biscuit Flat Area	No	No
	Calderwood Butte	YES	No
	Deem Hills	No	YES
	Hedgpeth Hills	YES	YES
	Hieroglyphic Mtns	YES	No
	Ludden Mtn	YES	YES
	Middle Mountain	No	No
	New River Terrace	YES	No
	Union Hills	No	YES
	West Wing Mtn	YES	YES
Southern Periphery	Table Top Mountain	YES	YES
	Vaiva Hills	YES	YES
	Vista Mountains	No	No
	Sand Tank Mountains	No	No
	Silver Reef Mtns	No	No
Western Periphery	Arlington Mesa	YES	No
	Arlington Station	No	No
	Powers Butte	YES	No
	Robbins Butte	YES	YES
	White Tank Mountains	No	No

(Ferguson and Skotnicki 1996; Jagiello 1987; Leighty 1997; Leighty and Holloway 1998; Leighty and Huckleberry 1998a, 1998b; Holloway and Leighty 1998). Lastly, Late Miocene basalt can be found at a handful of locations in the study area near the modern town of Florence. Poston Butte and the Florence Cinder Mine are examples of such deposits (Ferguson and Skotnicki 1996; Leighty 1997).

After identifying the location of primary source deposits, it is customary to discern the secondary distribution of any related materials so that the total geographic extent of a source area is understood (Shackley 1995b, 2005, 2008). The identification and eventual sampling of secondary deposits is espoused most explicitly by Shackley (1995b, 2005, 2008), who during his efforts to build a geochemical database for obsidian sources in the southwestern United States, came to realize that raw material from at least four spatially distinct primary sources along the Arizona-New Mexico border had become mixed together in east-central Arizona as a result of post-eruption erosional processes. The identification of these extensive and mixed secondary deposits was important for two reasons. First, it prevented Shackley from making false geographic provenance assignments for analyzed artifacts. Second, it kept archaeologists from using inaccurate provenance data in the development of inferences concerning prehistoric raw material acquisition and distribution practices. As such, Shackley (1995b, 2005, 2008) constantly reminds analysts that a successful lithic provenance study must take into account the possibility of secondary source deposits.

Shackley's advice regarding secondary source deposits is acknowledged, but unwarranted for this research study. The intermediate-mafic stone preferred by the prehistoric Hohokam for groundstone tool production occurs primarily at exposed fault-block remnants in the Salt-Gila Basin (see Figure 1.9). These outcrops were created approximately eight million years ago during the Basin and Range Disturbance and since have been buried by millennia of colluvial, alluvial, and fluvial deposits (Reynolds and Bartlett 2002; Reynolds and DeWitt 1991; Scarborough 1989). In a sense, then, bedrock outcrops may be thought of as the tip of an iceberg, with much of their material buried beneath dozens to hundreds of feet of relatively recent and geologically unrelated deposits. Thus, the vast majority of the primary and secondary source deposits were actually inaccessible to the prehistoric Hohokam.

Secondary deposits of intermediate-mafic stone are occasionally found in the primary drainages of the Hohokam territory, such as the lower Salt and associated tributaries. However, the stone located in these contexts is not of much concern for the present study because they do not comprise a signification portion of river gravels (Drosendahl 1989; Kokalis 1971; Reynolds and Bartlett 2002; Reynolds and DeWitt 1991)[4]. Additionally, river rock typically does not exhibit the physical properties ideal for groundstone production. Fluvial forces have turned what were once large, rough boulders into smooth and much smaller cobbles. These latter attributes are not suitable for the production of trough-shaped metates and two-handed manos, the primary tool forms the Hohokam made using vesicular material (Stone 1994a, 1994b). River stone also tends to become highly altered and flawed as a result of abrasive and violent

[4] River cobbles in the Salt-Gila Basin are derived from a diversity of parent bedrock and were a significant source of raw material for several types of Hohokam tools, including axes, mauls, pestles, one-handed manos, and flaked stone. As noted, though, vesicular basalt river cobbles are neither ubiquitous nor suitable for producing the large metates and two-handed manos that are the focus of this study.

transport. These physical changes render the workability of the stone effectively useless for groundstone tool production (Hayden 1987:24).

Ethnographic research on traditional groundstone manufacture further suggests that secondary stream deposits are not a preferred material source area. In a study of toolmakers from the Maya Highlands of southern Mexico and western Guatemala, Hayden (1987) observed that craftsman did not rely on river cobbles (due to the previously stated problems with such stone), but instead preferred to acquire material from bedrock sources. Intriguingly, the bedrock quarry utilized by Hayden's informant was located nine kilometers further upstream than the first sizable boulders in the river channel, which was the main travel corridor between the informant's village and the quarry. Hayden (1987) concluded from this observation that traditional toolmakers found it more efficient to procure groundstone material from more distant bedrock sources than local riverbeds. Given the availability of volcanic bedrock outcrops in the Salt-Gila Basin, and the undesirability of secondary deposits, the same decision making process observed in the Mayan region is presumed to have been operative among the Hohokam as well.

In sum, geological, physical, and ethnographic observations strongly indicate that the nearly three dozen intermediate-mafic bedrock outcrops in the Salt-Gila Basin represent the geographic extent of the target population, and that secondary deposits associated with these bedrock outcrops are not relevant.

Sampling Target Populations

The second requirement in developing a geochemical database for a geographic provenance study is to acquire a representative sample of each target population (Beardsley and Goles 2001; Rapp 1985; Shackley 2008; Size 1987; Tykot 2003). Collecting a material sample from a geological deposit is more than just walking up to the base of a hill and putting some rocks in a bag. Perhaps the greatest concern in the present study is geochemical variability. Compared to obsidian outcrops, basaltic outcrops have the potential to exhibit considerable intra-source compositional heterogeneity as a result of repeated and long-term flow events (Bostwick and Burton 1993; Lundblad et al. 2011:66; MacDonald 1967). Therefore, knowing where and how much to sample is an important decision.

Scholars who are familiar with the challenge of characterizing heterogeneous deposits have come to recognize that sampling strategies need not take into account the full range of geochemical variation within a geological formation, but rather only capture the relevant portions that were exploited prehistorically (Beardsley and Goles 2001; Eiselt 2006; Richardson 1987; Rutter 2003). A sampling strategy that focuses on a select portion or portions of a population is known as cluster sampling (Beardsley and Goles 2001; Garrett 1983; Size 1987). Cluster sampling makes intuitive sense for this research since the purpose of a provenance analysis is to determine the geographic origin of a culturally-relocated material, and is not a geological exercise. Its use is also supported by three related observations. First, certain geophysical attributes are preferred by toolmakers for groundstone material; second, these preferred attributes tend to be naturally isolated at specific locations among primary source deposits, which leads to the continuous exploitation of these locales (e.g., quarries); and third, analysts have shown that the sampling and characterization of these locales greatly improves the efficacy of lithic provenance analyses by eliminating unnecessary noise in reference databases (Eiselt 2006; Rutter 2003; Rutter and Philip 2008).

Physical Considerations

Ethnographic and archaeological studies of traditional groundstone manufacture and use suggest that both consumer need and producer preference leads to increased selectivity in raw material choice. In groundstone production, the workability of the stone is the most important variable. For groundstone users, material selectivity is based in certain functional considerations related to the processing of foodstuffs, including the material to be processed, grinding efficiency, and the acceptable amount of stone grit introduced into the substance being processed (Adams 1989, 1999; Hard 1990; Horsfall 1987; Mauldin 1993; Schneider 2002). The use-life of the implement is also important in circumstances when preferred groundstone material is relatively scarce (Horsfall 1987; Stone 1994b). Significantly, the underlying variable in both producer and consumer preference is not the material type itself, but rather the stone's texture.

Rock texture is important to groundstone consumers because grain size and pore space determines the grinding potential of a material (Horsfall 1987; Schneider 2002:392). For instance, coarse-grained crystal inclusions (i.e., phenocrysts) and vesicles are desirable for processing dry foods because their inherent angularity helps to shear large-grained domesticates, such as corn, and other cultivars (Schneider 2002:391). Phenocrysts and vesicles also permit grinding tools to maintain an effective working surface, even after repeated use, whereas other materials must be regularly roughened to maintain grinding efficiency (Horsfall 1987:341; Russell 1908:108; Schneider 2002:391). The overall importance of these geophysical properties to groundstone users is supported by a cross-cultural examination of material selection practices in traditional agricultural societies (Schneider 2002; Schneider and LaPorta 2008:24). This study found that most populations deliberately sought materials featuring either a porphyritic texture – course-grained phenocrysts within a fine-grained groundmass – or an aphanitic texture with a high density of small vesicles.

Rock texture is of further regard to groundstone uses because it figures into tool use-life and grit production. Empirical studies have demonstrated that grain size is in part related to material durability. For instance, Tuğrul and Gürpiner (1997) found that basalt with large plagioclase phenocrysts was stronger than varieties of basalt with smaller or fewer phenocrysts assemblages. Stronger materials are less prone to attrition during use, which means a longer use-life and also the decreased production of grit during grinding activities. Tool use-life and grit yield are two major concerns to groundstone users in several ethnographic and historical cases (i.e., Adams 1993; Hayden 1987:24; Horsfall 1987; Leung 1981; Runnels 1981;Schneider 2002:391). For instance, Hayden (1987:14; see also Horsfall 1987:344) observed that traditional groundstone users in southern Mexico recognized textural differences in several types of intermediate-mafic stone, but clearly preferred the varieties that were sufficiently textured to grind food effectively, but dense enough to prevent it from wearing away too quickly or introducing large amounts of grit into maize dough during grinding activities.

Groundstone producers are also concerned with the textural properties of a stone, but in a slightly different way. The primary characteristic sought by a tool maker is a material's workability, which is in part a function of grain size and pore space. For example, materials with a homogenous grain size distribution exhibit more predictable fracturing mechanics and are consequently easier to work and shape (Rich1947). Thus, materials with minimal variability in crystal size are often preferred by groundstone tool producers (Horsfall 1987:345). For a similar reason, a high density of equally-sized vesicles also makes stone easier to work compared to material with a variable distribution of irregularly-sized pore (Hayden 1987:15). Tool makers often refer to rock featuring homogenous vesicles as "soft" stone, because it is easier to work and results in fewer traumas to the hands during lithic reduction (Hayden 1987:14).

It is noteworthy that the textural preferences for groundstone manufacture are slightly dissimilar than those desired by consumers or users. The two groups seem to both prefer stone with a high density of small and equally-sized vesicles. However, groundstone users also prefer stone with coarse-grained inclusions, while tool manufacturers do not. The nature of this contrastive relationship has been described as conflicting among groups with an extremely high ratio of tool consumers to tool producers (Hayden 1987; Cook 1973, 1982), but it is less clear among groups in which the producer and consumer are one in the same. In this case, it would be expected that a balance between a stone's availability, workability, and functionality would be sought.

Either way, the preceding paragraphs are all tied together by the same underlying theme: groundstone material selection is largely guided by preferences for certain textural attributes.

Geological Considerations

The desire among groundstone users and tool makers for specific textural attributes is argued to have encouraged the development of spatially discrete resource procurement areas, or quarries. This argument has been best developed by Schneider (2002), who investigated aboriginal groundstone quarries in western Arizona. Here, in this part of the Basin and Range Territory located to the west of the Hohokam culture territory, Schneider observed that one basaltic outcrop might exhibit intensive quarrying activities, while its neighbor remained untouched (Schneider 2002:382). Archaeological documentation of these exploited outcrops further revealed that only certain portions of them contained evidence of material quarrying and tool production activities (Huckell 1986; Schneider 1992, 1996; Schneider and Altschul 2000). It was clear from this patterning that prehistoric populations in the area were purposely extracting material from specific locations on the landscape.

To better understand material selection practices in prehistoric western Arizona, Schneider (2002) conducted a petrographic evaluation of the exploited material at each quarry. Her analysis revealed that groundstone users were consistently selecting only a narrow portion of the range of material variation present at each bedrock outcrop (Schneider 2002). A similar observation was made by Hayden (1987), who found that groundstone manufactures in southern Mexico exploited only specific flow fields within a larger geological unit. In both cases, then, the extraction of groundstone material was not based on material type alone, but, instead, involved a purposeful decision for specific textural or physical attributes. Again, the "best" stone in these cases featured either coarse-grained phenocrysts or an abundance of small, similarly-sized vesicles (Hayden 1987:15; Horsfall 1987:344; Schneider 2002; Schneider and LaPorta 2008:24).

Due to natural geological patterning, material featuring preferred textural attributes for groundstone tool production is often located in small sections of larger bedrock exposures (Rutter and Philip 2008). These relatively small areas eventually became known to groundstone producing populations and consequently become the areal focus of material exploitation. Sillar and Tite (2000) further propose that quarry sites become part of the cultural landscape. They suggest that once a suitable material type is deemed ideal by a cultural group, the location of this material became part of the cultural knowledge that is passed down through the generations, resulting in continued use of the same specific source area (Sillar and Tite 2000).

Repeated or intensive use of material extraction sites over the course of years eventually results in the formation of an archaeological quarry site. Typical archaeological characteristics of groundstone material sites include material extraction pits, material testing (e.g., pecked, flaked, shaped boulders), tool production (e.g., discrete chipping stations, tool blanks and preforms, large "macro-flakes, hammerstones and picks), and even temporary residences (e.g., windbreaks and other ephemeral structures). Such features and artifact types have been documented as spatially discrete loci among several of the basaltic outcrops in the Hohokam territory (Bostwick and Burton 1993; Bruder 1983a, 1983b; Crownover et al. 1994: Doyel et al. 1985; Greenwald 1996; Lundin 2003; Ryden 2002). It is possible, then, that the prehistoric groundstone quarries in the Salt-Gila Basin were also important places that were mapped into the cultural memory and traditions of Hohokam tool makers. The collection of raw material samples for a representative source reference database should therefore be concentrated in these quarries sites rather than portions of basaltic outcrops unused by prehistoric toolmakers.

Analytical Considerations

The argument that groundstone producers and consumers preferred and exploited specific textural attributes for groundstone material, and that provenance analyses should direct sampling efforts within these areas, has recently gained empirical support (Beardsley and Goles 2001; Eiselt 2006; Rutter 2003; Rutter and Philip 2008). One particularly relevant case study concerns the origin of basalt groundstone in the southern Levant. For two decades, researchers from this region have applied a number of analytical techniques to determine the probable source of groundstone material, including petrographic, geochemical, and isotopic techniques, (e.g., Philip and Williams-Thorpe 1993, 2001; Rutter 2003, Rutter et al. 2003; Watts et al. 2004; Weinstein-Evron et al. 1995; Williams-Thorpe 2008; Williams-Thorpe and Thorpe 1993; Williams-Thorpe et al. 1991). Although these efforts have identified and characterized broad regional source areas, researchers have not been able to consistently determine the origin of artifacts due to natural compositional variation within each source area.

In an effort to improve the reliability and validity of basalt provenance analyses in southern Levant, Rutter (2003, see also Rutter et al. 2000; Rutter and Philip 2008) evaluated the methods, materials, and results of earlier studies, as well as analyzed the composition of additional geological and archaeological samples. The results of his efforts revealed that all of the artifacts in his archaeological sample originated from at least one basaltic dike that is exposed at several different locations in the region. Rutter (2003) inferred from this result that there was a clear preference among tool-makers for a certain type of basaltic material, and that this preference led to the identification and exploitation of specific locales within larger igneous formations. Furthermore, he concluded that the previous lithic provenance analyses had been unsuccessful because their sampling strategies attempted to characterize entire igneous formation rather than specific flows that contained the material preferred by prehistoric peoples for groundstone production.

The results of Rutter's (2003) research are relevant to this research study for two reasons. First, it provides additional evidence that prehistoric tool makers were well aware of and sought certain material or textural characteristics for groundstone production. This observation is consistent with the previously noted observations in the New World (Hayden 1987; Horsfall 1987; Schneider 2002). Second, and perhaps more importantly, it demonstrates that when the quarry area itself is the focus of analytical investigation and not the entire geological formation, a substantial amount of unnecessary noise can be removed from the representative geochemical database. The elimination of this noise in turn improves the reliability of lithic provenance assignments. Both of these points strongly support the use of a clustered sampling approach that involves collecting sample material at target populations within known quarry areas or portions of outcrops exhibiting like material.

In sum, there are certain geophysical attributes that are preferred by groundstone producers and consumers. Material exhibiting these features is generally available within discrete areas of larger geological formations due to natural geological patterning. Tool manufactures were of aware of these locations and therefore focused material extraction efforts within them. These locations thence became part of the cultural knowledge for a group, resulting in continuous and sometimes intensive use of specific locations on the landscape. If raw material sampling efforts are also focused within these quarry areas during the development of a representative geochemical database, then intra-source chemical variability, a major hindrance in groundstone material provenance analyses, can be substantially reduced. Therefore, a clustered sampling approach presents a more effective sampling strategy than a systematic or random approach for the development of a geochemical database for compositionally heterogeneous geological formations. Furthermore, a clustered sampling plan aids in significantly reducing the financial costs of a lithic provenance analysis by avoiding unnecessary sample collection and analysis efforts. For these reasons, the current raw material collection efforts undertaken at primary intermediate-mafic source deposits were focused within known quarry areas or locations with material exhibiting similar geophysical attributes.

Field Sampling Protocol

Sample collection efforts at each target population involved collecting material from within the bounds of prehistoric quarries. Analysts generally advise a minimum of 10 or 15 samples be collected from compositionally homogenous formations (e.g., Shackley 2008; Tykot 2003:68). For heterogeneous formations like those considered in our study, Beardsley and Goles (2001) simply recommend larger sample sets, but caution that the exact number will vary depending on the research context and goals. However, large samples can be prohibitive for logistical and financial reasons. Thus, it was decided as a baseline to collect a minimum of 30 samples from each primary source deposit known or suspected to have been used as a groundstone quarry by the prehistoric Hohokam. No less than 10 samples were collected from any subarea, defined as a quarry, within each primary deposit. If material variability was observed among a primary target population, further sampling efforts may have been undertaken.

For quarry sites with known spatial boundaries, collection efforts involved walking one or more linear transect across the long axis of the site and picking up a material specimen at metered intervals. The exact number of transects and the space between sample spots varied by the width and length of the site, but most often included walking two transects along the upper and lower slopes of a hill and collecting a sample every 20-25 meters. For quarry sites that are known by the archaeological community but not officially recorded (e.g., Poston Butte, Robbins Butte, Picture Rocks), a preliminary reconnaissance of the geological formation was completed first that sought the densest concentration of groundstone manufacture debris. When available, raw material samples were grab- sampled within any discrete activity areas. If no such patterning was present, or if evidence of groundstone quarry and tool production were diffuse, a single linear sample transect was executed across the formation.

Raw Material Source Areas

A clustered sampling strategy calls for the identification and collection of material samples from within the bounds of groundstone quarry sites. As noted earlier, an inspection of available documents identified at least 35 bedrock outcrops in the Salt-Gila Basin that contain andesitic or basaltic material potentially used by the Hohokam for groundstone tool production (see Table 4.1). Examination of archaeological site records, as well as discussions with archaeologists and geologists familiar with the region, resulted in the identification of 40 quarry sites among 23 basaltic outcrops in the Salt-Gila Basin. Sample collection was undertaken at 27 quarry sites within 17 formations, resulting in the acquisition of 738 raw material samples (Table 4.2; Figure 4.1). Samples were not collected from bedrock formations that have been systematically surveyed and show no signs of prehistoric groundstone manufacturing activity (Dozer Hill, Hunt Highway Buttes, Middle Mountain), from quarry sites that have been obliterated (Calderwood Butte and portions of West Wing Mountain), or from areas beyond the scope of the current research project (Agua Fria Terrace, New River Terrace, Gila Bend, Tucson, or Lake Pleasant areas). Future investigations will expand the current scope to include these other intermediate-mafic bedrock outcrops. The following subsections provide a summary of the geological formations and archaeological sites from which raw material samples were collected. This discussion is grouped into five sections representing subdivisions of the Hohokam culture territory: lower Salt River Valley, middle Gila River Valley, and the Northern, Southern, and Western Peripheries.

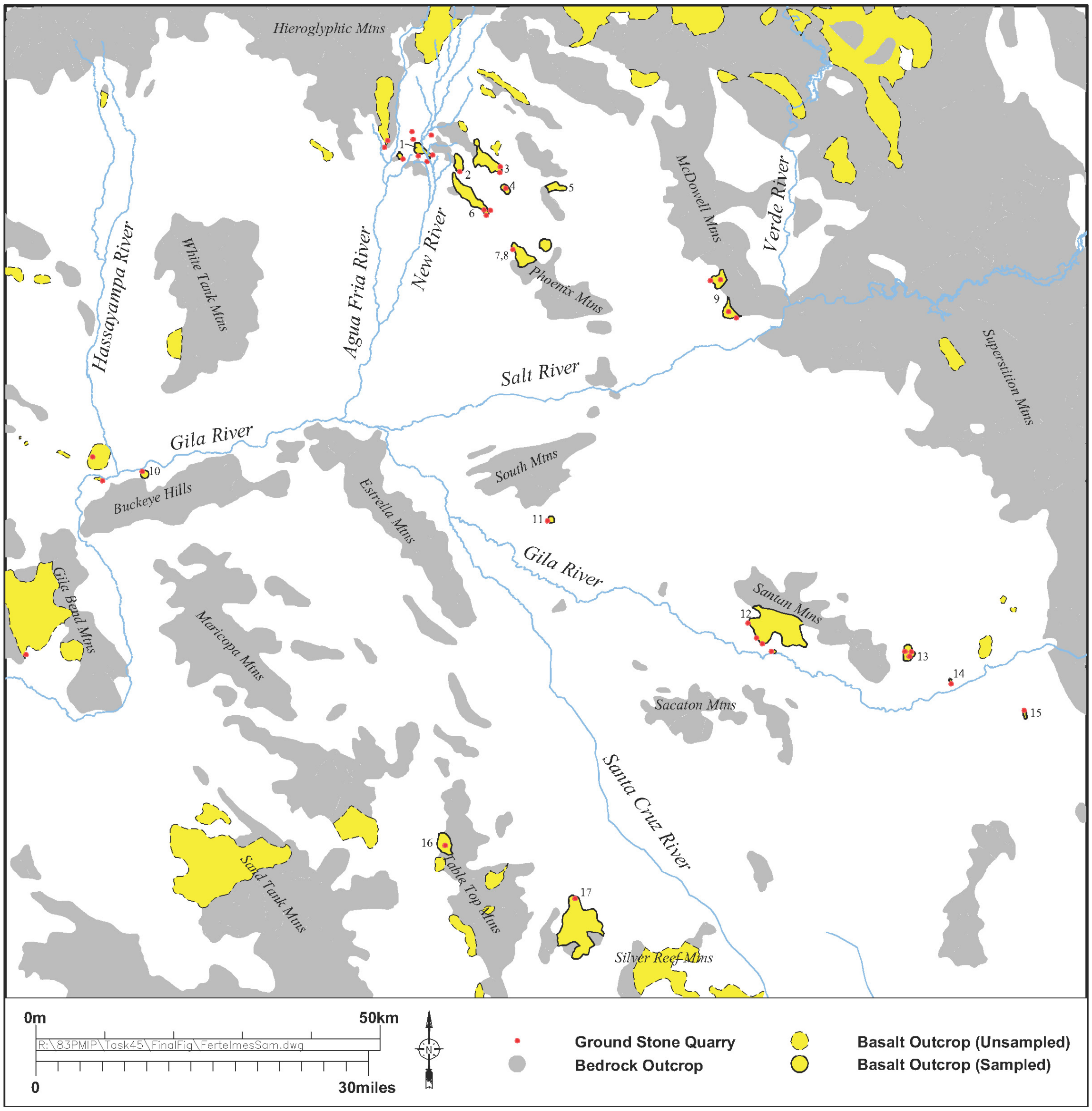

Figure 4.1 . Map of the Salt-Gila Basin Showing Vesicular Basalt Outcrops, Prehistoric Hohokam Quarry Sites, and Raw Material Sample Locations (see Table 1.1 for key to numbered locations).).

Table 4.2. Total Vesicular Basalt Raw Material Sample

Source Area	Quarry Site No./Name	Samples Collected
Adobe Mtn	NA17236	33
Deem Hills	AZ T:8:46 (ASM)	20
	Non Site Area	20
Florence Cinder Mine	AZ U:15:433 (ASM	10
	AZ U:15:433 (ASM)	10
	AZ U:15:435 (ASM)	10
Hedgpeth Hills	AZ T:8:3 (ASM)	32
	AZ T:8:164 (ASM)	20
	AZ T:8:70 (ASM)	30
	Undocumented Quarry	10
Lone Butte	GR-671	30
Ludden Mtn	AZ T:8:47(ASM)	10
	AZ T:8:50 (ASM)	10
	Undocumented Quarry	11
McDowell Mtn	U:5:143 (ASM)	20
	U:5:144(ASM)	10
	SRPMIC-129	30
	SRPMIC-132	15
	SRPMIC-133	15
Moon Hill	AZ T:8:101 (ASU)	11
	AZ T:8:107 (ASM)	15
	Undocumented Quarry	15
Picture Rocks	Undocumented Quarry	35
Poston Butte	AZ U:15:6 (ASM)	30
Robbins Butte	Undocumented Quarry	36
Santan Mtns.	Purple Ridge	10
	Turtle Ridge	10
	Caterpillar Ridge	10
	GR-181	10
	GR-449	20
	Non Site Area	45
Shaw Butte	Non Site Area	10
Table Top Mountain	Undocumented Quarry	35
Union Hills	Non Site Area	30
Vaiva Hills	Undocumented Quarry	30
West Wing Mtn	AZ T:8:63 (ASU)	10
	AZ T:8:19 (ASM)	10
	AZ T:8:21 (ASM)	10
	AZ T:8:22 (ASM)	10
Total		**738**

Lower Salt River Valley

The lower Salt River Valley is defined in this study as the portion of the Hohokam core territory that stretches from the Verde River in the east to the Salt-Gila confluence in the west, and from the Phoenix Mountains in the north to South Mountain in the south (see Figure 4.1). The lower Salt River Valley features several bedrock protrusions that are composed of andesitic-basaltic material (Jagiello 1987; Leighty 1997; Richard et al. 2000). Some of these locations, including Moon Hill and several small outcrops in the McDowell Mountains, contain an abundance of porphyritic or vesicular material that is preferable for groundstone tool production (Bruder 1983a, 1983b; Bostwick and Burton 1993). Other outcrops contain only a very small quantity of basaltic material within the uppermost portions of the formations (e.g., Lookout Mountain and Shaw Butte; Leighty 1997:285; Schaller 1985; Shank 1973). At least two outcrops are composed predominantly of trachyandesite that has been heavily altered by local tectonic activities (e.g., Tempe and Twin/Bell Buttes). This material does not contain textures favorable for groundstone production or use (Hayden 1987; Horsfall 1987; Schneider 2002; Schneider and LaPorta 2008).

The lower Salt River Valley has been the focus of intensive archaeological investigation for over a century (e.g. Cushing 1890, 1892; Foster 1994b; Haury 1945; Midvale 1945, 1966, 1968; Mitchell 1988, 1989; Ruppé 1966; Schroeder 1940). Much of this scholarly attention has been directed at excavating and interpreting the large Hohokam irrigation settlements, such as Pueblo Grande (Foster 1994b), Las Colinas (Gregory et al. 1989), Grand Canal Ruins (Mitchell 1989), and La Plaza (Schilz et al.

2011) that are located alongside the Salt River. However, a few small scale projects have resulted in the identification and documentation of vesicular basalt groundstone quarries (see Table 3.1). Three quarry sites have been identified within the southern portion of the McDowell Mountain range in the city of Scottsdale, including AZ U:5:143 (ASM), AZ U:5:144 (ASM), and AZ U:5:177 (ASM) (Bostwick and Burton 1993; Crownover et al. 1994; Schroeder 1994; Schroeder and Riggs 1995). Three groundstone quarries (SRPMIC-129, SRPMIC-122, and SRPMIC-133) located in a portion of the McDowell Mountain range within the Salt River Pima-Maricopa Indian Community were documented as part of this study. Two other quarries, AZ T:8:101 (ASU) and AZ T:8:107 (ASM), were recorded at Moon Hill in the northern end of the Phoenix Mountains (Bostwick and Burton 1993; Bruder 1983a, Bruder 1983b; Rubenstein et al. 1995).

Raw material samples from Hohokam quarry sites in the McDowell Mountains and Moon Hill were collected and incorporated into the representative geochemical database. Specimens were also collected from Shaw Butte near AZ T:8:88 (ASM), a prehistoric lookout and petroglyph site that features several trails (Rodgers 1977). Although this is not a quarry site, and no quarry has been thus observed at Shaw Butte, samples were collected from the outcrop nonetheless because it represents one of the closets sources of vesicular basalt to the Hohokam villages of the lower Salt River. Sample material was not collected from Lookout Mountain. The basalt at this bedrock protrusion is slightly altered and is restricted to the uppermost section of the outcrop, thus representing an undesirable resource (Holloway and Leighty 1998:9; Shank 1973:15). Additionally, no groundstone quarry has been identified at Lookout Mountain. A more detailed geological and archaeological description of the sampled areas is provided below.

<u>McDowell Mountains</u>

The McDowell Mountains are an extensive and geologically complex formation located north of the Salt River and immediately west of the Verde River. Of importance to this study are a series of comparatively small hills in the southern portion of the range that are composed of Late Oligocene to Middle Miocene volcanic rock (Richard et al. 2000). Archaeological investigations in this area have identified the volcanic material as basalt (Bostwick and Burton 1993). However, the color of the rock is highly varied, ranging from reddish brown to gray and black. There are also large quartz and plagioclase inclusions within the rock matrix. Therefore, it is possible that this material is related to the Hedgpeth Formation found in the hills of the Hohokam northern periphery, which was first erroneously defined as quartz-bearing basalt (Bostwick and Burton 1993; Jagiello 1987), but is now classified as andesite (Leighty 1997:289).

Archaeological investigations in the southern portion of the McDowell Mountains have identified six prehistoric groundstone quarries: AZ U:5:143 (ASM), AZ U:5:144 (ASM), AZ U:5:177 (ASM), SRPMIC-129, SRPMIC-132, and SRPMIC-133). The first two of these sites are located atop Little Saddle Mountain, a small east-west trending bedrock protrusion. AZ U:5:143 (ASM), better known as the McDowell Mountain Quarry (Bostwick and Burton 1993; Crownover et al. 1994:11), features over 350 discrete groundstone manufacturing stations, scores of hammerstones, talus pits, petroglyphs, ceramic scatters, and one rock-walled structure. AZ U:5:144 (ASM) is much smaller than AZ U:5:143 (ASM), consisting of only seven distinct knapping stations (Schroeder 1994). The focus of production at these sites appears to have been manos, based on the 3:1 ratio of mano to metate blanks at the sites (Crownover et al. 1994:11). Unfortunately, the exact age of these sites is unknown due to the absence of temporally diagnostic ceramics at both sites.

A third groundstone quarry, AZ U:5:177 (ASM), is located approximately two km to the north of Little Saddle Mountain atop a conical-shaped igneous outcrop known as Vista Mountain. The site is defined as a small groundstone material quarry consisting of just one discrete manufacturing station (Schroeder and Riggs 1995). A tested boulder was found near the chipping area, but no tool blanks or hammerstones were noted at the site. No additional cultural features or artifacts were observed. Thus, it appears that AZ U:5:177 (ASM) represents a very short-lived groundstone quarry of indeterminate age.

SRPMIC-129, the fourth groundstone quarry in the McDowell Mountain range, is located atop Saddleback Mountain. This quarry was brought to the author's attention by members of SRPMIC Cultural Resources Department, who in turn permitted the site to be recorded as part of this study. The site recording effort resulted in the identification of 142 groundstone manufacturing stations, several of which contained evidence of multiple reduction episodes. Scores of hammerstones, worked boulders, and tool blanks were also identified. It appears, based on the ratio of manos to metate tool blanks at SRPMIC-129, that manos were the focus of production, similar to the other quarries at Little Saddleback Mountain. No other cultural features were observed at the quarry. Thus, the available evidence indicates that SRPMIC-129 was used almost exclusively as a groundstone material quarry and tool production center. No chronological data is available for the Saddleback quarry.

SRPMIC-132 and SRPMIC-133 are located at the southern extent of the McDowell Mountain range on a large isolated bedrock exposure known as Sawik Mountain. Both sites were, with permission of the SRPMIC, identified and recorded by the author as part of the current project. Each site contains scores of discrete groundstone manufacturing stations, multiple hammerstones, and several groundstone preforms. Intriguingly, the raw material at SRPMIC-132 is primarily a dark gray andesite with large quartz inclusions, while the material at SRPMIC-133 consists largely of reddish-gray and purple-hued rock with a variety of crystal inclusions. The preliminary reconnaissance suggests that SRPMIC-132 is the larger of the sites in spatial terms, but more intensive groundstone manufacture was observed at site SRPMIC-133.

A total of 90 raw material samples were collected from the McDowell Mountain quarry sites. Half of the samples were collected from the Little Saddle Mountain quarry sites, with twenty specimens coming from AZ U:5:143 (ASM) and another ten from AZ U:5:144 (ASM). Another thirty samples were collected from Saddleback Mountain within the bounds of SRPMIC-129. The final 30 samples were collected from Sawik Mountain, where the sample was split between SRPMIC-132 and SRPMIC-133. Samples were not collected from AZ U:5:177 (ASM) at Vista Mountain due to the low density of groundstone production debris at the site.

Moon Hill

Moon Hill is a relatively small igneous protrusion located east of 19th Avenue, between Greenway Road and Thunderbird Road in the city of Phoenix. The outcrop is composed of Middle to Late Miocene basaltic rock associated with the Hickey Formation (Richard et al. 2000; Shank 1973). Cultural resource investigations have identified evidence of groundstone manufacture at two locations on the mountain (Bruder 1983b; Rodgers 1977). One site, AZ T:8:101 (ASU), was originally described as a prehistoric Hohokam petroglyph site with a single dry-laid masonry structure and assorted artifacts (Rodgers 1977). However, subsequent inspection of the area by Bruder (1983b:73) identified evidence of groundstone manufacture at the site. The second quarry, AZ T:8:107 (ASM), is located approximately 500 meters south of AZ T:8:101 (ASM) on the westernmost ridge of Moon Hill. This site also features petroglyphs, dry-laid masonry rooms, assorted artifacts, and evidence of groundstone tool manufacture (Bostwick and Serocki 2000). There is no specific description available concerning the nature and intensity of the groundstone tool production at either site. The specific temporal occupation of the sites also is unreported.

A total of 40 raw material samples were collected from the quarries at Moon Hill. Fifteen specimens were collected from within the bounds of site AZ T:8:107 (ASM); ten specimens were collected from within the bounds of site AZ T:8:101 (ASU); and another fifteen specimens were collected along the southwestern face of Moon Hill, where several large basalt boulders suitable for groundstone production were observed during sample collection efforts.

<u>Shaw Butte</u>

Shaw Butte is a large and steeply sloping igneous protrusion located southeast of the intersection between Thunderbird Road and Interstate 17 in the city of Phoenix. The formation is listed on the Geological Map of Arizona as being composed of Middle to Late Miocene basaltic rock (Richard et al. 2000). More detailed geological investigations of the mountain have identified two distinct basalt regimes. The first and lower deposit consists of alkaline basalt associated with the Chalk Canyon formation. This deposit is overlain by a second layer of subalkaline basalt related to the Hickey Formation (Leighty 1997). Both of these geological units are found at the very top of Shaw Butte and thus the raw material outcrop was not as readily accessible as at other formations in the area. Furthermore, the majority of the material exists as bedrock and not as boulders in talus fields, thereby making extraction extremely difficult. The practical difficulties of acquiring basaltic material at Shaw Butte may in part explain the absence of documented Hohokam groundstone quarries in the area.

The archaeological record for Shaw Butte is scant but consistent with current geological descriptions. Several early investigations of the mountain report a few habitation and petroglyph sites (e.g., Rodgers 1977; Schroeder 1940). However, these studies do not mention the presence of prehistoric groundstone quarries. A reconnaissance of the mountain was undertaken as part of the current research effort, which also concluded that much of the volcanic material at Shaw Butte consists of an aphanitic and non-vesicular volcanic stone that is not suitable for groundstone tool production. Furthermore, inspection of a previously reported (see Bruder 1983b) hilltop "fortress" and petroglyph site (AZ T:8:88 (ASU)) did not yield any evidence of groundstone tool manufacture. A low density of small basaltic boulders with porphyritic and vesicular texture was scattered at the very top of the butte (as reported by Leighty 1997). Although no evidence of groundstone production was observed in these areas during the reconnaissance, 10 samples were collected from Shaw Butte because the outcrop represents one of the closest available sources of basalt for the Hohokam of the lower Salt River Valley.

Middle Gila River Valley

The middle Gila River Valley encompasses the expanse of land from the edge of the Superstition Mountains in the east to the confluence of the Gila and Salt Rivers in the west. This region features several volcanic rock outcrops, including Lone Butte (i.e., Jackson Butte), Olberg Butte, Poston Butte, Picture Rocks, the Hunt Highway Buttes, the Santan Mountains, the Florence Cinder Mine, the Black Hills, and Dozer Hill (Richard et al. 2000; Wilson et al. 1963). Basaltic rock within this region can be subdivided into two temporally and spatially distinct groups. The western half of the region, within the bounds of the GRIC, features Early Miocene Basalt. To the east, within the vicinity of the towns of Coolidge and Florence, exits much younger Late Miocene-Pliocene basalts (Ferguson and Skotnicki 1996). Material associated with both groups is porphyritic and contains a minor to moderate density of vesicles (Bostwick and Burton 1993; Ferguson and Skotnicki 1996; Leighty 1997). It also occurs as boulder debris at several of the above-named outcrops and is therefore conveniently available for groundstone tool production.

Cultural resource investigations in the middle Gila River Valley have resulted in the identification of several indigenous groundstone quarries. Broad scale systematic archaeological survey within the GRIC previously identified two quarry sites in the Santan Mountains (GR-181l, GR-449) and one at Lone Butte (GR-671; Neily et al. 1999a; Neily et al. 1999b). Additionally, reconnaissance efforts associated with the current research project found evidence of groundstone tool production at three other locations in the Santan Mountains (Caterpillar Hill; Purple Ridge, and Turtle Ridge). Vesicular basalt quarry sites also have been documented east of the GRIC at the Florence Cinder Mine (AZ U:15:433 (ASM); AZ U:15:434 (ASM); AZ U:15:435 (ASM)), Poston Butte (Rapp 1995; Rubenstein et al. 1995), Picture Rocks (Bostwick and Burton 1993), and Black Hill (Rapp 1995). Recent archaeological surveys have been undertaken at the Hunt Highway Buttes (North et al. 2004) and Dozer Hill (Darrington et al. 1997; Deaver and Altschul 1994; Hill and Rogge 1999), but no groundstone quarries have been identified at these locations.

Raw material samples were collected from Lone Butte, Olberg Butte, and from four different quarry locations within the Santan Mountains on the GRIC. Specimens were also collected from documented quarry sites at the Florence Cinder Mine, Poston Butte, and Picture Rocks. Samples were not collected from any basaltic exposures that have been previously surveyed and do not contain evidence of prehistoric material extraction and tool production activities, including the Hunt Highway Buttes and Dozer

Hills. It was also decided not to collect raw material samples from the Black Hill quarry given its remoteness to archaeological habitation sites in the study sample. Thus, the representative geochemical source database includes material from eleven quarry sites that are located among six different basaltic outcrops in the middle Gila River Valley. A more detailed geological and archaeological description of the sampled areas is provided below.

Lone Butte

Lone Butte is a relatively small early Miocene basaltic outcrop located within the northwest portion of the GRIC, approximately eight kilometers southeast of South Mountain (see Figure 4.1; Figure 4.2). Although no focused geological investigation of Lone Butte has been undertaken, the basaltic rock at this outcrop features a diverse phenocryst assemblage and an abundance of large vesicles. Based on these attributes, it is possible that the volcanic rock at Lone Butte is associated with the early Miocene lava rock that is also found in the Santan Mountains.

Archaeological survey of Lone Butte resulted in the identification of a prehistoric (and possibly historic) groundstone quarry (GR-671) that features a multitude of tested boulders, large basalt flakes, hammerstones, and tool preforms (Neily et al. 1999b). The densest concentration of groundstone production occurs along the southern and eastern slopes of the butte. Here, at least eight discrete groundstone manufacturing loci were identified, each of which contained evidence of multiple reduction events and several mano or metate blanks (Neily et al. 1999b:53). Petroglyphs, flaked-stone tools, and ceramic sherds were also identified, but no temporally diagnostic materials were observed. A total of 30 raw material samples were collected from Lone Butte. These specimens were pulled from various locations on the mountain due to the widespread occurrence of groundstone manufacture at the site.

Figure 4.2. Lone Butte, Middle Gila River Valley (facing north).

<u>Florence Cinder Mine</u>

The Florence Cinder Mine is the name applied to a low-relief exposure of volcanic bedrock located east of the Santan Mountains and north of the Gila River (see Figure 4.1). This outcrop is listed on the Geological Map of Arizona as being composed of Late Oligocene to Middle Miocene volcanic rock (Richard et al. 2000). However, Ferguson and Skotnicki (1996) report that it is composed of Late Miocene to early

Pliocene basalt. In addition, hand inspection of the material revealed several large quartz inclusions, a phenocryst assemblage different from anything else in middle Gila River Valley (see Jagiello 1987; Leighty 1997; Lundin 2003). Thus, the exact age of the volcanic rock at the Florence Cinder Mine is currently unknown, though it is likely that the reported discrepancies are due to fact that multiple flow periods are present at the outcrop.

Archaeological research efforts conducted in advance of a mine expansion project resulted in the identification of three prehistoric groundstone quarries (AZ U:15:433 (ASM); AZ U:15:434 (ASM); AZ U:15:435 (ASM)) (Lundin 2003). AZ U:15:433 (ASM) was found atop a crescent-shaped ridge in the northern portion of the volcanic outcrop. This site contained nine discrete groundstone manufacturing loci, each of which consisted of "100-500 quartz-bearing basalt macroflakes representing all stages of reduction, one to ten macrocores, and anywhere from 5-10 large (15-30 cm in diameter) hammerstones" (Lundin 2003:12). Other artifacts observed at the site included flaked stone tools, such as choppers and utilized flakes, and a handful of ceramics. Two nondiagnostic red-on-buff ware sherds were recovered among the ceramic collection, hinting at possible Preclassic period occupation of the site.

The other two quarry sites are similar to AZ U:15:433 (ASM), differing only in size. AZ U:15:434 (ASM) is much larger, spreading across roughly 132,000 square meters along the western slope of the basaltic outcrop. It features 13 discrete manufacturing loci, each of which displayed a range of 100-1000 quartz-bearing basalt macroflakes, 10-20 macrocores, and anywhere from 5-10 large hammerstones (Lundin

2003:15). AZ U:15:435 (ASM) is the smallest of the three quarries. It covers an area roughly 4,300 square meters and contains only four discrete manufacturing loci. These loci contain 50-100 quartz-bearing basalt macroflakes, 10-20 macrocores, and anywhere from 5-10 large hammerstones (Lundin 2003:17). A handful of flaked stone tools were also found at these sites, but ceramics or other temporally diagnostic materials were not encountered.

Ten samples were collected from each of the three quarry sites, yielding a total of 30 representative raw material specimens for the Florence Cinder Mine.

Picture Rocks

Picture Rocks is the name of the north-south oriented outcrop of igneous rock located southeast of Florence along the Florence Kelvin Highway (see Figure 4.1). The formation is listed on the Geological Map of Arizona as being composed of Middle to Late Miocene (16-8 Ma) basaltic rock (Richard et al. 2000). However, most of the material in the Florence area actually dates from the late Miocene to early Pliocene (Ferguson and Skotnicki 1996). Hand inspection of the raw material samples collected from the field revealed a highly variable phenocryst assemblage, with some specimens exhibiting abundant milky-white plagioclase phenocrysts, and others being dominated by altered olivine (to iddingsite) or augite. This heterogeneous phenocryst assemblage is similar to and therefore presumably geologically related with Poston Butte, a known late Miocene to early Pliocene formation.

Systematic archaeological investigation of Picture Rocks has not been completed. Approximately 90 percent of the bedrock protrusion is on private land, with the remaining 10 percent being parceled to the state trust of Arizona. AZSITE does not show any archaeological projects or previously documented sites on either the private or state land. Nonetheless, Picture Rocks, as its name implies, is a known prehistoric petroglyph site. Furthermore, Bostwick and Burton's (1993:364) investigation of the site did produce evidence of groundstone material quarrying and tool production activities. No information pertaining to the size, density, and nature of groundstone procurement activities at this site is known to the author, and no evidence of these activities was observed during the collection of 30 material specimens on the small sliver of state land on the south side of Picture Rocks. It is presumed that the rock art and quarry site are located on the north side of Picture Rocks, which faces the Gila River.

Poston Butte

Poston Butte is a steep basalt protrusion located on the north side of the Gila River in the vicinity of Florence (see Figure 4.1; Figure 4.3). This outcrop is listed on the Geological Map of Arizona as being composed of Late Oligocene to Middle Miocene volcanic rock (Richard et al. 2000). However, a more detailed study of the outcrop by Ferguson and Skotnicki (1996) found that it is composed primarily of Late Miocene to early Pliocene basalt. Hand inspection of the sample material revealed a moderate to high density of vesicles and a heterogeneous phenocryst assemblage of plagioclase, pyroxene, and altered olivine crystals (Ferguson and Skotnicki 1996:18). Thus, this material type

Figure 4.3. Poston Butte, Middle Gila River Valley (facing northwest)

appears to be geologically related with most other basalt outcrops in the Florence area, excluding material from the previously discussed Florence Cinder Mine.

One archaeological site (AZ U:15:6 (ASM)) encompasses all of Poston Butte. The site is defined as a historical Euroamerican cultural resource, consisting of a large mineral exploration shaft, a well, and a road that were all constructed by Charles Poston at end of the nineteenth century. A large stone and cement pyramidal tomb was erected at the top of the butte in 1925 to entomb the hill's namesake. Although it is not stated in the official site record, Poston Butte is also the location of a prehistoric Hohokam groundstone material quarry. Evidence of groundstone tool manufacture and quarrying activities have been observed by the author and reported in multiple documents (e.g., Rubenstein et al. 1995; Rapp 1995). Reconnaissance of the outcrop by the author determined that the greatest concentration of quarry activities was reserved to the upper portions of the outcrop, where few discrete reduction stages and numerous large basalt flakes were encountered. A total of 30 raw material samples were collected from this portion of Poston Butte and included in the representative material database.

Santan Mountains

The Santan Mountains feature a collection of relatively low-lying southwest trending finger ridges of early Miocene basalt in the southwestern portion of the range known as the Malpais Hills (see Figure 4.1). Lava rock in these hills exhibits a porphyritic texture of variable inclusions and a moderate to major density of vesicles (Bostwick and Burton 1993:354; Ferguson and Skotnicki 1996:19). Previous archaeological investigations in the area have identified one groundstone quarry (GR-449) atop one of the ridges at the southern extent of the range and another (GR-181) at Olberg Butte (Neily et al. 1999a). Three additional groundstone quarries were located during reconnaissance conducted in conjunction with the current research project. These lithic procurement and tool production sites are referred to here as the Caterpillar Hill, Purple Ridge (AZ U:14:12 (ASM), and Turtle Ridge quarries (AZ U:14:14 (ASM)).

GR-449 is a large complex site consisting of two distinct groundstone tool production loci, agricultural terraces, several rock enclosures, multiple wall alignments, artifact scatters, and an extensive distribution of petroglyphs (Neily et al. 1999a; Figure 4.4). One of the groundstone production loci is located along a ridge line at

Figure 4.4. Basalt Talus at GR-449, Santan Mountains, Middle Gila River Valley (facing north)

the western end of the site; the other is located to the east at the base of the hill. Associated artifacts in both areas include tested boulders, large basalt flakes, mano and metate blanks, and hammerstones. Based on the nature of groundstone production debris present, it has been suggested that groundstone blanks were being prepared at GR-449, but transported elsewhere for shaping and finishing (Neily et al. 1999a:106). However, it is also possible that these latter activities occurred on the lower slopes, which have been subsequently disturbed by modern agriculture and the construction of railroad tracks, canals, and two alternative routes of the same highway (SR-87).

GR-181 is officially defined as prehistoric petroglyph and resource-processing site based on the presence of hundreds of pecked glyphs and more than one dozen bedrock mortars and cupules (Gregory and Johnson 1994:291). However, it is possible that the site was also used as a groundstone quarry. In an assessment of groundstone production locations along the middle Gila River, Rapp (1995) reported that Olberg Butte showed evidence of groundstone material quarrying and tool manufacturing. A few concentrations of large basalt flakes were observed by the author within the granitic portion of the mountain during sample collection efforts. Evidence of similar activity on the basaltic side of the formation is unfortunately unavailable, though, since approximately one-quarter of the butte has been destroyed by modern mining and material borrowing. A total of 10 samples were collected from Olberg Butte and included in the representative source database.

The Turtle Ridge quarry (AZ U:14:14 (ASM)) is located at the northern end of a northwest-southeast trending basaltic outcrop approximately 2.0 km northwest of GR-449. The site was originally recorded in the early 1970s as a large prehistoric Hohokam petroglyph site (Ayres 1975). Reexamination of the site area as part of this research project resulted in the identification of groundstone material quarrying and tool production. A total of five discrete groundstone manufacturing stations and a handful of tested boulders were located. Other artifacts typical of groundstone quarry sites, such as hammerstones, were not observed. The site name was ascribed by the author after viewing the evidence for groundstone production beneath a petroglyph panel that depicts what is inferred to be five turtles.

Purple Ridge (AZ U:14:12 (ASM)) is a third groundstone quarry in the Malpais Hills area of the Santan Mountains (Figure 4.5). This site is located atop a north-south trending basaltic ridge less than 1.0 km northwest of Turtle Ridge. The name Purple Ridge derives from the purple hue of the basaltic material as seen on aerial imagery, although field inspection confirmed that the material is actually dark gray basalt. The quarry area was recorded in the 1970s as including prehistoric Hohokam and historical Akimel O'odham petroglyphs, trails, rock piles, check dams, and stone alignments (Ayers 1975). The current reconnaissance efforts observed these features alongside

Figure 4.5. The Purple Ridge Quarry, Santan Mountains, Middle Gila River Valley (facing northeast).

evidence of groundstone tool manufacture. Specifically, worked boulders and large macro-flakes were observed along the base and lower slopes of Purple Ridge on its western, southern, and eastern flanks. Groundstone production at the site appeared to have been more intense than that observed at other sites in the Santan Mountains. This may be due to the fact that Lower Santan (GR-441), a substantial Hohokam Preclassic ballcourt and Classic period platform mound village is located a few hundred meters to the south.

The fourth groundstone quarry identified in the Santan Mountains is the Caterpillar Site. This quarry is located roughly 2.5 km northeast of the Purple Ridge site. Field inspection of the exposure revealed an interesting geological attribute relevant to groundstone tool production. Instead of groundstone material being largely available as boulders in a talus field, the material at the site occurs in tabular form thanks to natural jointing patterns in the exposed bedrock. This natural block-fracturing is argued by some to have been preferable for groundstone manufacture because it provides tool makers with a readymade preform (Schneider 2002; Schneider and LaPorta 2008); however, this extraction technique has not been documented or observed at any other prehistoric Hohokam quarry in the study area. Examination of the exposed bedrock at the Caterpillar Site revealed large amounts of flakes and shatter beneath the jointed basalt blocks. Although much of this appeared to be natural spall, samples were collected anyway.

A total of 105 raw material samples were collected from the Santan Mountains for this study. A total of 20 samples were collected from GR-449, with 10 specimens coming from each of the previously identified quarry and production loci. Another 10 samples stem from GR-181 at Olberg Butte. Thirty more samples were collected from the newly identified groundstone quarry sites, with 10 samples each representing Turtle Ridge (n=10), Purple Ridge (n=10), and the Caterpillar site (n=10). Lastly, a total of 45 samples were collected along systematic transects between the identified and quarried sample sites.

Northern Periphery

The Hohokam northern periphery includes the stretch of land between the Phoenix Mountains and the upland areas of the mountainous Transition Zone of central Arizona (Doyel and Elson 1985; Hackbarth et al. 2002; McGuire 1991). Several volcanic bedrock protrusions occur in this region, including Calderwood Butte, Adobe Mountain, Hieroglyphic Mountain, Ludden Mountain, Middle Mountain, West Wing Mountain, the Pyramid Peak area, and the Deem, Hedgpeth, and Union Hills (Richard et al. 2000). Volcanic rock associated with these outcrops includes Chalk Canyon, Hedgpeth, and Hickey Basalts (Holloway and Leighty 1998; Jagiello 1987; Leighty 1997; Leighty and Holloway 1998; Leighty and Huckleberry 1998a, 1998b). Andesitic and basaltic rock associated with the Hedgpeth and Hickey formations is present at most of these outcrops. Lesser amounts of felsic rock (i.e., rhyolite and dacite) also occur in the area within portions of Calderwood Butte, the Deem Hills, and West Wing Mountain. However, as previously noted, felsic material was not desired by Hohokam groundstone toolmakers.

The northern periphery has been subject to intensive archaeological investigation for over thirty years as a result of private development and massive public works projects (e.g., Aguila et al. 2011; Bruder 1983a, 1983b; Cable 1987; Dittert 1974; Doyel and Elson 1985; Green 1989; Holiday 1974; Rodgers 1977; Yunker 2002; Yunker and Robinson 2006). Archaeologists have found scores of Hohokam settlements and resource procurement sites along the four major drainages (Agua Fria, New River, Skunk Creek, and Cave Creek) that flow north-south through the territory. In addition, multiple prehistoric groundstone quarries have also been identified in the talus fields of many of the area’s igneous outcrops, such as Adobe Mountain, Ludden Mountain, West Wing Mountain, Hieroglyphic Mountains, and the Hedgpeth Hills (Aguila et al. 2011; Bruder 1983a, 1983b; Cable 1987). Evidence of groundstone production also has been observed among exposures of basalt within the Agua Fria and New River terraces (Aguila et al. 2011; Doyel and Elson 1985). Some of these quarries contain the well-known “quartz-bearing basalt” that stimulated initial groundstone provenance research in Hohokam archaeology (e.g., Doyel 1985a; Euler 1989; Schaller 1985).

Raw material samples were collected for this study from previously documented groundstone quarries at Adobe Mountain, Ludden Mountain, West Wing Mountain, and the Hedgpeth Hills. A reconnaissance of previously uninvestigated portions of the Union and Deem Hills resulted in the collection of additional raw material samples from other potential groundstone quarries. Samples were not collected from volcanic outcrops or known quarries outside of the current project scope (e.g., Agua Fria River Terrace Gravels, New River Terrace Gravels, Hieroglyphic Mountains), nor from those outcrops which have been previously surveyed and do not exhibit evidence of prehistoric groundstone production (e.g., Biscuit Flats, Middle Mountain, Pyramid Peak; see Bruder

1983a, 1983b). Lastly, a previously recorded vesicular basalt groundstone tool production site (AZ T:7:295 (ASM)) at Calderwood Butte was visited as part of the current reconnaissance, but no raw material samples were collected. Inspection of the area revealed that the site had been destroyed completely by residential development. The remainder of the volcanic outcrop is comprised entirely of aphanitic dacite, which is not suitable for groundstone tool production, and therefore, was not sampled. The lack of samples from Calderwood Butte is not of great concern because the vesicular basalt associated with AZ T:7:295 (ASM) could have only come from a very small talus exposure, which suggests that material from this outcrop did not play a substantial role in the regional Hohokam economy (Leonard et al. 2006). The ensuing paragraphs provide more detail on the geology and archaeology of those outcrops which were sampled.

Adobe Mountain

Adobe Mountain is a relatively small outcrop of igneous rock located west of Interstate 17, approximately two miles north of the Loop 101 freeway (see Figure 4.1). The formation is listed on the Geological Map of Arizona as Late Oligocene to Middle Miocene volcanic rock (Richard et al. 2000). A more focused study of the mountain specifies that it is composed of andesitic lava featuring large plagioclase phenocrysts and resorbed quartz inclusions (Holloway and Leighty 1998:9). Visual inspection of the collected samples confirms these textural attributes. Therefore, the igneous rock from Adobe Mountain is likely related to the early Miocene Hedgpeth formation, which is correlative with the “quartz-bearing” basalts found in the Hedgpeth Hills, West Wing

Mountains, and Deem Hills (Bostwick and Burton 1993; Jagiello 1987; Leighty 1997; Schaller 1985).

Adobe Mountain has been previously investigated for cultural resources (Bruder 1983b; DeMaggs et al. 2002) and one groundstone quarry (NA17236) has been documented. NA17236 was discovered by investigators associated with the Adobe Dam Project during an effort to record petroglyph sites in the northern periphery (Bruder 1983b). The quarry is reported to contain a total of eight discrete groundstone manufacturing loci on the eastern and southern flanks of the hill. Each locus was approximately 15 meters in diameter and included several "large and small pieces of gray andesite shatter…large hammerstones, shatter off those hammerstones, flakes, and mano blanks" (Bruder 1983b:90). NA17236 also features a few linear rock alignments and possible structures. However, investigators of the site inferred these features to be of relatively recent origin (Bruder 1983b:90). Thirty raw material samples from Adobe Mountain were collected from the eastern and southern slopes of the mountain, where evidence of prehistoric groundstone manufacture is concentrated.

Deem Hills

The Deem Hills are a collection of igneous peaks located west of Interstate 17 in north Phoenix (see Figure 4.1; Figure 4.6). This formation is divided in half geologically, with volcanic material in the southern half of the range related to the quartz-bearing basalt of the Hedgpeth Formation, and material in the northern half of the range associated with Hickey basalt (Jagiello 1987; Leighty 1997; Leighty and Holloway 1998;

Figure 4.6. Basalt Talus on the North Side of the Deem Hills, Hohokam Northern Periphery (facing south)

see also Potter et al. 1999). Roughly one-third of the Deem Hills has been investigated for cultural resources, including the entire southern face of the range (e.g., Bruder 1983b; Cable 1987; Lindly and Schmidt 2003). These efforts have resulted in the identification of two small prehistoric Hohokam habitation sites (AZ T:8:48 (ASM); AZ T:8:63 (ASM)) and one agricultural terrace complex (AZ T:8:46 (ASM); Cable 1987; Potter et al. 1999). Although not specifically stated in the site reports, it is possible that these sites were involved to some degree in groundstone material quarrying and tool production. A reconnaissance of the Deem Hills by the author found a moderate density of groundstone tool production debris in both the Hedgpeth and Hickey basalt flow fields located near the sites. Consequently, a total of 40 raw material samples were collected from the outcrop. Twenty specimens were taken from among the Hedgpeth Formation on the south side of the range within the vicinity of AZ T:8:46 (ASM). Another twenty samples were collected from previously unsurveyed areas within the Hickey Formation that exhibited evidence of groundstone production.

Hedgpeth Hills

The Hedgpeth Hills are a collection of igneous peaks located immediately north of the Loop 101 Freeway in north Phoenix (see Figure 4.1). The formation is similar to the Deem Hills in that it features material from both the Early Miocene Hedgpeth Formation and middle Miocene Hickey Formations (Leighty 1997; Leighty and Huckleberry 1998a; Richard et al. 2000). The Hedgpeth Hills have been previously investigated for cultural resources as a result of several private and public development projects (Bostwick 1995; Bruder 1983a, 1983b; Kennedy and Bauer 2003; Ryden 2002; Tate 2005). These past projects identified three groundstone quarries. Two of the quarries (AZ T:8:3 (ASM); AZ T:8:164 (ASM) are located on the southern end of the main formation (Bruder 1983a, 1983b; Ryden 2002). Another (AZ T:8:70 (ASM)) was found on small related outcrop just south of the Loop 101 Freeway (Bostwick 1995).

AZ T:8:3 (ASM), better known as the Hedgpeth Hills Petroglyph Site, is located within Arizona State University's Deer Valley Rock Art Center. Although the site is well known for its outstanding rock art, AZ:T:8:3 (ASM) is also important because it represents the first documented case of a Hohokam groundstone quarry. Evidence of groundstone quarrying and tool production was initially observed during the Adobe Dam Project, when field crews noticed "areas where the ground was littered with chunks of shattered andesite" (Bruder 1983b:46). Subsequent identification of broken mano blanks and cobble hammerstones in the same areas led investigators to conclude that groundstone material extraction and tool manufacture were a component of the petroglyph site as well. Ultimately, a total of 21 discrete manufacturing stations were recorded at AZ T:8:3 (ASM). Additional cultural remains, including seven dry-laid masonry rooms, two rock alignments, a check dam, and three artifact scatters were also recorded (Bruder 1983a, 1983b). Unfortunately, temporally diagnostic ceramics were not observed at the site, leaving the time of use for the quarry component of the site uncertain.

AZ T:8:164 (ASM), or the Saddle Site, is located roughly 0.5 kilometers west of the Hedgpeth Hills Petroglyph Site in a natural divide between two larger steeply sloping igneous protrusions (Bruder 1983a, 1983b; Ryden 2002). Between these slopes, investigators for the Adobe Dam Project identified roughly 180 cobble hammerstones, hammerstone spall, dense quantities of large flakes, nine mano blanks, and one metate blank (Bruder 1983a). A more recent investigation of the site recorded one large chipping station in the same area (Ryden 2002). This production loci measured approximately 240 square meters and contained roughly 150-200 flakes, six hammerstones, one metate blank, and one mano blank (Ryden 2002:8). Up to eight dry-laid masonry rock structures have also been documented at the site, but the available evidence indicates that these are not prehistoric (Bruder 1983b:72; Ryden 2002:8). Lastly, no temporally diagnostic materials have been identified at the Saddle Site and the use-period of the quarry remains undefined.

AZ T:8:70 (ASM), the third groundstone quarry site in the Hedgpeth Hills, is situated atop an isolated volcanic outcrop at the southern end of the Hedgpeth range. Investigators for the Adobe Dam Project first identified a groundstone quarry at this location during their reconnaissance of petroglyph localities in the northern periphery. However, because not a single glyph was encountered at this time (though petroglyphs were observed by the author during raw material collection efforts), the site was not officially recorded. It was not until the 1990s, when the City of Phoenix sponsored an archaeological investigation of the hill, that the quarry was recorded (Bostwick 1995). At this time, scores of hammerstones and several scatters of groundstone tool manufacturing debris were observed, some of which appeared to be discrete groundstone manufacturing. As with other quarry sites, no temporally diagnostic artifacts were identified, leaving the exact use history of the quarry unknown.

A total of 95 raw material samples were collected from the groundstone quarry sites in the Hedgpeth Hills. Thirty samples were collected from the Hedgpeth Hills Petroglyph Site (AZ T:8:3 (ASM)), twenty samples were collected from the Saddle Site (AZ T:8:164 (ASM)), and another thirty samples were collected from AZ T:8:70 (ASM). The fifteen remaining samples were collected from a dense concentration of groundstone tool manufacturing debris observed by the author between the Hedgpeth Hills and Saddle Sites.

<u>Ludden Mountain</u>

Ludden Mountain is a massive, steeply sloping igneous formation located to the north and west of the Hedgpeth and Deem Hills, respectively. Similar to the other tilted fault-block remnants in the northern periphery, this outcrop is comprised of lava rock correlated with the Early Miocene Hedgpeth Formation and the Middle Miocene Hickey Formation (Leighty 1997; Leighty and Huckleberry 1998b). Unlike the other outcrops that exhibit discrete spatial separation between the two fields (e.g., Deem Hills and Hedgpeth Hills), the material at Ludden Mountain appears to be well mixed in the talus fields. This inference was confirmed in the present study by the identification of two discrete chemical groupings within the sample material, each of which exhibited geochemical properties similar to material collected from outcrops with either Hedgpeth or Hickey basalt (see Chapter 5).

Ludden Mountain has been previously investigated for cultural resources (Cable 1987) identifying one groundstone quarry site (AZ T:8:50 (ASM)). The quarry site is located on a flat-topped ridge in the southwestern portion of the mountain. AZ T:8:50 (ASM) is reported to contain several worked boulders, large macro flakes, and hammerstones (Cable 1987). No other cultural remains, such as ceramics and flaked stone artifacts, or linear rock features were noted. A total of 30 raw material samples were collected from Ludden Mountain for this study. Ten of the specimens were collected from the southwestern base of Ludden Mountain on the approach to the quarry, where the author observed additional evidence of lithic reduction and groundstone tool manufacture. The remaining twenty samples were collected from within the bounds of the quarry site.

Union Hills

The Union Hills are a massive fault-block remnant located near Happy Valley Road between Interstate 17 to the west and Cave Creek Road to the east. This outcrop is composed primarily of Early Proterozoic metavolcanic rock. However, in the southern portion of the range there are three smaller hills that are covered in basalt correlative with the Middle Miocene Hickey Formation (Holloway and Leighty 1998). Cultural resource investigations of these lesser buttes have been extensive and multiple site types have been identified, including terraced hillsides, habitation sites, petroglyph locals, and even a “fortified” hilltop site. However not one site in this area is reported to contain evidence of groundstone quarry and tool production activities (Bruder 1983a, 1983b; Foster 1994a; Henderson and Rodgers 1979; Schmidt and Mitchell 2004; Shaw 2002). A reconnaissance of the southern half of each of the three outcrops by the author also failed to identify any evidence of intensive groundstone material extraction or tool production activities.

Despite the dearth of documented groundstone quarry sites and evidence for tool production, a total of 30 raw material samples were collected from among the three small hills. The is justified in part by the location of the Union Hills, which are situated as close to the lower Salt River Valley as Adobe Mountain and the Hedgpeth Hills and are known groundstone raw material source areas. Moreover, the Union hills are located along a reliable water source (Cave Creek) that was settled for hundreds of years by the prehistoric Hohokam (Henderson and Rodgers 1979; Rodgers 1974; Schmidt and Mitchell 2004; Shaw 2002). Thus, it is possible that basaltic material from the Union Hills was obtained by local prehistoric residents and eventually found its way into irrigated lowlands. The sample collection included 10 specimens from each of the three basaltic protrusions for a combined total of 30 samples.

West Wing Mountain

West Wing Mountain is located on the west side of the New River drainage in the city of Peoria. This formation is listed on the Geological Map of Arizona as a Late Oligocene to Middle Miocene volcanic rock (Richard et al. 2000). Petrographic analysis of material from one location in the mountain identified it as "quartz-bearing basalt" and thus is likely part of the Hedgpeth Formation (Bostwick and Burton 1983; Schaller 1985).

West Wing Mountain has been subject to extensive cultural resource investigations, resulting in the identification of at least six discrete groundstone quarries. Three of the six sites (AZ T:8:19 (ASM), AZ T:8:21 (ASM), and T:8:22 (ASM)) were documented along the eastern flank of the formation during the New River Authorized Dam Project (Doyel and Elson 1985). Another three sites (AZ T:8:63 (ASU), AZ T:7:7 (BLM), and AZ T:7:8 (BLM) were identified along a southern ridge of the mountain in advance of urban development (McQuestion and Gibson 1987; Mitchell 1996; Mitchell et al. 1996). Archaeological investigations have also identified evidence of groundstone tool production to the north and west of West Wing Mountain along basalt rock exposures within the Agua Fria and New River terraces (Aguila et al. 2011; Doyel and Elson 1985). However, these sites were not within the scope of the current research project. The site summaries provided below include only those located on West Wing Mountain.

AZ T:8:19 (ASM), or the Terrace Garden Site, is located on a low-lying bedrock outcrop at the southern tip of West Wing Mountain. The site contains several archaeological features, including trails, water-control features, petroglyphs, rock shelters, cobble structures, a rock-lined oval-shaped ball court, ceramic and flaked stone artifacts, and extensive evidence of groundstone manufacture (Doyel et al. 1985). Mano artifacts were the most frequent tool form identified in the production debris, with metate blanks and preforms occurring less frequently (Doyel et al. 1985:105). The co-occurrence of a ceremonial ballcourt, Santa Cruz through Sacaton phase Red-on-buff pottery, and intensive groundstone tool production led Doyel and colleagues (1985:106) to surmise that "the ballcourt may have served as the focal point for the redistribution, trade or exchange of groundstone tools in this area." This supposition was later supported (though not definitively proven) when a petrographic analysis of material from AZ:8:19 (ASM) was found to be similar in composition to groundstone artifacts recovered from Hohokam sites in the lower Salt River Valley (Schaller 1985, 1988, 1989a).

AZ T:8:21 (ASM), also known as the GSM site, is located on the eastward facing slope of West Wing Mountain. The site features a total of 40 concentrated areas of groundstone manufacturing debris, 21 cleared areas representing either quarrying activities or temporary shelters, 20 caches of cobble hammerstones, 7 stockpiles of raw materials, scores of mano and metate blanks, and multiple rock alignments representing the fallen walls of structures that probably served as temporary habitations (Doyel et al. 1985:107). In contrast to the Terrace Garden Site, the focus of production at the GSM site appears to have been metates, as this tool form was four times more common than manos (Doyel et al. 1985:107). No temporally diagnostic artifacts were observed at AZ T:8:21 (ASM), leaving the use-history of the site uncertain. However, it is likely that the site was occupied during the Colonial and Sedentary periods based on associated prehistoric occupations in the New River drainage (Doyel 1985b:728).

AZ T:8:22 (ASM), or the Spillway site, is located just 100 meters to the southeast of the GSM Site. This site features five dense concentrations of groundstone manufacturing debris (Doyel et al. 1985:107). Here, again, metates appear to have been the focus of production activities, as evidence by the 2:1 ratio of metate to mano tool blanks and preforms. One possible windbreak, which may have been used as a temporary shelter by prehistoric tool makers, was also noted at this site. Based on the available evidence, Doyel and colleagues (1985:119) inferred that the Spillway site was used at the same time and for the same purposes as the GSM site, but much less intensively (Doyel et al. 1985:119).

AZ T:8:63 (ASU) is located on the south slope of West Wing Mountain (Figure 4.7). It the largest quarry and tool production site in the area, encompassing approximately 57 acres and including over 200 discrete groundstone manufacturing stations, two large concentrations of debitage, mano and metate blanks, hammerstones, several trail segments, trail markers, ceramic scatters, a cobble structure, and rock piles (Greenwald 1996:41; McQuestion 1988; McQuestion and Gibson 1987). Temporally

Figure 4.7. Overview of AZ T:8:63 (ASU) Site Area, West Wing Mountains, Hohokam Northern Periphery (facing north).

diagnostic ceramics indicate that the site may have been used from the early Colonial to the late Classic periods, making it the longest utilized groundstone quarry known in the Hohokam territory (Greenwald 1996:41). Given its size, artifact density, and length of occupation, AZ T:8:63 (ASU) may have been the primary quarry site in the West Wing Mountain. Unfortunately, most of the site area has been disturbed by modern housing development.

Two more groundstone tool production sites, AZ T:7:7 (BLM) and AZ T:7:8 (BLM) were recorded in the western region of West Wing Mountain. Both sites are characterized by a handful of discrete groundstone manufacturing stations. Fifteen processing stations were recorded at site AZ T:7:7 (BLM) and nine were documented at AZ T:7:8 (BLM) (Greenwald 1996; Mitchell 1996). No other significant cultural features were observed at either site. The former site did contain several Hohokam Plain ware sherds and six Gila Polychrome sherds. The presence of the polychrome sherds indicates that the site was used at least during the Late Classic period, although this evidence does not preclude earlier or later occupations (Mitchell 1996:24). No temporally diagnostic materials were observed at AZ T:7:8 (BLM), and the exact use-period of the site remains unknown.

A total of forty raw material samples were collected from West Wing Mountain. Ten samples each were collected from the Terrace Garden, GSM, and Spillway sites. The remaining ten samples were collected from the AZ T:8:63 (ASU) at the west end of the range, where material likely associated with the former site is located. Samples were not collected from AZ T:7:7 (BLM) or AZ T:7:8 (BLM) because these areas have since been destroyed by residential development or did not constitute large enough sites for sampling.

Southern Periphery

At its greatest extent, the Hohokam cultural territory extended as far south as the United State-Mexico Border. However, within the context of this study, the southern periphery is considered to be the territory located immediately south of the Sacaton Mountains of the middle Gila River Valley (McGuire 1991:349). This expanse of land includes several large late Oligocene to middle Miocene igneous fault-block remnants. Better known outcrops include the Vaiva Hills and the Table Top, Tat Momoli, Saw Tooth, and Silver Reef Mountains (Richard et al. 2000). The majority of basaltic rock found on these mountains formed during the early Miocene and contains geophysical attributes preferred for groundstone production (Bostwick and Burton 1993; Leighty 1997).

The archaeological record for the Hohokam southern periphery, as defined here, is largely unreported due to its present location in the Tohono O'odham Nation and Sonoran Desert National Monument. However, the author is aware of two prehistoric groundstone quarries in the region. One quarry exists at a lone outcrop in the northern part of the Vaiva Hills. This site was reported but not described in Bostwick and Burton's (1993) article on Hohokam groundstone. A second quarry is found at an exposure of basalt in the northwestern corner of Table Top Mountains (Burton 2012, personal communication). Thirty samples each were collected from both quarries with the permission of the Tohono O'odham Nation and the Sonoran Desert National Monument. Samples were not collected from other volcanic outcrops in the region, such as the Tat Momoli, Saw Tooth and Silver Reef Mountains because there are no known quarry sites in these hills (though they most likely exist). A brief description of the sampled areas is provided below.

<u>Table Top Mountain</u>

Table Top Mountain is a composed of early Proterozoic metasedimentary, middle Proterozoic granite, and late Oligocene to middle Miocene volcanic rock (Richard et al. 2000). The more recent volcanic material can be found atop the mountain, along its southwestern face, and in the northernmost reaches of the formation. Leighty (1997:245) reports and field inspection confirms that these exposures are primarily characterized by subalkaline basalts with large labrodorite phenocrysts. The single known prehistoric groundstone quarry in this area is unreported and is located at an exposed basaltic outcrop in the northern portion of the Table Top Mountain Range east of the Vekol Wash and south of Interstate 8. The location of the site was provided by James Burton (personal communication). Reconnaissance of the site by the author revealed it contained a low density and diffuse spattering of large basalt flakes from the western to eastern end of the outcrop. No hammerstones or tool preforms were observed, but only two transects were undertaken across the entire outcrop. A total of 30 raw material samples were collected.

Vaiva Hills

The Vaiva Hills are a collection of several small basaltic bedrock protrusions located near the village of Cockleburr in the northernmost region of the Tohono O'odham Nation. The basalt in these hills is peculiar, containing large hornblende and augite phenocrysts, and a moderate density of small vesicles filled in with gold mica and red heulandites (Bostwick and Burton (1993:364). The prehistoric groundstone quarry identified by Bostwick and Burton (1993) is located atop a single outcrop that extends north out of the Tohono O'odham Nation and into the Sonoran Desert National Monument. Though known by the archaeological community, no official description of the site exists. Examination of this formation by the author and Jefford Francisco of the Tohono O'odham Nation Cultural Resources staff revealed several groundstone production stations on the western face of the mountain. These stations generally include large basalt flakes, tool preforms, and cobble hammerstones that are presumably from the nearby Santa Cruz Wash. A total of 30 raw material specimens were collected from the area of greatest artifact concentration.

Western Periphery

The western periphery of the Hohokam cultural territory region is considered by most scholars to include the expanse of land between Hassayampa Creek in the east and Gila Bend to the west (e.g., McGuire 1991). This region contains multiple igneous outcrops, including Robbins Butte, Powers Butte, Arlington Mesa, the Gillespie Dam Mountains, and the Gila Bend Mountains (Richard et al. 2000). Extensive flow fields, such as those present in the Arlington Valley, are also present (Leighty 1997). These volcanic landforms were formed during several geological stages and consist of a wide variety of material. The Gila Bend Mountains are composed of Late Oligocene and early Miocene rhyolitic tuff, basaltic andesite, and basaltic flows (Leighty 1997:77). Early to Middle Miocene andesite and basalt is also present in the western Gila Bend Mountains, but these rocks are typically poorly exposed and highly altered (Gilbert 1991; Gilbert and Skotnicki 1993; Skotnicki 1994). Basaltic rock from the recent Pliocene epoch is found among several vents and related lava sheets in the Arlington Valley and Gillespie Dam areas (Leighty 1997:78).

Cultural resource investigations and archaeological reconnaissance efforts have identified several groundstone material quarry sites in the Hohokam western periphery. Perhaps the best known quarry site is the Painted Rocks Reservoir site near Gila Bend (Wallace 1989). Other lesser known sites are located closer to the Hohokam heartland at

Robbins Butte and Arlington Mesa (Macnider 1989; Rubenstein et al. 1995). Although several groundstone quarries have been documented in the western periphery, and several more undocumented sites likely exist, the current sampling efforts were concentrated at Robbins Butte. This decision was based simply on geography. Robbins Butte is the easternmost known quarry in the Western Periphery and, therefore, represents the closest source to Hohokam in the Salt-Gila Basin. Thus, if material from the western periphery was transported to villages along the Salt or Gila Rivers, it most likely came from Robbins Butte. A more detailed geological and archaeological description of this outcrop is provided below.

Robbins Butte

Robbins Butte is a conical-shaped basaltic bedrock protrusion located on the south bank of the Gila River in the Robbins Butte State Game Management Unit (see Figure 4.1). The outcrop is listed on the Geological Map of Arizona as being composed of Late Oligocene to Middle Miocene volcanic rock (Richard et al. 2000). Cultural resource investigations at the hill have not been conducted since the 1960s, when a terraced hillside and associated single habitation structure (AZ T:10:6 (ASM)) were recorded (Ayers 1965). The designation of Robbins Butte as a prehistoric groundstone quarry was made by Rubenstein and colleagues (1995:324) on their map of basaltic outcrops and groundstone manufacturing sites within the Salt-Gila Basin. Due to the lack of specific knowledge about the location, nature, and scope of quarrying activities, a single transect was walked along the eastern and southern flanks the butte. Evidence of groundstone production was observed during the entire transect. A total of 30 raw material samples were collected during the transect. Hand inspection of these specimens identified several varieties of basalt, possibly representing the different flow stages reported by Leighty (1997).

Summary

The vesicular basalt geochemical reference collection is composed of 738 raw material samples from 25 groundstone production quarries that are located among 17 geographically-discrete basaltic outcrops (see Table 4.2). This sample features material from source areas included in previous groundstone provenance analyses (e.g., Hedgpeth Hills, McDowell Mountain and, West Wing Mountain), as well as material from a number of additional source locations never before considered (e.g., Deem Hills, Poston Butte, and Florence Cinder Mine). Therefore, it represents the largest and most diverse raw material reference collection ever assembled in the Hohokam territory. Although additional quarries and source areas known to have been used prehistorically by the Hohokam are not included in this sample (see Table 4.1), it is nonetheless considered sufficiently large for assessing the Provenance Postulate for geochemical sourcing and also, potentially, for identifying the precise geographic origin of most Hohokam vesicular basalt groundstone

CHAPTER 5: VESICULAR BASALT ARTIFACT SAMPLE

A sample of vesicular basalt artifacts is required to evaluate the five different hypotheses concerning Hohokam groundstone tool provisioning practices. The artifact sample for this study consists of nearly 500 vesicular basalt groundstone tools from nine Hohokam sites: Casa Grande, Gila Crossing, Hospital Site, Lower Santan, Upper Santan, Pueblo Grande, La Plaza, Las Colinas, and Los Hornos (see Figure 4.1; see Table 1.3). Five of the nine sites, including Casa Grande, Gila Crossing, the Hospital Site, Lower Santan, and Upper Santan are found in the middle Gila River Valley. Two sites, Pueblo Grande and Las Colinas are located in Canal System 2 on the north bank of the Salt River. The final two sites, La Plaza and Los Hornos are found on the south bank of the Salt River opposite of Pueblo Grande.

Artifact samples from these nine sites are desirable for four key reasons. First, all of the sites are located various distances from known source areas. For instance, Upper Santan in the middle Gila River Valley is less than two km from the Santan Mountains, while sites in the lower Salt River Valley are 15 to 21 km from the nearest source area. Spatial variability among the sample sites permits an evaluation of the influence of distance-to-source on vesicular basalt provisioning practices. Second, the excavations at Pueblo Grande, Las Colinas, and Lower Santan were large enough in scope to uncover discrete habitation areas. An analysis of intra-site patterning, the second test variable examined as part of the hypothesis testing, is thus possible. Third, each site contains a Preclassic ballcourt and/or a Classic period platform mound. The inclusion of sample contexts with public architecture permits the evaluation of hypotheses (i.e., marketplace exchange and elite-controlled redistribution) that suggest the movement of vesicular basalt was embedded in communal ritual ceremonies. Lastly, archaeological excavations at each of these sites were intensive enough to produce scores of groundstone artifacts from dateable contexts. The large size of these samples have the potential to provide clear data provenance provenance patterns in the data and, in most cases, significant statistical results. The ensuing chapter discusses the archaeological context and vesicular basalt sample for each of the nine sample sites included in this study.

Casa Grande

Casa Grande, located on the outskirts of Coolidge in the middle Gila River Valley, is probably the most famous Hohokam archeological site in Arizona. The site is known to most for its four-story high Late Classic Great House ("*Casa Grande*"), which is today the main attraction of Casa Grande Ruins National Monument. However, the site (and Monument) also includes two large compounds, two platform mounds, a ballcourt, a possible reservoir, and several irrigation ditches (Ambler 1962; Wilcox 1991:262; Wilcox and Sternberg 1983:137; Wells 2006). This central precinct of public architecture and relatively large habitation areas is further surrounded by a ring of smaller compounds and other habitation areas. Two of these lesser habitation sites include GR-9065 and GR-9067 on the south side of the park walls. The artifact sample for this research project derives from these two sites.

GR-9065 (AZ AA:2:66 (ASM)), also known as the Vahki Inn Village Site, is considered part of the Casa Grande settlement complex. Early descriptions of GR-9065 indicate that it was a Classic period habitation consisting of two adobe-walled compounds and 13 associated trash mounds (Baldwin et al. 2005; Midvale 1963; Rice et al. 2002; Valcarce and Kayser 1969). In 1969, Valcarce and Kayser stated that one of the compounds may have contained a two-story structure in the northeast corner. A more recent investigation of the site was completed by GRIC Cultural Resource Management Program in advance of improvements to the Pima Canal – Later Canal, which represents the partition between GR-9065 and Casa Grande Ruins National Monument. Preliminary survey for this project identified the remains of two compounds, three trash mounds, four undefined depressions, and one possible one-room structure (Baldwin et al. 2005). Subsequent subsurface archaeological investigations in 2009 resulted in the documentation of more than 100 prehistoric features within the canal right-of-way corridor (Woodson 2014). Data recovery efforts were undertaken for a portion of these features, netting 25 vesicular basalt groundstone specimens from Classic period habitation rooms and extramural features.

GR-9067 (AZ AA:2:239 (ASM)) lies approximately 500 meters to west of GR-9065. This site was originally defined as a low density prehistoric artifact scatter associated with the larger Casa Grande settlement complex (Baldwin et al. 2005; Moore 2005). Later, subsurface investigations by the GRIC Cultural Resource Management Program resulted in the discovery of more than two dozen cultural features, including six pit houses and several extramural pits among others (Woodson 2014). Four of the identified pit houses were found to form a possible Sacaton phase courtyard group based on their spatial association and inferred chronology. The recent excavation also resulted in the recovery of hundreds of Hohokam artifacts, including 16 vesicular basalt specimens from datable contexts.

The vesicular basalt groundstone sample from Casa Grande totals 37 artifacts (see Table 5.1). This sample set is composed of fifteen artifacts from Sedentary period contexts at GR-9067 and twenty-two samples from Classic period contexts at GR-9065 (one vesicular basalt specimen from GR-9067 and three pieces from 9065 were not located in curatorial contexts). The artifacts from GR-9067 stem from five pit house structures (n=11), one extramural pit (n=1), and nonfeature contexts (n=3). The artifacts from nonfeature contexts were included in the Sedentary period sample assemblage because all excavated contexts at the site date to this interval. The classic period sample from GR-9065 comes from a wider diversity of features types, including buried midden deposits (n=2), extramural pits (n=7), an early Classic pit house structure (n=1), Classic period adobe-walled pit rooms (n=3), a plaza precinct (n=5), a trash mound (n=1), and nonfeature contexts (n=3). Samples from unsealed deposits, such as plazas, trash mounds, and nonfeature contexts, are all presumed to date to the Classic period due the absence of culture material from other temporal intervals in the excavated portion of the site.

Gila Crossing

Gila Crossing (GR-1112) is located in the middle Gila River Valley about 14 km southwest of the intersection of the Salt and Gila Rivers (see Figure 1.3). The site is primarily defined as a Preclassic Hohokam ballcourt village, but also includes Classic, Historic, and even modern components (Brodbeck 1999; Plumlee et al. 2013). To date,

Table 5.1. Vesicular Basalt Sample from Casa Grande

Sample Context	No. of Features	Sample Count		Total
		Sedentary	Classic	
Buried Midden	1		2	2
Extramural Pit	3	1	7	8
Non feature	2	3	3	6
Pit House	5	11	1	12
Pit Room	2		3	3
Plaza	1		5	5
Trash Mound	1		1	1
Total	15	15	22	37

the GRIC cultural resource management program has conducted over 50 archaeological investigations at Gila Crossing in conjunction with several housing and utility installation projects (e.g., Brodbeck 1999; Plumlee et al. 2013; Rodrigues and Landreth 2013;Rodrigues and McCool 2011; Tiedens and Plumlee 2013). As a result of these projects, over 250 trenches and 100 stripping units have been excavated, and over of 760 features have been recorded. Prominent prehistoric features include the ballcourt, three distribution canals, approximately 50 pit houses, 60 artifact scatters or middens, and at least 400 extramural pit features. Close to 300 specimens of vesicular basalt groundstone have been recovered from excavated contexts at GR-1122.

A total of 42 vesicular basalt groundstone artifacts recovered from Sedentary period contexts at Gila Crossing were included into the current sample set (Table 5.2). Artifacts from datable Classic period contexts are uncommon at the site and, therefore, were not included in this study. The Sedentary period sample includes artifacts from a total of 18 different features representing five different feature types. The majority of artifacts are from buried midden deposits (n=14) and surface trash mounds (n=14). The rest of the sample is from pit house structures (n=5), extramural pits (n=14), and an artifact cache (n=4).

Table 5.2. Vesicular Basalt Sample from Gila Crossing

Sample Context	No. of Features	Sedentary Period Sample Count
Artifact cache	1	4
Buried Midden	3	5
Extramural Pit	8	14
Pit house	4	5
Trash Mound	2	14
Total	18	42

Hospital Site

The Hospital Site (GR-915) is a large prehistoric Hohokam village that also contains a substantial late historic Akimel O'odham component (Vivian and Spaulding 1974; Wasley and Scovill 1969; Wood 1972; Woodson and Randolph 1997). The site is located in the modern town of Sacaton, on the south site of the Gila River, in the middle Gila River Valley (see Figure 1.3). Currently, private residences, commercial buildings, schools, paved roads, and governmental buildings cover most of the site. Extant among these modern facilities are two to three ballcourts, five trash mounds, 62 artifact concentrations that possibly represent deflated trash mounds or habitation areas, and the projected alignments of the prehistoric Sweetwater Canal (Miles et al. 2008; Woodson 2010, 2013). Additionally, subsurface archaeological investigations conducted in conjunction with modern construction projects have resulted in the identification of scores of structural and pit features and thousands of artifacts. Well over 200 vesicular basalt groundstone artifacts have been recovered from datable contexts at the Hospital Site. A total of 31 of these specimens from Sedentary period contexts were included into the current sample set. Again, Classic period samples are rare and were not incorporated into this sample set (Table 5.3).

Table 5.3. Vesicular Basalt Sample from the Hospital Site

Sample Context	No. of Features	Sedentary Period Sample Count
Buried Midden	2	8
Extramural Pit	5	8
Pithouse	5	15
Total	12	31

La Plaza

La Plaza (AZ U:9:165 (ASM)) is a large Hohokam village located on the south side of the Salt River near Tempe Butte (see Figure 1.3). The site was a member of Canal System 1, the second largest canal system ever constructed by the Hohokam. The prehistoric occupation of La Plaza was long lived, with a probable date range spanning the Pioneer through late Classic period (Schilz et al. 2008:10). Documentation of the site in the early twentieth century prior to modern development indicates that La Plaza contained at least three platform mounds and several large trash mounds (Midvale 1968; Turney 1929), Given its size, location, and long occupational history, La Plaza probably also contained a Preclassic ballcourt. Unfortunately, any surface manifestation of the site has been obliterated by modern development.

More recent archaeological investigations in the Tempe area shed much needed light on the Hohokam occupation at La Plaza. To date, mitigation and data recovery projects have resulted in the documentation of more than 300 prehistoric subsurface features at the site (e.g., Hanson 1972; Rice and James 1988; Schilz et al. 2011; Stone 1991; Wright 2005). One excavation project that is of particular relevance to this research study was undertaken in advance of the construction of Central Phoenix/East Valley Light Rail. The investigations for this project resulted in the collection of 37 vesicular basalt groundstone artifacts from Colonial, Sedentary, and Classic period contexts. All 37 of these artifacts were included in the current study sample (Table 5.4). Unfortunately, intra-site source provenance analysis was not available for La Plaza due to the spatial limits that were imposed by the narrow project corridor.

Table 5.4. Vesicular Basalt Sample from Gila Crossing

		Sample Count				
Sample Context	**No. of Features**	**Colonial**	**Colonial/ Sedentary**	**Sedentary**	**Classic**	**Total**
Extramural Pit	8	3	2	3	8	16
Pit House	6	7	3	2		12
Pit Room	6				9	9
Total	20	10	5	5	17	37

Las Colinas

Las Colinas (AZ T:12:10 (ASM)) was a major Hohokam settlement located on the north side of the Salt River and a member of Canal System 2. Early reports of the village suggest it was quite extensive and featured a ballcourt, four platform mounds, and at least eight other large trash mounds or residential compounds (Gregory et al. 1989:1). Regrettably, most of the surface features at Las Colinas were destroyed in the 1930s as a result of urban development in Phoenix. The majority of the current archaeological knowledge that exists for Las Colinas stems from excavations undertaken in preparation for constructing the final leg of Interstate 10. Fieldwork for this project unearthed dozens of Sedentary and Classic period pit houses and other structures, scores of various extramural pits, one Sedentary period ballcourt, and one Classic period platform mound with a surrounding ceremonial precinct (Gregory 1989; Gregory et al. 1989). Additionally, the large investigative corridor for the highway project permitted archaeologists to delineate discrete spatial groupings, including the Classic period platform-mound compound and several household clusters or habitation areas.

Relatively recently, the excavated features at Las Colinas were re-dated using Wallace's (2001, 2004) recent refinements of the Hohokam red-on-buff ceramic chronology (Abbott 2006). By employing a rigorously designed, fine-scale, temporal seriation of the painted designs and vessel forms, Wallace modeled the rise and fall of Hohokam decorative traditions, leading to temporal subdivisions of Haury's (1976; see also Gladwin et al. 1937) pottery types. Important to this study is the four-part division of Sacaton Red-on-buff, the type that Haury defined to represent the Sacaton phase, which is equivalent to the Sedentary period. Wallace has been able to divide this type into Early Sacaton, Middle Sacaton 1, Middle Sacaton 2, and Late Sacaton Red-on-buff. Thus, what had been a single pottery category representing a 200-year block of prehistory, has been split into four types, each associated with a relatively short interval of time.

A recent application of the refined ceramic typology has shown that Las Colinas was probably settled during the early/middle Sacaton period and was continuously occupied through the Classic period. The site's ballcourt was securely dated to the middle Sacaton period and, a large number of contemporaneous dwellings and extramural features were discriminated on the basis of the associated ceramics (Abbott 2006). Numerous contexts that postdated the ballcourt and were occupied during late Sacaton times have also been similarly identified. Lastly, based on the presence of Classic period decorated and red-slipped wares, early Classic period deposits and features were identified in the domestic portion of the settlement and in the ceremonial precinct surrounding the platform mound. The Las Colinas sample set is therefore extremely critical to this study because it includes vesicular basalt groundstone from variable spatial and temporal contexts.

The vesicular basalt sample from Las Colinas analyzed in this study consists of 95 vesicular basalt specimens (Table 5.5). These artifacts stem from features that have been dated to the middle Sacaton (n=31), late Sacaton (n=33), and early Classic period (n=31) contexts at the site. The middle and late Sacaton period collections include groundstone from two distinct domestic habitation areas (Areas 4 and 5) encountered during the excavations. The early Classic period sample includes artifacts from one domestic habitation area (Area 7) and also the platform mound compound (Area 3). In sum, the vesicular basalt sample includes artifacts from discrete habitation areas that date to 1) the middle Sacaton period (ca. A.D. 1000-1070), when the ballcourt network had grown to its greatest extent and the ballcourt at Las Colinas was in use, 2) the late Sacaton period (ca. A.D. 1070-1150) when the ballcourt network collapsed and the Las Colinas ballcourt fell into ruins, and 3) the early Classic period (ca. A.D. 1150-1300) when platform mounds were built at Las Colinas and elsewhere in the Salt-Gila Basin.

Table 5.5. Vesicular Basalt Artifact from Las Colinas

		Sample Count			
Row Labels	**No. of Features**	**Middle Sacaton**	**Late Sacaton**	**Early Classic**	**Total**
Habitation Area 4					
Borrow Pit	3		6		6
Extramural Pit	2		1	1	2
Horno	1		5		5
Pit House	11	17	10		27
Subtotal	*17*	*17*	*22*	*1*	*40*
Habitation Area 5					
Borrow Pit	2		6		6
Pit House	4	14	4		18
Pit Room	**1**			**5**	**5**
Subtotal	*7*	*14*	*10*	*5*	*29*
Habitation Area 7					
Horno	1			13	13
Pit House	1		1		1
Subtotal	*2*		*1*	*13*	*14*
Platform Mound Compound					
Pit Room	6			12	12
Subtotal	*6*			*12*	*12*
Total	32	31	33	31	95

Los Hornos

La Ciudad de los Hornos (AZ U:9:48 ASM), more commonly known as Los Hornos, is another large Hohokam village located on the south side of the Salt River. The site is located in the modern city of Tempe approximately 4.0 km south-southwest of La Plaza (see Figure 1.3). Los Hornos was occupied from the early Pioneer through the Classic period and features a central plaza with at least one, possibly two, Preclassic ballcourts and a Classic period platform mound. Early descriptions and recent archaeological investigations at the site have also documented multiple Preclassic courtyard groups, at least 15 Classic period residential compounds, dozens of large trash mounds, and scores of extramural features (Chenault et al. 1993:1; Cushing 1890; Effland 1990; Wilcox et al. 1990).

The vesicular basalt sample from Los Hornos included in this study is from the Lassen Substation Project (Effland 1990). This archaeological investigation resulted in the discovery of 160 archaeological features, the majority of which are from the Colonial and Sedentary periods, and more than 100 groundstone artifacts from datable contexts. The study sample consists of a total of 32 vesicular basalt groundstone artifacts (Table 5.6). The majority (n=29) of these artifacts are from late Colonial/early Sedentary and Sedentary pit house structures. The remaining few artifacts are from an extramural pit that dates to around the Colonial to Sedentary transitions. Although the vesicular basalt sample from Los Hornos derives from several pit house features, intra-site source diversity analyses are not possible for the sample site due to the narrow window of the project corridor.

Table 5.6. Vesicular Basalt Sample from Los Hornos

Sample Context	No. of Features	Sample Count: Colonial/ Sedentary	Sample Count: Sedentary	Total
Extramural Pit	1	3		3
Pit House	8	10	19	29
Total	9	13	19	32

Lower Santan

Lower Santan (GR-522) represents the remains of an extensive prehistoric Hohokam village that was occupied continuously from the early Colonial through Late Classic periods (Neily et al. 1999a). The site is located in the middle Gila River Valley on an expansive river terrace immediately southwest of the Santan Mountains. The central precinct of the village was first recorded in 1928 by Frank Midvale, who described it as having a “sun temple” (ballcourt), one compound (platform mound), two house mounds (residential compounds), two mescal pits (hornos or roasting pits), and 37 trash mounds, some of which were described as “gigantic” in size (Midvale 1928). The current site boundary extends northwest to southeast for approximately 4.8 km along both sides of State Route-87. The platform mound is still visible at the site, but surficial manifestation of the ball court, compounds, and most trash mounds has been largely erased by modern agricultural enterprises in the area.

Lower Santan has been divided into 21 discrete loci (Locus A-T) to facilitate site documentation (Neily et al. 1999a). Vesicular basalt artifacts used in this study derive from Locus A and D. These two loci correspond with the central precinct of the site that was originally identified by Midvale in 1928. They also have been the focus of significant subsurface archaeological investigations in preparation for the revamping of agricultural irrigations systems on the GRIC. Data recovery excavations in Locus A and Locus D have resulted in the identification of over 100 prehistoric houses, 1,000 associated features, and a plethora of groundstone tools (Loendorf et al. 2007; Rodrigues 2011). Subsequent analysis of the remains revealed that the two loci represent two temporally distinct occupations at the site. Locus D is the center of a substantial Sedentary period occupation, while Locus D primarily exhibits a Classic period age. Furthermore, the Sedentary period occupation in Locus A has been subdivided into early/middle Sacaton and late Sacaton/early Soho phases based upon Wallace's (2001, 2004) microseriation of Hohokam red-on-buff decorated ceramics (Woodson and Kelly 2010). Thus, the data sample from Lower Santan includes artifacts from three different temporal intervals: the early/middle Sacaton, the late Sacaton/early Soho, and Classic period (which include Early, Late and undifferentiated Classic period contexts).

The archaeological sample from Lower Santan totals 100 specimens (Table 5.7). Thirty-four specimens were selected to represent the early/middle Sacaton phase contexts, 35 specimens were selected from the late Sacaton, and 31 specimens were analyzed from Classic period contexts at the site. Nearly the entire early/middle Sacaton sample (n=34) and much of the late Sacaton/early Soho period sample (n=35) derive from dated pit house features in Locus D. One early/middle Sacaton sample is from an extramural pit in Locus A. The rest of the late Sacaton period sample includes material from borrow pits (n=3) and extramural pits (n=8) in Locus D. The bulk of the Classic period sample (n=20) derives from adobe-walled pit rooms in Locus A, with the remainder from datable pit features (n=11).

Table 5.7. Vesicular Basalt Sample from Lower Santan Village

		Sample Count					
Sample Context	**No. of Features**	**Early/ Middle Sacaton**	**Late Sacaton/ Early Soho**	**Early Classic**	**Late Classic**	**Classic, undefined**	**Total**
Locus A							
Extramural Pit	4	1		1		8	10
Pit House	1		1				1
Pit Room	8			4	16		20
Subtotal	*13*	*1*	*1*	*5*	*16*	*8*	*31*
Locus D							
Borrow Pit	4		3	2			5
Extramural Pit	6		8				8
Pit House	20	33	23				56
Subtotal	*30*	*33*	*34*	*2*			*69*
Total	43	34	35	7	16	8	100

Pueblo Grande

Pueblo Grande (AZ U:9:1 (ASM)) is a large Hohokam village that was occupied continuously from the Pioneer period through the Classic period (Abbott et al. 1994; Abbott and Foster 2003; Mitchell 1994b, 1994c). The village is located in the lower Salt River Valley at the head of Canal System 2, the largest irrigation cooperative in the Salt-Gila Basin (see Figure 1.3). Its favorable location is generally inferred to have been of great significance, since the village would have overseen the delivery of irrigation water to dozens of other settlements and thousands of Hohokam households (Abbott 2003b). In support of its importance, one only need look to the center of the site where they will find a ceremonial plaza with one of the largest, if not the largest, platform mounds ever built by the Hohokam. The mound measures 90 meters by 47 meters (the size of a football field) and is estimated to encapsulate 16,000 cubic meters of compacted fill (Abbott et al 2003:19).

Approximately one-quarter of Pueblo Grande was subject to intensive archaeological excavation in advance of the Hohokam Expressway Project (Foster 1994b). The field investigations resulted in the identification of 2,980 archaeological features directly to the east of the central precinct, including exposures of 14 spatially discrete domestic habitation areas. For this study, a sample of 65 vesicular basalt artifacts was selected from eight of the investigated habitation areas (Areas 2, 3, 5, 6, 7, 8 and 10; Table 5.8). The sample includes 34 specimens from Early Classic period contexts and another thirty-one from different Late Classic. Thus, similar to Stone's (1994a, 1994b, 2003) previous research of vesicular basalt acquisition practices at Pueblo Grande, this study too will benefit from the availability of samples from numerous spatially-discrete habitation areas. Specifically, the Pueblo Grande dataset, along with data from Las Colinas, provides an excellent situation to evaluate intra-site variability in vesicular basalt acquisition and distribution patterns.

Upper Santan

Upper Santan (GR-441) is a large Preclassic and Classic period Hohokam village in the middle Gila River Valley (Neily et al. 1999a). As its name implies, Upper Santan is

Table 5.8. Vesicular Basalt Sample from Pueblo Grande

		Sample Count		
Sample Context	**No. of Features**	**Early Classic**	**Late Classic**	**Total**
Habitation Area 2				
Pit House	2	2		2
Pit Room	4		6	6
Subtotal	*6*	*2*	*6*	*8*
Habitation Area 3				
Pit House	2	11		11
Subtotal	*2*	*11*		*11*
Habitation Area 5				
Pit House	2	6		6
Pit Room	7	1	13	14
Subtotal	*9*	*7*	*13*	*20*
Habitation Area 6				
Pit Room	2	2		2
Subtotal	*2*	*2*		*2*
Habitation Area 7				
Pit House	6	11		11
Pit Room	4		7	7
Subtotal	*10*	*11*	*7*	*18*
Habitation Area 8			2	2
Pit Room	1		2	2
Subtotal	*1*		*2*	*2*
Habitation Area 10				
Pit House	1	1		1
Pit Room	2		3	3
Subtotal	*3*	*1*	*3*	*4*
Total	33	34	31	65

located upstream from the neighboring Lower Santan village (see Figure 1.3). Surface features present in this area include a ballcourt and platform mound, as well as several residential compounds, trash mounds, rock wall alignments, canal alignment and ditches, miscellaneous structural mounds, and an artifact scatter (Neily et al. 1999a; Wilcox 1977). Also notable is that the village sits in the shadows of several vesicular basalt quarry sites in the Santan Mountains (e.g., GR-449, Purple Ridge, and Turtle Ridge). Today, Upper Santan is home to a sizable Akimel O'odham community.

Extensive archaeological investigations have been undertaken at Upper Santan in advance of modern housing development, highway construction (State Route 87), and massive irrigation projects (Loendorf et al. 2007; Rodrigues 2011; Thompson and Fertelmes 2014). Survey efforts have identified 27 spatially-discrete loci (Locus A-Z & AA) at the site and several extant trash mounds and structural areas, including habitation areas, the ballcourt, and the platform mound. Subsurface excavations have uncovered hundreds more prehistoric features and yielded more than 500 groundstone artifacts. Based on architectural forms and material culture evidence, subsurface archaeological investigations at Upper Santan appear to have been concentrated in Colonial and Classic period site components. Although a substantial Sedentary period occupation is also likely to have been present at the site based the presence of a ballcourt, excavated features dating to this temporal interval are not well represented in archaeological projects.

A total of 45 vesicular basalt groundstone artifacts from datable contexts at Upper Santan were included in this analysis (Table 5.9). This sample includes specimens from the Preclassic Colonial (n=23) and Sedentary periods (n=6), as well as Early (n=11), Late

Table 5.9. Vesicular Basalt Sample from Upper Santan

Sample Context	No. of Features	Sample Count: Colonial	Sedentary	Early Classic	Late Classic	Classic, undefined	Total
Locus A							
Extramural Pit	1		3				2
Pit House	3	6					6
Pit Room	2			4			4
Subtotal	*6*	*6*	*2*	*4*			*12*
Locus B							
Buried Midden	1	3					3
Extramural Pit	3	13	3				16
Pit Room	1			3			3
Subtotal	*5*	*16*	*3*	*3*			*22*
Locus F							
Buried Midden	1				1		1
Subtotal	1				*1*		*1*
Locus H							
Buried Midden	2			2		2	4
Trash Mound	2			2		1	3
Subtotal	*4*			*4*		*3*	*7*
Locus W							
Extramural Pit	1		2				2
Pit House	1	1					1
Subtotal	*2*	*1*	*2*				*3*
Total	18	23	6	11	1	3	45

(n=1), and undifferentiated (n=3) Classic period contexts. The Colonial and Sedentary period samples stem from pit house structures and extramural pits in Loci A, B, and W in the central precinct of the site. All of these features are found within 100 m of the communal ballcourt and ceremonial platform mound. More than half of the Classic period sample is from structural contexts from the village center (Loci A, B, and H). The remainder (n=7) is from trash or midden deposits in Locus H, which is found approximately 500 m east of the platform mound. The presence of artifacts from datable contexts in several site loci potentially provides a chance to investigate intra-site source consumption practices. However, it is anticipated that such variability will be quite low due to the proximity of Upper Santan to the Santan Mountain source area.

Summary

The geochemical composition of 484 vesicular basalt groundstone artifacts from nine Hohokam archaeological sites will be analyzed to determine the geographic origin of the stone. This artifact inventory consists of 181 manos, 180 metates, and 123 indeterminate groundstone fragments from well-dated contexts. The nine sites include five Hohokam villages from the middle Gila River Valley (Casa Grande, Gila Crossing, Hospital Site, Lower Santan and Upper Santan) and four from the lower Salt River Valley (La Plaza, Las Colinas, Los Hornos, and Pueblo Grande). Artifact samples from Gila Crossing, Hospital Site, and Los Hornos date to the Preclassic period; the sample set from Pueblo Grande dates to the Classic period; and artifacts from Casa Grande, La

Plaza, Las Colinas, Lower Santan, and Upper Santan date to both Preclassic and Classic period contexts

The large groundstone inventory and diverse site sample allows the test expectations for each of the five research hypotheses to be evaluated. For example, a provenance analysis of vesicular basalt samples from Preclassic contexts at Gila Crossing will reveal if the site's inhabitants relied on the nearest available basaltic outcrop (Lone Butte) or if they instead chose to acquire material and tools from more distant source areas. Likewise, the sample sets from Las Colinas and Pueblo Grande permit an inspection of intra-site source diversity variance. Additionally, the five sites that contain artifacts from both Preclassic and Classic period contexts will provide information on temporal trends in provisioning practices. Lastly, when all nine sites are examined in aggregate, it can be determined whether these Hohokam villages were self-sufficient in procuring groundstone or if they all relied on tool producers working near one or more source areas.

The inclusion of artifact samples from Hohokam sites in the lower Salt and middle Gila Valleys is further important given the history of archaeological research in the study area. Aside from the major excavations at Snaketown (Haury 1976), archaeological research in the middle Gila Valley has been until recently quite modest compared to the lower Salt River Valley. Consistent and large-scale excavations in the former area have not frequently occurred because most of it is located within the bounds of the GRIC and therefore did not experience the massive urban growth and associated compliance archaeology that occurred in the Phoenix metropolitan area. As a result, archaeological interpretations from the Salt River Valley are often applied to the middle Gila River, even though it is also recognized that the two river valleys may have had independent cultural trajectories (Doyel 1991a; Graybill et al. 2006; Woodson 2010). Not until archaeological efforts associated with the 1994 Pima-Maricopa Irrigation Project (P-MIP), a long term Bureau of Reclamation funded undertaking designed to refurbish irrigation agricultural within the GRIC, was there comparable archaeological data between the two river valleys. The vast majority of artifacts from the middle Gila River Valley in this study were recovered during P-MIP. Thus, the vesicular basalt provenance data patterns observed in this research will be unique in that they will provide information on groundstone tool provisioning patterns in both the lower Salt and middle Gila River Valleys.

CHAPTER 6: THE EFFICACY OF PORTABLE X-RAY FLUORESCENCE SPECTROMETRY FOR NONDESTRUCTIVE ANALYSIS OF VESICULAR BASALT

An inherent goal of this research study is to develop a practical and reliable analytical method for Hohokam vesicular basalt provenance studies. Based on past research results and the current goals of this study, geochemical sourcing of groundstone using PXRF analysis is the preferred method. The PXRF method was chosen because it provides an efficient, objective, practical, and nondestructive analytical technique for determining sample chemistry. Additionally, previous sourcing studies in the Hohokam Basin have demonstrated that XRF has the potential to be a reliable and valid analytical tool for differentiating various basaltic outcrops in the region (Shackley 1994, 1995a; Skinner 2000a, 2000b, 2001). Thus, the PXRF approach has a number of advantages compared to other compositional analytical techniques for the analysis of Hohokam vesicular basalt groundstone.

Although there are several benefits of using nondestructive PXRF, there are also several analytical limitations to the technique that had to be addressed in this study. One of the primary challenges in charactering the geochemistry of vesicular basalt is generating a reliable measurement. Irregular sample morphology, irregular surface texture, variable particle size, and geochemical variability affect the reliability of XRF through multiple X-ray phenomena (Forster et al. 2011; Jenkins 1999: Lundblad et al. 2008, Lundblad et al. 2011; Potts and West 2008; Potts et al. 1997; Shackley 2011). A second potential concern in using XRF is the geochemical variability inherent to basaltic formations. This variability presents analytical challenges for determining the geographic provenance of individual artifacts, because the variation within a source area often exceeds the variation among sources. Thus, demonstrating the validity of PXRF for Hohokam vesicular basalt groundstone provenance analysis was a necessary component of the current research.

To improve the reliability of nondestructive PXRF for Hohokam vesicular basalt provenance analyses, three experiments were performed to determine: 1) the minimum analysis time necessary to yield a consistent geochemical measurement for a single-spot assay; 2) the minimum number of differently-placed assays needed to produce a consistent characterization of sample geochemistry; and 3) whether the minimum analysis requirements are capable of generating accurate geochemical data useful for vesicular basalt provenance analyses. The results of these three experiments were used to develop an efficient data collection protocol for the analysis of the vesicular basalt raw material sample and, subsequently the evaluation of the Provenance Postulate for Hohokam sourcing studies. This chapter begins with an overview of XRF theory and methods, before discussing the objectives, results, and implications of the three experiments.

XRF Theory

Understanding the advantages and disadvantages of XRF as an analytical technique first requires a simplified overview of the theoretical atomic physics. As is well known, the atom is the basic unit of all matter. For example, water is composed of two hydrogen atoms and one oxygen atom (i.e., H_2O). Though fundamental, the atom itself is composed of three smaller particle types known as protons, neutrons, and electrons (Figure 6.1). Protons (positively-charged particles) and neutrons (neutrally-charged particles) clump together to form a dense mass in the center of the atom called the nucleus. Electrons (negatively-charged particles) are found circumventing the nucleus, being held in fixed orbits by a balance between kinetic (i.e., repulsive) and potential (i.e., attractive) energies. The number of protons present in the nucleus is unique for each naturally occurring atom and is therefore indicative of element type. XRF spectroscopy, however, depends on idiosyncrasies among the electron orbits to identify the quality and quantity of elements within a sample.

The orbits of atomic electrons are not entirely random, but have a high probability of occupying well defined energy regions commonly referred to as levels or shells (Jenkins 1999:53; Lachance and Claisse 1995:5). These levels are designated by the letters K, L, M, N, etc. as they become further removed from the atomic nucleus (see Figure 6.1). Electrons may also occupy sublevels within each energy region after the innermost K shell. For instance, the L level has three sublevels, the M level has five sublevels, and the N level has seven sublevels. Each of these orbital regions can accommodate a maximum of two electrons. Thus, the K shell holds a maximum of two electrons, the L shell a maximum of eight electrons, the M shell a maximum of 18 electrons, and so forth. As such, there is a logical structure in the ordering of orbital

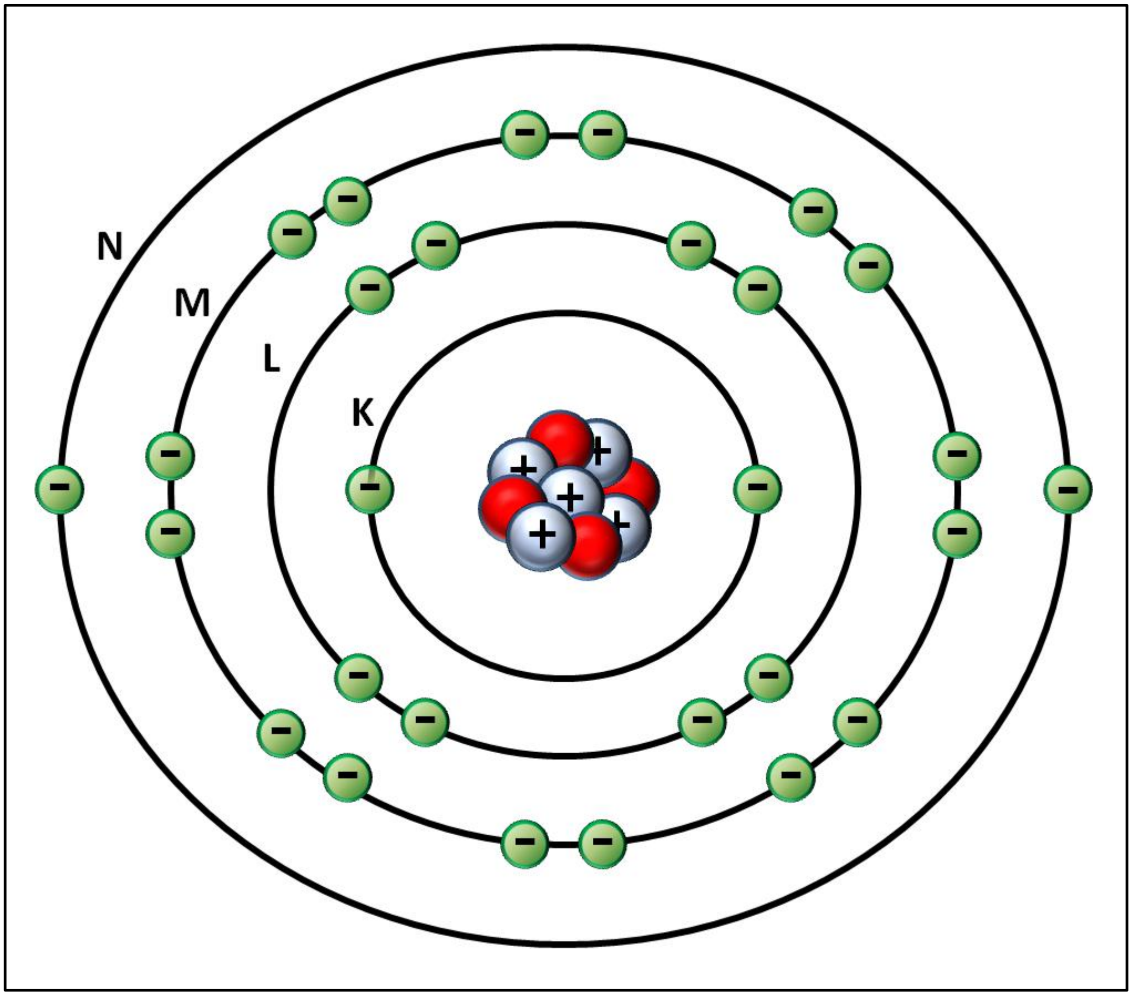

Figure 6.1. Schematic Representation of the Iron Atom.

electrons, with elements of increasing atomic number (i.e., more protons, neutrons, and electrons) being constructed according to a predictable sequence of electron additions to the orbital shells (Enge et al. 1972; Jenkins 1999:54).

It is further understood that each electron shell is characterized by a specific and unique amount of electrostatic or "binding" energy. This energy field is governed by the rules of quantum physics, but for the present purposes it is best to conceive it as the sum of an electron's kinetic and potential energies. Kinetic energy is the positive momentum an electron possesses while in motion around the nucleus. It can also be regarded as a repulsive or centrifugal force that keeps the electron from crashing into the atomic nucleus. In contrast, potential energy is stored energy and is twice as large as and is opposite of kinetic energy (Enge et al. 1972). This negative energy constitutes the attractive or centripetal force that exists between a negatively-charged electron and the positively charged nucleus. In a normal atomic state, inner orbital electrons travel with greater kinetic energy than outer orbital electrons. Therefore, electrons located closer to the core exhibit a much stronger electrostatic attraction to the nucleus. In an iron atom, for instance, K-shell electrons are attracted to the nucleus with a binding energy more than eight times stronger than the L-shell electrons (Table 6.1).

Table 6.1. Electron Binding Energies of an Iron Atom

Electron Shell	**Binding Energies (eV)**
K	-7112
L_I	-845
L_{II}	-720
L_{III}	-707
M_I	-92
M_{II}	-53
M_{III}	-53

An atom is in a stable state when it possesses the lowest overall amount of electrostatic energy. This condition is satisfied by keeping the innermost energy shells filled with electrons, since electrons closer to the atomic core exhibit much larger negative energies compared to those in the outer shells (see Table 6.1). It is possible to raise the total energy state of an atom above that which defines stability by introducing an external source of positive energy. For instance, if a high-speed particle such as a photon or other electron is delivered into the atom, it has the potential to collide with and transfer a portion of its kinetic energy onto an inner shell electron. This transmission of positive energy raises or "excites" the energy of the affected electron, thereby promoting its transfer to an outer orbital which can accommodate higher energy levels. If the inertia of the incident particle is equal to or greater than the binding energy of the orbital electron, then the latter will be ejected from the atom altogether, leaving the atom in an "ionized" state. This later phenomenon is known as the *photoelectric effect* and the emitted electron is called a *photoelectron*.

An excited or ionized atom instantly regains stability by losing the additional electrostatic energy through one of two ways, one of which is pertinent to understanding the XRF method. The relevant process involves the transfer of another electron into the newly created vacancy and the corresponding release of excess energy (Figure 6.2). For example, if a K-shell electron is ejected from the atom as a result of the photoelectric effect, a second electron from the L or M shell may fall to the inner shell and fill in the void. Though, in order for this transition to occur, the shifting electron must release a

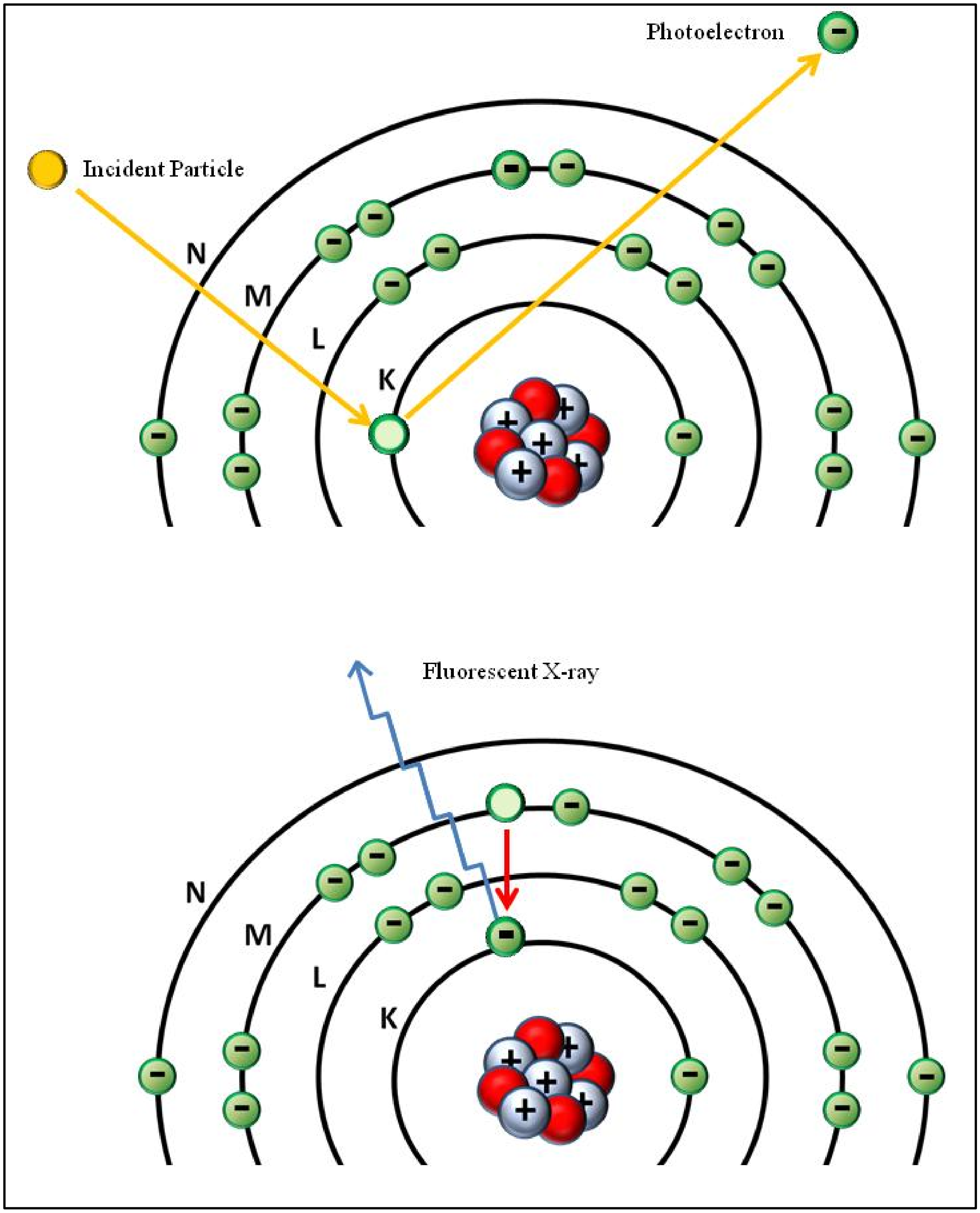

Figure 6.2. Schematic Representation of the Photoelectric Effect Showing the Production of a Photoelectron (above) and Fluorescent X-ray (below).

quantum of energy in the form of an X-ray that is equal to the difference between the binding energies of the two involved shells (Bertin 1975; Jenkins 1999:55; Lachance and Claisse 1995:10). Thus, if an electron from the L_I subshell (-845 eV) in an iron atom moves to occupy a position in the K shell (-7,112 eV), an X-ray photon will be emitted from the atom with an energy of 6,267 eV (see Table 6.1). This release of positive energy results in a net loss of energy for the atom, thereby allowing it to return to a neutral state. The emission of X-ray photons from atomic particles is the underlying principle of XRF (Bertin 1975; Jenkins 1999; Lachance and Claisse 1995). As noted earlier, each electron shell has a distinctive electrostatic energy due to the fixed structure of electron oribtals. These energies are also unique for different elements due to slight nuances in the electrostatic field that are introduced by each additional electron (Jenkins 1999:56; Lachance and Claisse 1995:10). Thus, the energy of an X-ray that results from the photoelectric effect is characteristic of the atom (and orbital shell) from which it was derived. It follows, then, that by delivering particles of sufficient energy into a specimen of unknown chemistry, it is possible to cause the emission of several X-rays that are representative of the sample's chemistry. X-ray spectroscopy is a broad label for several analytical techniques (e.g., of x-ray photoelectron spectroscopy [XPS], X-ray diffraction [XRD], X-ray fluorescence [XRF], proton induced X-ray emission [PIXE]) that study characteristic X-ray emissions. When a beam of X-ray photons is used as the excitation source, the term X-ray fluorescence (XRF) is applied.

XRF Method

The XRF method is based on the fundamental principles of atomic physics. As an analytical technique, though, XRF requires the production, fluorescence, detection, and analysis of characteristic X-rays. The production of X-rays is concerned with the generation of primary radiation that is capable of ionizing atoms in sample matter. Fluorescence is rooted in the interactions between the incident X-rays and subatomic particles. The detection of characteristic X-rays involves isolating, ordering, and counting discrete wavelength bands or energy packets. Lastly, X-ray analysis entails using the detected X-ray counts for qualitative, quantitative, or semi-quantitative analysis. A basic understanding of these four facets is important for understanding the efficacy of XRF for nondestructive geochemical analyses. As such, a brief summary of these components is provided in the following sections.

X-ray Production

The first component of the XRF method involves the production of incident X-rays. To be clear, X-rays are a form of the electromagnetic radiation that occupies the region of the wave spectrum between gamma and ultraviolet rays (Table 6.2). This means X-rays share many of the same qualities as visible light, differing quantitatively in their wavelength, frequency, and energetic properties. For example, X-ray wavelengths occur in the range of 0.10–100 Angstroms [Å] while visible light is found between 4,000 and 7,000 Å. The periodicities of their waves are also measurably different, given the inverse

Table 6.2. The Electromagnetic Spectrum (the boundaries between radiations regions are arbitrarily defined, since no sharp limits can be assigned)

Frequency (hz)	Radiation Type	Photon Energy (eV)	Wavelength (Å)
10^{22}		10^{8}	10^{-4}
10^{21}	Gamma Rays	10^{7}	10^{-3}
10^{20}		10^{6}	10^{-2}
10^{19}	X-rays (hard)	10^{5}	10^{-1}
10^{18}		10^{4}	1
10^{17}	X-rays (soft)	10^{3}	10
10^{16}		10^{2}	10^{2}
	Ultraviolet		
10^{15}		10	10^{3}
	Visible Light		
10^{14}		1	10^{4}
10^{13}	Infrared	10^{-1}	10^{5}
10^{12}		10^{-2}	10^{6}
10^{11}		10^{-3}	10^{7}
10^{10}	Microwaves (UHF)	10^{-4}	10^{8}
10^{9}		10^{-5}	10^{9}
10^{8}		10^{-6}	10^{10}
10^{7}	Shortwave (FM Radio)	10^{-7}	10^{11}
10^{6}		10^{-8}	10^{12}
10^{5}		10^{-9}	10^{13}
10^{4}	Longwave (AM Radio)	10^{-10}	10^{14}
10^{3}		10^{-11}	10^{15}

relation between wavelength and frequency. The periodicity of an X-ray wave is around 10^{16} to 10^{20} hertz, while visible light oscillates below 10^{15} hertz. Finally, the increased periodicity of an X-ray translates to a photon energy level at least two orders of magnitude greater than that of light. The increased energy of an X-ray is one of the primary reasons why it can pass through opaque objects, while visible light cannot.

Most contemporary XRF instruments generate incident radiation by rapidly deaccelerating electrons in a sealed vacuum tube that contains a source of electrons and two metal electrodes (a cathode and an anode). A high voltage power source is used to establish a current of electrons between the negatively charged cathode, which emits electrons, and the positively charged anode, which receives the electrons. As electrons strike the anode target, their kinetic energy is quickly diminished as a result of their impact with other subatomic particles. Most of the lost kinetic energy is converted into heat. However, a small proportion (typically less than one percent) of the energy is released in the form of an X-ray (Cullity 1978:6). The transmission of energy from one medium to another is generically termed radiation. Thus, the conversion of kinetic energy from an electron into an X-ray photon is known as X-ray radiation.

Significantly, the production of X-rays within a vacuum tube is not entirely uniform. Some of the incident electrons will be stopped immediately upon their impact with particles in the target material and consequently release all of their energy at once. In other words, if an electron accelerated to a potential of 1000 eV is instantaneously halted by a collision with an atomic nucleus, an X-ray photon of 1000 eV will be produced. Other times, electrons are deviated randomly by the subatomic interactions and successively lose fractions of their total kinetic energy. The cumulative result of these erratic encounters is the production of X-rays with variable energies. This diverse array of X-rays is known as heterochromatic, continuous, or white radiation (Cullity 1978:8; Jenkins 1999; Lachance and Claisse 1995). Another commonly used term is *bremsstrahlung*, which is German for "braking radiation", an apt description of the deceleration process.

If certain conditions are met, the vacuum tube can also be used to generate characteristic X-rays. Again, this form of radiation results from the photoelectric effect, which involves the ejection of an inner orbital electron by an external particle (an electron in the current example), the filling of the vacancy by an outer orbital electron, and the subsequent release of a characteristic X-ray. The production of characteristic X-rays within a vacuum occurs only if the electron current is accelerated to a potential sufficient enough to excite or ionize atoms with the anode target. If this energy threshold is crossed, the resulting characteristic radiation will comprise the majority of the emitted radiation. For example, if a Cr target tube is operated at 45 kV, the resulting characteristic X-rays will account for 75 percent of the total emitted radiation (Lachance and Claisse 1995:15). XRF instruments harness this relatively focused and intense form of radiation and direct it out of the tube as a collimated beam of X-ray photons, thus comprising the primary excitation source in XRF spectroscopy.

X-ray Fluorescence

The second main component of the XRF method includes generating fluorescent X-rays within sample material. Fluorescence is by definition the absorption and subsequent emission of electromagnetic radiation by a substance (Jenkins 1999:7; Lachance and Claisse 1995:35). XRF, therefore, involves the irradiation of sample matter with primary X-ray photons and the subsequent emission of secondary fluorescent X-rays as predicated by the photoelectric effect. The physics behind photoelectric effect have been discussed earlier and do not need to be repeated again. However, what is worth noting here is that there are several additional phenomena associated X-ray interactions in matter, including attenuation, scatter, critical penetration depth, spectral overlap, and secondary and tertiary fluorescence. These different phenomena are collectedly known as *matrix effects* due to their underlying relation to sample composition as well as their influence on the quantity and quality of florescent radiation. Because matrix effects are extremely important in the analysis of vesicular basalt they too are discussed.

Mass Attenuation

Not all incident radiation will induce the photoelectric effect. For one, a portion of the beam photons will pass through the sample unchanged. The ratio of transmitted to affected photons is known as the mass attenuation coefficient. This measurement unit can be quantified, being a function of the X-ray beam energy, as well as the thickness, density, and elemental constitution of the sample material (Jenkins 1999:7; Lachance and

Claisse 1995:18). Experimental studies have shown, for example, that there is a proportional increase in the number of photons that successfully pass through a substance as the X-ray beam energy is increased. Similarly, research has also shown that when the energy of the X-ray beam is held constant, there is a negative correlation between the ratio of transmitted photons and the thickness, density, and atomic weight of a material (Cullity 1978:13). These effects are actually well-known to most people in the form of a medical X-ray image, in which denser bones appear in contrast to thinner and softer skin tissue. The concept is also important in XRF analyses because X-ray beam intensity and sample density determine the amount of analytical time needed to produce and detect characteristic radiation from specific elements.

Scatter

Another phenomenon that occurs when a beam of radiation impinges upon sample matter is known as scatter. Scatter transpires when the energy of an incident X-ray photon is insufficient to dislodge an atomic electron from its orbital and as a result is deflected out of the specimen. There are two types of scatter, elastic and inelastic. Elastic (i.e., Rayleigh or coherent) scatter includes those interactions in which the energy of the incident X-ray is not vigorous enough to even budge an orbital electron, resulting in the deflection of the incident particle at the same energy at which it arrived. Inelastic (i.e., Compton or incoherent) scatter describes those interactions in which the energy of the incident photon is sufficient enough to momentary displace the electron from its orbit, meaning there was a transfer of energy between the two particles, but not powerful enough to compel its absolute ejection from the orbital. In this case, the incident photon is redirected out of the atom at a lower energy (Jenkins 1999:12; Lachance and Claisse 1995:25). Scatter is an important part of XRF because it provides information on the chemical composition and density of the sample material (Markowicz 2008). Additionally, scattered X-ray intensities can be used to help control for slight variations in X-ray beam intensity and irregularities in surface texture since it is theoretically consistent for samples of similar composition (Feather and Willis 1976; Lachance and Claisse 1995:184; Markowicz 2008; Willis 1989).

Critical Penetration Depth

An incident photon will induce the photoelectric effect if it directly impacts an orbital electron at an energy level greater than the binding energy of the corresponding energy shell. In practice, this phenomenon will transpire only within a certain layer of the sample material. The depth of this analytical layer varies for each element and is dependent on the density and composition of the sample, as well as the intensity of the primary radiation. In general, though, there is a positive correlation between the sample depth and atomic weight. For instance, low-energy X-rays (e.g., Ca) originate from a sample layer near the surface of a specimen, while high-energy X-rays (e.g., Fe) come from a deeper part of the matrix (Markowicz 2008:18). This relationship exists due to the attenuation of both primary radiation and subsequent characteristic X-rays within the sample matrix. XRF analysts term the analytical layer from which fluorescence occurs as the *critical penetration depth*. Recognition of this depth is vital in XRF analyses because some samples (e.g., obsidian flakes) may not be sufficiently thick for the excitation of mid-Z elements (Davis et al. 2011). It is also important for nondestructive analyses because heterogeneous composition, irregular surface texture, and surface coatings all act to differently attenuate X-rays. Disregard of these factors thus has the potential to yield inconsistent measurements and misleading interpretations.

<u>Spectral Overlap and Interference</u>

Two additional aspects of the photoelectric effect that must be considered in XRF analysis are spectral overlap and interference. Recall that atomic electrons belong to specific energy shells (K, L, M, N, etc) and subshells (L_1, L_2, L_3, M_1, M_2, etc) that have constant and unique energy levels. Therefore, when an electron transfers from the L3 subshell to the K shell, the energy of the accompanying fluorescent radiation will differ than that observed if the transition were between the M3 and K-shells. The specific quantum of energy associated with each type of electron transfer is known for each naturally occurring element and also is labeled according to the nature of its transfer. For instance, if the transition is from the L_2 to the K shell, the emitted photon is labeled Kα radiation; a transition from the M_3 to the K shell is labeled Kβ radiation; a transition from the M_3 to the L_2 shell is labeled Lβ radiation; and so on (using Siegbahn notation). The Kα transition is the most common and therefore yields the most intense and observable form of characteristic radiation (Shackley 2011:17). However, due to the presence of multiple energy possibilities for each element, there is often spectral overlap and interference in the fluorescent spectrum when multiple elements are present. XRF analysts must recognize the origin of multiple spectra lines in order to avoid mischaracterizing sample chemistry.

Secondary and Tertiary Fluorescence

Another phenomenon that must be taken into consideration during XRF analysis is secondary and tertiary fluorescence. Additional fluorescence can occur when a characteristic X-ray photon departs from an atom and collides with another orbital electron within the same sample, thereby leading to the ejection of the latter and the emission of another characteristic X-ray. This sequence of internal X-ray interaction occurs because electron binding energies are proportional to atomic number. Thus, fluorescent X-rays from heavier elements such as iron have the potential to initiate the photoelectric effect among elements of lesser atomic weight. This concept is important in nondestructive XRF analyses because it often leads to the underrepresentation of certain heavy elements, while enhancing the emission and detection of fluorescent X-rays from other light elements (Bertin 1975; Jenkins 1999; Lachance and Claisse 1995; Potts et al. 1984). Thus, again, analysts must understand and account for this possibility when interpreting sample chemistry.

In sum, the photoelectric effect is the foundation of XRF analysis. However, there are several other phenomena that occur when a beam of X-ray photons bombards sample matter. These phenomena have important analytical implications for XRF analysis. Although most current software programs take into account these concerns and offer correction procedures to mitigate their influence on measurement reliability, it is still necessary for analysts to be cognizant of these influences when interpreting the quality of characteristic radiation. A lack of awareness for these phenomena can lead to extremely unreliable results and improper conclusions. This is particularly true for the analyses of compositionally heterogeneous materials, such as vesicular basalt, as will be discussed later in this chapter.

X-ray Detection

The third major part of the XRF method entails the detection, sorting, and conversion of characteristic X-rays (as well as scatter and continuous radiation) into interpretable electronic signals. These processes can be executed using either the wavelength or energy-dispersive approach. In wavelength-dispersive X-ray fluorescence (WDXRF), fluorescent radiation emanating from the sample is first dispersed using a single crystal of known interplaner spacing. By rotating this crystal (or detector) around the sample during the time of analysis, different characteristic radiations will be observed because X-ray wavelengths are diffracted at distinct angles (Cullity 1978:421; Jenkins 1999:102). In Energy-Dispersive X-ray fluorescence (EDXRF), the emitted radiation impinges directly onto a semiconductor detector that itself acts to disperse the incoming photons according to their intrinsic energy. The sorting process is completed first by transforming the X-ray photons into an electrical current via immediate interaction with the detector material. Then, each electron in the current is converted to a voltage pulse using a capacitor and resistor, such than one pulse is produced for each X-ray photon. Finally, the various pulses are sent to a multichannel analyzer. Here, each pulse is digitized and stored as a single count in a discrete channel corresponding to its amplitude, or X-ray energy level (Jenkins 1999:98; Shackley 2011:32). Thus, the end result of an EDXRF analysis is a collection of storage digital signals representing the total number of X-ray counts gathered over the total analyses time.

X-ray Analysis

Digitized X-ray count data are commonly displayed graphically as a frequency distribution (histogram of energy [keV] versus X-ray count) referred to as a spectrograph. Figure 6.3 is an example of a typical spectrograph resulting from an EDXRF analysis of a vesicular basalt specimen with a Rh equipped X-ray tube operating at 40 kV. As the image shows, there are several peaks in the analytical spectrum that correspond to the energy of characteristic X-rays. For instance, at approximately 6.5 keV, there is a large peak for the Kα emission of Fe. Also present in the figure are the inelastic and elastic peaks associated with the Rh scatter, at around 19.0 and 20.2 keV, respectively. Between the Fe and Rh peaks are several other outstanding elements, including Sr (14.3 keV) and

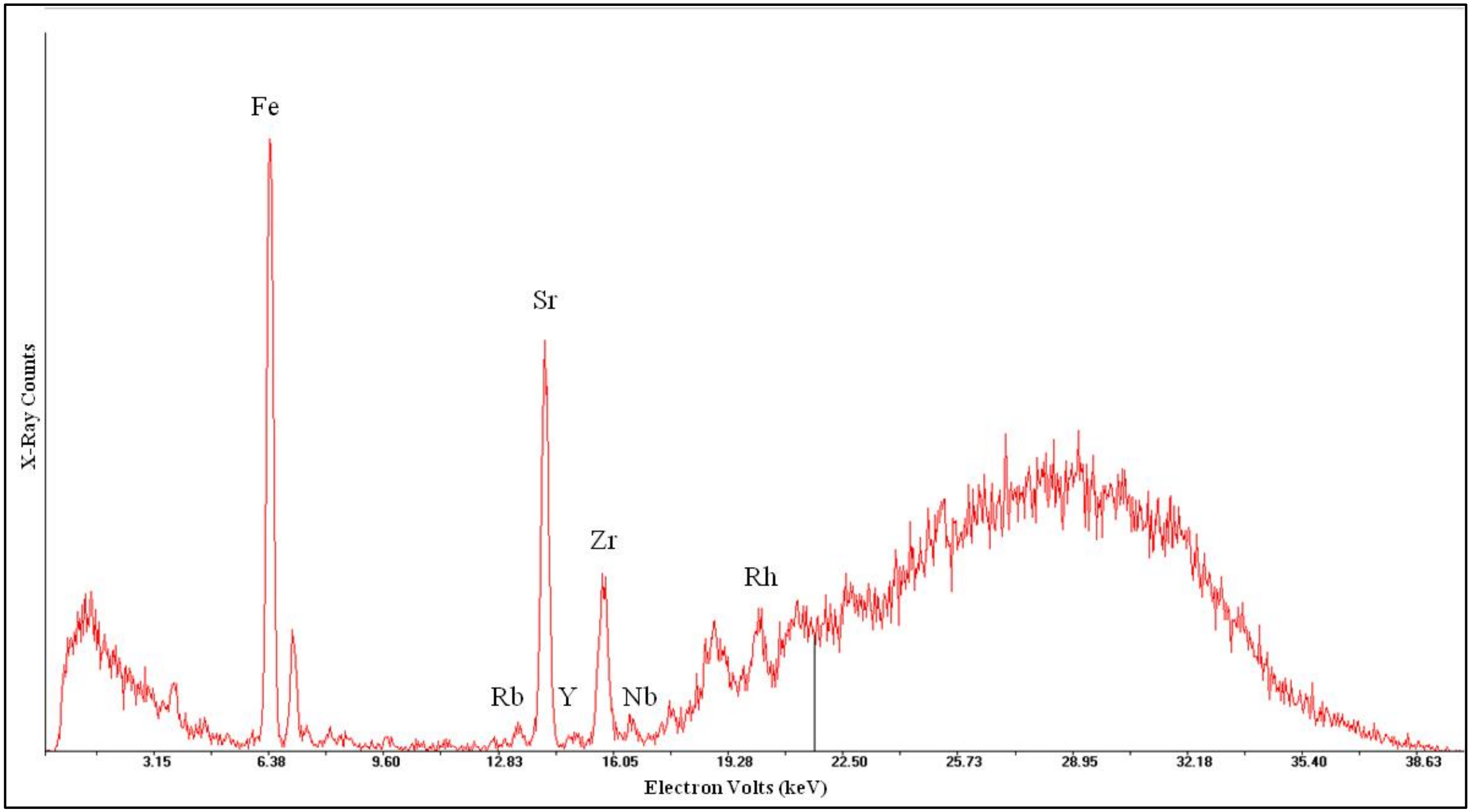

Figure 6.3. Typical XRF Spectrograph Resulting from Nondestructive Analyses of Vesicular Basalt Specimen (instrument operated at 40 keV and 12 µa and with a beam filter placed between X-ray tube and sample).

Zr (15.9 kV). To the right of the Rh scatter is the continuous radiation that was created during incident X-ray production. This region of the spectrograph is more commonly referred to as “background”, even though meaningful information can still be gleaned from it (Shackley 2011:24).

An X-ray spectrograph and the information it portrays can be used for qualitative, semi-quantitative, or quantitative analyses. A qualitative analysis of X-ray spectra generally involves conducting a presence/absence evaluation for elements of interest. This type of visual inspection can be used, for instance, for the immediate identification of harmful agents, such as lead or mercury. Archaeologists can use qualitative XRF analysis to help separate material types that are difficult to distinguish using macro or microscopic techniques, such as shell from stone beads (Loendorf et al. 2013). Slightly more advanced, semi-quantitative analysis involves evaluating the X-ray count data used to form the histogram. Though, in many cases, analysts don’t just assess these numbers at face value. They actually calculate the “area under the curve” of the spectrographs by using software programs that allow the analysts to strip background noise from the x-ray count data. Sometimes the X-ray count data is ratioed to one another or to the peak representing inelastic scatter (Feather and Willis 1976; Jenkins 1999:159; Lachance and Claisse 1995:184; Willis 1989). Comparison of these relative X-ray counts can in some cases prove useful for discriminating geological deposits from one another, though one must be aware that quantitative differences can be concealed by qualitative data (Shackley 2005, 2008).

Finally, the information shown in an X-ray spectrograph can also be used for quantitative analyses. This type of evaluation involves converting the X-ray count data into elemental concentration data (e.g., weight percent; parts-per-million). There are several techniques for transforming X-ray counts into absolute values, each with its own explicit assumptions about the XRF instrument operating conditions and the nature of the sample being analyzed (see Lachance and Claisse 1995; Jenkins 1999; Potts et al. 1984; Revenko 2002). Empirical calibration of X-ray counts to reference materials of known concentration is perhaps the most employed data transformation technique in archaeometric studies. This approach allows for all analysts, regardless of instrument, operating condition, or laboratory setting, to convert their X-ray count data into comparable elemental data, thereby allowing for inter-laboratory research collaboration (Bishop et al. 1990; Neff 1998, 2001; Revenko 2002; Shackley 1995b, 2005, 2011; Speakman and Shackley 2013).

Practical Advantages of PXRF

Several instruments are used in the analysis of cultural artifacts, including XRF, PIXE, neutron activation analysis (NAA), electron microprobe (EMP), electron microscopy (i.e., SEM, TEM, STEM), inductively coupled plasma mass spectrometry

(ICP-MS), and laser-ablation (LA) ICP-MS. However, PXRF is favored in this study because 1) the technique requires little or no sample preparation; 2) material analysis can be nondestructive; 3) it is a relatively rapid analytical technique; 4) it is comparatively affordable; and 5) the technique is available as a portable instrument that can be used in the field or artifact repositories. All five of these factors make the technique an appropriate choice for the analysis of vesicular basalt raw material and groundstone and are thus discussed in detail below.

Minimal Sample Preparation

One reason why the PXRF method is preferable for this research is because sample material can be analyzed with little or no pre-treatment (Shackley 2011:8). Analysts typically perform only a light rinse of artifacts with distilled water prior to their analysis. Empirical research has demonstrated that a minor coating of dirt or other substances (i.e., blood, oil, calcium carbonate, and even bat guano!) has no significant effect on analytical results due to the ability of most X-rays to penetrate and subsequently escape through the sample coatings (Forster et al. 2011; Lundblad et al. 2011:72; Shackley and Dillian 2002). Minimal sample preparation translates to lower analytical cost and, in turn, the submission and interpretation of larger sample sets. Moreover, the limited preparation requirements mean that material analysis can be conducted outside of laboratory settings.

In comparison, many other analytical techniques include costly sample preparation requirements. EMP and SEM, for instance, require the use of carbon coatings, epoxy resin mounts, or petrographic thin sections (e.g., Acquafredda et al. 1999; Fialen et al. 1999; Kayani and McDonnell 1996; Merrick and Brown 1984). Likewise, ICP-MS and LA-ICP-MS necessitate solid samples be turned into an aerosol either before or during analysis (i.e., Hall 1992; Lichte 1995; Lichte et al. 1987; Ridley 2000; Ridley et al. 1998). Such sample preparation requirements greatly increase the expense of analytical services by introducing additional material and person-hour costs. Greater analytical expenses are not preferred for archaeological study given the large number of raw material or artifacts that are needed to yield useful datasets.

Nondestructive Analysis

PXRF is further preferred for the current study because it does not necessitate the destruction or alteration of samples during analysis. Sample material is only excited for a short while before it returns to a stable state. In comparison, the NAA method not only involves the drilling, extraction, and powdering of several hundred milligrams of material from each sample, but the analyzed material will remain radioactive for many years and must be properly treated and disposed (Blackman and Bishop 2007:324). Analytical procedures that leave scars on artifacts or necessitate their complete destruction are not preferred for the analysis of archaeological artifacts given the empirical desire for reproducibility, as well as more ethical concerns such as artifact preservation. Hence, the XRF method is generally preferred when artifacts are from museums or subject to repatriation (Shackley 2008:203). In fact, the nondestructive quality of XRF is a large reason why this study was able to gain access to and analyze such a large number of artifacts from state and tribal repositories.

Efficiency

PXRF is an extremely rapid analytical technique. X-ray spectral data can be viewed in live-time using a computer software program. Hence, a presence/absence or qualitative analysis of chemical composition can be completed in only seconds (Shackley 2011:9). The GRIC Materials Science Laboratory, for example, uses PXRF to differentiate shell from stone beads after only five seconds of analysis time (Loendorf et al. 2013). Quantitative chemical analyses does not require much time either, generally being able to be completed between two and five minutes (e.g., Davis et al. 2011:49; Forster et al. 2011:390; Frahm 2013a:1084; Nazaroff et al. 2010:888; Lundblad et al. 2008:4; Phillips and Speakman 2011:1258; Shackley 2005:544). Other analytical approaches can be painstakingly slow. For example, the length of time required to obtain accurate geochemical data for a single specimen using NAA can last days to weeks due to the slow rate of radioactive decay (Glascock and Neff 2003; Neff 2001). Furthermore, because NAA is only performed at a handful of institutions worldwide, submitted samples may wait months before they are even analyzed. The relatively fast analysis time of the XRF method, along with minimal sample preparation requirements, makes it ideal for the creation of large archaeological datasets. It is also important for this study because, as is discussed below, multiple assays are needed to yield accurate geochemical data.

Portability

The portability of the handheld Bruker Tracer III-V was clearly an important benefit for this research study. Until relatively recently, XRF was primarily a laboratory-based technique undertaken at dedicated research facilities using large and expensive instruments. Although the Hohokam were able to transport large quantities of groundstone throughout the Salt-Gila Basin, the current movement of such artifacts from the repository to laboratory setting is problematic due to proprietary issues. Additionally, the sheer weight and volume of groundstone artifacts would have made the transport of such artifacts an extremely costly enterprise. Large expenses in turn lead to decreased sample sizes, which again is a major concern for this study. Lastly, handheld devices are beneficial because they do not have sample-size constraints. PXRF instruments can be positioned in almost any conceivable posture to collect data on large (Figure 6.4 and 6.5) or irregular-shaped objects. Other methods, such as EMP, ICP-MS, PIXE, XRD, and even laboratory or desktop XRF necessitate some form of material reduction or

Figure 6.4. Compositional Analysis of Vesicular Basalt Manos Using Handheld PXRF

modification in order to fit specimens within an instrument's sample chamber. Issues pertaining to sample size constraint needed to be avoided in the current study given the large size of groundstone tools and the desire to avoid destructive sample preparation.

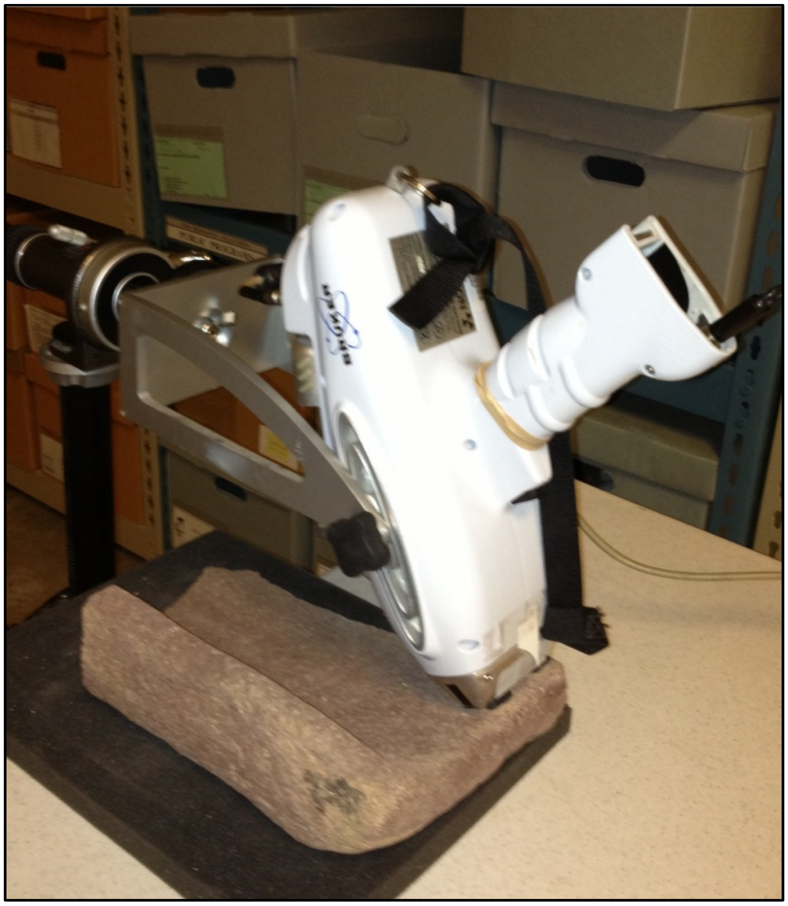

Figure 6.5. Compositional Analysis of a Vesicular Basalt Metate Using Handheld PXRF.

Affordability

Minimal sample preparation, non-destructive analyses, and quick analyses times combine to make PXRF an extremely affordable analytical technique. As an example, the Archaeometry Laboratory at the University of Missouri advertized on their website (accessed April 7, 2013) the per sample cost of nondestructive XRF at $25 per sample. If the sample needed to be powdered, homogenized, and pressed into a pellet prior to XRF analyses, then the price per sample doubled to $50. The same laboratory offered NAA analyses for as low as $100 per sample; bulk characterization of materials using ICP-MS was a minimum of $1,000. The comparatively high costs of these other analytical techniques result in an exclusion limit for most archaeological institutions. Thus, for researchers interested in having robust datasets, XRF presents a more cost-effective method.

XRF devices are also much more affordable than other analytical instruments. Though instrument costs will vary by manufacturer and model type, a brand new PXRF instrument will cost around $20,000 to $60,000. In comparison, an ICP-MS devise costs hundreds of thousands of dollars and an electron microprobe can cost over one million dollars. Instrumental maintenance can also be expensive. Generally, upkeep fees are correlated with the listing price for an instrument, meaning it is less expensive to maintain and repair an XRF device than other analytical instruments. The purchase and maintenance costs are undoubtedly passed onto sample fees in most analytical laboratories. Therefore, the affordability of XRF instruments is another reason why XRF analytical services are much lower than they are for other compositional analysis techniques.

Analytical Considerations of PXRF

The practical benefits of XRF have made it a commonly-used analytical tool for archaeological research. Unquestionably, it has been applied most successfully in the nondestructive analysis of chemically-homogenous obsidian artifacts for geographic provenance analyses (e.g., Acquafredda et al. 1999; Carter and Shackley 2006; Giauque et al. 1993; Jack and Heizer 1968; Shackley 2008). The recent proliferation of PXRF instruments has furthered the intensity of obsidian provenance studies in several regions (see Speakman and Shackley 2013 for a comprehensive bibliography). However, the use of PXRF for the nondestructive analysis of chemically-heterogeneous lithic material has been slow. Three factors contribute to this situation. First, the analytical sensitivity of portable instruments is only beginning to be on par with desktop models. Second, variable sample morphology, surface texture, and chemical composition can have detrimental effects on the reliability of nondestructive geochemical assays. Third, basalt formations and deposits generally exhibit substantial geochemical variability that can invalidate source provenance analyses. Recently, though, researchers have begun to address and mitigate these perceived limitations, thereby elevating the suitability of PXRF for Hohokam vesicular basalt provenance analyses. Both the analytical challenges and mitigative techniques of PXRF for this study are presented in the following sections.

Sensitivity

In archaeometry, the minimal amount of an elemental concentration that can be reliably measured given the experimental conditions is typically known as sensitivity (e.g., Bishop et al. 1982:289; Bishop et al. 1990:538). However, when discussing the parameters of technical instruments, analysts use the term "detection limit" in reference to the lowest concentration level that can be detected (Lachance and Claisse 1995:272; Markowicz 2008:19). In the latter context, sensitivity is actually the minimal concentration difference that yields an interpretable signal (Lachance and Claisse 1995:260). Although there is a slight technical difference between analytical sensitivity and detection limits, the former term as interpreted by archaeologists is used throughout the remainder of this text. This decision was made because of its more common usage in the archaeometric literature, which facilitates comparisons with other research.

XRF is regarded as a sufficiently sensitive analytical technique for most archaeological applications. The method is capable of detecting all naturally occurring elements from magnesium to uranium at concentrations as low as a few parts-per-million (Liritzis and Zacharias 2011). Additionally, it is particularly sensitive to the "mid-Z" elements, which includes those elements found on the periodic table between K (Z=19) and Mo (Z=42). This chemical group is significant because it encapsulates several trace elements (i.e., Rb, Sr, Y, Zr & Nb) that are particularly useful for discriminating geographically discrete igneous formations, including obsidian and basaltic outcrops

(Giauque et al. 1993; Latham et al. 1992; Philip and Williams-Thorpe 1993; Phillips and Speakman 2009; Skinner 2000a, 2000b, 2001; Shackley 2005, 2008; Watts et al. 2004; Weisler 1990, 1993, 1998; Weisler and Sinton 1997). Other destructive analytical techniques, such as NAA and ICP-MS, may offer greater analytical sensitivity than XRF (detection limits as low as a few parts-per-billion), but they are not as reliable as XRF in measuring some of these mid-Z "fingerprinting" elements (Glascock and Ferguson 2012; Glascock and Neff 2003; Shackley 2005:90). Therefore, the practical benefits and analytical sensitivity of XRF makes it an ideal geochemical technique for igneous provenance studies.

Although there is presently some skepticism about the analytical sensitivity of PXRF instruments, the truth is that they are comparable to or even better than their desktop brethren in the analysis of homogenous samples. Recent technological advances have improved the performance of XRF instruments (in both portable and desktop models) by reducing stochastic error emanating from a number of different sources (Forster et al. 2011:389). Speakman and Shackley (2013:1436) even remarked that most PXRF systems currently on the market have superior detector resolution than laboratory-based instruments that were manufactured 5-10 years ago, and that there is no reason to think the miniaturization of instrumental components is problematic. This statement is now empirically supported by a number of recent studies that have found comparable concentration data between laboratory and portable instruments (e.g., Craig et al. 2007;

Frahm 2013a; Guilheme et al. 2008; Liritzis and Zacharias 2011; Millhauser et al. 2011; Nazaroff et al. 2010; Phillips and Speakman 2009; Speakman and Shackley 2013; Vázquez et al. 2011). Thus, recently manufactured PXRF instruments are more than suitable for archaeological evaluations of material chemistry and, in most cases, geographic provenance analyses.

The Bruker Tracer III-V PXRF instrument employed in this study has also been found to be sufficiently sensitive for geochemical assays. The device features a user-configurable beam filter (composed of 304 μm of Al, 25 μm of Ti, and 152 μm of Cu) that blocks incident X-rays below 17 keV from reaching the sample, thus providing for more efficient excitation and detection of the mid-Z X-rays. In addition, the instrument's detector has a resolution of approximately 145 eV Full Width at Half Maximum for 5.9 keV X-rays in an area of 10 mm^2 (Speakman 2012). These two attributes enable the Bruker instrument to reliably record trace element concentrations in both compositionally homogenous and heterogeneous samples (Forster et al. 2011; Loendorf et al. 2013; Nazaroff et al. 2010; Phillips and Speakman 2009). Loendorf and others (2013), for instance, used the Bruker PXRF in the analysis of obsidian artifact and found that the instrument successfully recorded mid-Z elemental concentrations below 100 ppm. Likewise, Forster and others (2011) used the device to test the plausibility of nondestructive ceramic analyses. This study found that sample preparation had no significant impact on the instrument ability to measure mid-Z trace elements and that their results were comparable to those obtained by destructive NAA method. Thus, there is little question that the nondestructive PXRF is sufficiently sensitive to the elemental concentrations that are important for geological provenance research.

Reliability

Analytical reliability involves consideration of both precision and accuracy (Bernard 2011; Bishop et al. 1982; Bishop et al. 1990; Hughes 1998). In geochemistry, precision is concerned with the repeatability and stability of a measurement, or the control an analyst has over the method being employed (Bishop et al. 1982:289; Bishop et al. 1990:54; Hughes 1998:108). Accuracy is a statement of how close a measurement is to its actual value (Bishop et al. 1990:539). XRF has long been recognized as a precise and accurate method for characterizing the chemical composition of homogenous or homogenized geological samples (Bertin 1985; Bishop et al. 1982; Giauque et al. 1993; Jenkins 1999; Potts et al. 1984; Shackley 2005, 2008; Tykot 2003). However, nondestructive analysis of unprepared heterogeneous samples, such as basalt, is more complicated. Irregular sample morphology, coarse surface texture, variable mineralogy all have the potential to adversely affect the precision and accuracy of single-specimen geochemical measurements (Davis et al. 2011; Jenkins 1999; Lundblad et al. 2008; Lundblad et al. 2011; Potts et al. 1997).

Irregular sample morphology can affect analytical reliability because non-plane surfaces feature an air gap that serves to attenuate fluorescent X-rays (Davis et al. 2011; Forster et al. 2011; Potts et al. 1997). For instance, in an analysis of concave-shaped samples, Forster and colleagues (2011) found that roughly half (52%) of the fluorescent X-rays associated with the element Ca failed to reach the instrument's detector. Uneven sample morphology is further problematic because X-rays are not equally attenuated by air. Generally, fluorescent radiation from lighter elements cannot travel as far as heavier elements due to their lower energy potential and, as a result, are not as readily detected during XRF analysis (Davis et al. 2011; Forster et al. 2011; Lundblad et al. 2008, Lundblad et al. 2011). The disproportional representation of X-ray counts can result in an inaccurate representation of sample chemistry, which in turn has the potential to introduce false variation in large sample sets.

Textural irregularities, such as grooves or cavities, also have the potential to adversely affect the reliability of XRF. Much like a flat mirror reflects light-rays at a predictable angle, the primary trajectory of florescent X-rays can also be calculated based on the angle of the incident radiation. The primary direction of fluorescent radiation is known as the take-off angle. However, as X-rays travel away from their source, the radiation spreads out and its intensity weakens as it is diffused across a larger area. Thus, differences in surface texture diminish the dependability of chemical assays because they introduce variability in the penetration depth, take-off angle, and recorded intensity of the detected radiation (Davis et al. 2011; Markowicz 2008; Potts et al. 1997; Van Grieken and Markowicz 2002). The effects of surface irregularity on the reliability of XRF have been experimentally studied by Potts and colleagues (1997), who found that even a small (<2 mm) discrepancy in surface texture had a significant effect on measured X-rays, particular for low-energy low-Z elements. To mitigate the adverse effects of surface texture, X-ray tubes and detectors are set at specific angles relative to the sample stage, instruments are calibrated using flat references samples, and analysts tend to polish samples to a flat finish prior to analysis.

Uneven surface features can further decrease the reliability of XRF through a phenomenon known as the "shielding effect". In this process, relatively deep grooves or vugs can act to block or attenuate fluorescent radiation originating from within the sample matrix. For example, imagine that a characteristic X-ray photon escapes an irradiated specimen from the bottom of a dimple, only to reenter the sample through the upper wall of the same depression. The energy of this photon will likely be attenuated or absorbed completely by the renewed atomic interactions, thus resulting in a misrepresentation of radiation intensity and thus sample chemistry (Forster et al. 2011:393). Here again, lighter elements are disproportionally affected compared to heavier elements.

Complex mineralogy is the third major complicating factor in nondestructive analysis of heterogeneous samples (e.g., Johnson 2011; Latham et al. 1992; Lundblad et al. 2008; Lundblad et al. 2011; Markowicz 2008; Shackley 1994, 1995a, Skinner 2000a, 2000b, 2001). Basaltic rock is composed of variable distributions of plagioclase feldspar, pyroxene, and olivine group minerals (Brown 1967). These minerals may be fine-grained and hidden to the naked eye within the lithic matrix, or can occur as large macroscopic crystals (i.e., phenocrysts). The presence of multiple mineral types and sizes in a single specimen can reduce the reliability of nondestructive XRF analyses because each assay records a unique collection of these minerals, resulting in an inaccurate portrayal of the sample's bulk chemistry. Variable mineralogy also affects analytical precision since differently placed assays are likely to yield inconsistent measurements between different readings. Additionally, if a mineralogically heterogeneous sample is not homogenized prior to analysis, then denser particles within the sample matrix have the potential to attenuate or block fluorescent X-rays from escaping the sample, thereby resulting in an improper representation of sample chemistry (Jenkins 1999:145).

The negative impact of variable mineralogy on nondestructive XRF is perhaps augmented by the design characteristics of portable instruments. Compared to most desktop models, PXRF instruments have relatively small analytical windows. The Bruker Tracer III-V, for instance, has an ellipsoid window that is only 7.0 square millimeters. Most desktop models are by comparison at least 50 times as large (Jenkins 1999:142). A smaller analytical window greatly diminishes the chance that the area assayed adequately represents the overall chemistry of the sample. Moreover, due to a phenomenon known as the penumbra effect, those elements that are located within the center of the analytical window will contribute more fluorescence signal than those at the periphery (Forster et al. 2011). Thus, again, there is a distortion of sample chemistry that in turn reduces the analytical reliability of nondestructive XRF analyses.

The limitations imposed by uneven sample morphology, coarse surface texture, and variable mineralogy have traditionally necessitated the use of destructive sample preparation techniques for reliable XRF analyses. Commonly employed modifications include polishing sample surfaces, grinding samples into a fine powder and then compressing the residue into pellets, or fusing powdered material with a glass forming material to preserve chemical homogeneity (Jenkins 1999:142). However, the destruction of cultural materials is not a practical option for archaeologists. The predicament between analytical needs and practicality has in some cases negated the adoption of XRF for archaeological provenance analyses of non-glass materials (see Shackley 2008). In fact, it is one of primary reasons for the underdevelopment of Hohokam vesicular basalt groundstone provenance studies.

In a recent effort to expand the analytical capabilities of XRF for archaeological research, a number of scholars have investigated ways to increase the reliability of nondestructive analyses (e.g., Forster et al. 2011; Grave et al. 2012; Johnson 2011; Lundblad et al. 2008; Lundblad et al. 2011; Markowicz 2008; Mintmier et al. 2012; Mills et al. 2008; Potts et al. 1997; Potts and West 2008). One study that is particularly relevant is that of Forster and colleagues (2011). These researchers investigated the impact that variable surface texture and morphology have on the precision of PXRF measurements. As expected, their study found that several different sample textures and shapes can negatively affect X-ray yield and detection. In somewhat of surprise, though, they also found that these sample attributes had no significant impact on the consistent measurement of mid-Z elements. Forster and the others (2011:393) inferred from these observations that that the majority of mid-Z X-rays have sufficient energy to escape primary and potential secondary matrix attenuation, and extend through possible air gaps before reaching the detector. Thus, it was concluded that while nondestructive PXRF may not be able to reliably record all elements, it is sufficient for measuring the mid-Z elements that are important for archaeological provenance analyses.

In the same study, Forster and others (2011) also assessed the impact of variable mineralogy on the accuracy of nondestructive PXRF. The researchers analyzed several different material types and found that mineral size and variability do negatively affect analytical accuracy. However, they also found that measurement accuracy could be improved if multiple measurements on the same sample were averaged together. To illustrate this point, the authors performed ten replicate assays on rock types of differing grain size and mineralogy and then used the results to calculate the number of analyses needed to achieve sufficient accuracy (<10% Standard Error). The results of their efforts found that between one and five differently placed assays were required to achieve a standard measurement of the mid-Z elements in fine-grained materials (e.g. Clay and Basalt) and that anywhere from 5 to 17 assays were needed for the analysis of medium to coarse grained material (e.g., granite, diorite; Forster et al. 2011:394). Thus, there is a practical means for mitigating the negative impact of variable composition on nondestructive PXRF analyses.

A second study worthy of mention is that of Lundblad and others (2011; see also Lundblad et al. 2008). These researchers assessed the potential of nondestructive XRF for fine-grained basalt provenance analyses by evaluating the impact of surface texture and sample composition on analytical reliability. In the first part of their study, they examined the effects of surface morphology and texture by comparing measurement results for hundreds of flat-cut and irregular-shaped lithic samples from the same basalt quarry. In the second part, which examined the effects of heterogeneous sample composition, the researchers analyzed ten vesicular basalt specimens whole and then once more after they had been converted into pressed pellet samples. The first test observed greater measurement variation among the unprepared samples, but found no substantial difference in the average elemental compositions between the two groups for the mid-Z elements (see Table 4.4 in Lundblad et al. 2011:75). The second test again revealed that there was greater measurement variation among the unprepared samples, but that there was no statistically significant difference in the concentration value for the mid-Z elements when multiple measurements were averaged together (see Table 4.5 in

Lundblad et al. 2011:76). From these two results, the researchers concluded that irregular surface textures and sample morphology may increase measurement uncertainty, but that the accuracy is not significantly altered if multiple measurements from the same specimen or sample group are averaged together (Lundblad et al. 2011:77).

Together, the studies by Forster and others (2011) and Lundblad and others (2011) have extensively examined two factors critical to the reliability of nondestructive PXRF. First, surface morphology, irregular texture, and variable mineralogy have no meaningful impact on the detection of the mid-Z elements that are important for archaeological sourcing studies. Second, an accurate characterization of the mid-Z elements can be ascertained for single specimens or sample groups if multiple differently placed assays are taken on each sample and the results are subsequently averaged together. Thus, nondestructive PXRF is a potentially reliable tool for archaeological sourcing studies if certain analytical procedures are employed. Based on this understanding, one of the primary goals of this study was to develop an efficient data collection protocol for the reliable measurement of single-sample chemistry.

Validity

Analytical validity concerns the extent to which measurement units are suited to the goals of the research (Hughes 1998:109). For the purpose of an archaeological provenance study, a technique is considered valid if 1) it can be used to identify geochemical variation among spatially-discrete geological deposits; and 2) if artifact chemistry can be confidently linked to these constructed geochemical groupings (Hughes 1998; Neff 1998, 2002; Neff and Glowacki 2002; Weigand et al. 1977). Hence, the first component of validity involves satisfying the Provenance Postulate, which states that a technique must be able to identify some qualitative or quantitative difference among spatially-distinct units that exceeds in some manner variation within units (Weigand et al. 1977:24). The second aspect of validity is related to the specific task of sourcing. Sourcing entails determining the geographic origin for a cultural artifact by matching its geochemical composition to that observed for a well characterized, natural geological unit (Frahm 2013a, 2013b; Hughes 1998; Neff 2002; Neff and Glowacki 2002; Shackley 2008).

The validity of nondestructive PXRF for Hohokam groundstone sourcing studies is potentially complicated by the natural properties of basaltic formations. Basalt outcrops are often created by expansive and long-term mafic eruptions. Different rates of flow and variable exposures to external elements can lead to different mineralogical, chemical, and textural properties across a single flow, but subtle variation among nearby flows (Brown 1967; MacDonald 1967). Long-term evolution in magma chambers can also lead to considerable geochemical variation within a single source area (e.g., Clague and Dalrymple 1987; Leighty 1997; Weisler 1993, 1998; Weisler and Sinton 1997). A striking example of this intra-source geochemical variability occurs in the Deem Hills of the Salt-Gila Basin, where the southern half of the geological unit consists of Sr-rich basalt associated with the Hedgpeth Formation, while the northern half contains Sr-poor Hickey Basalt (Jagiello 1987; Leighty and Huckleberry 1998). The complex geochemical patterning associated with basalt formations has impeded the rapid and widespread adoption of lithic provenance studies in many parts of the world (e.g., Latham et al. 1992; Greenough et al. 2001; Jones et al. 1997; Lundblad et al. 2008; Watts et al. 2004; Weisler 1997; Williams-Thorpe and Thorpe 1993; Williams-Thorpe et al. 1991).

However, in contrast to these expectations, previous characterizations of basaltic formations in the Salt-Gila Basin have shown distinct geochemical differences. The most comprehensive analysis of volcanic formations in the region was completed by Leighty (1997) as part of his dissertation research. His investigation found appreciable geochemical variation between temporally distinct formations and flow fields, which he then used to help reconstruct the structural and magmatic evolution of southern Arizona. Leighty's research is relevant to the current study because it establishes that there is some degree of geochemical variability among the basaltic outcrops in the Hohokam core territory. However, because the focus of his research was geological and not archaeological, his analysis did not seek to systematically evaluate major and trace element variability among spatially discrete basaltic formations in the Salt-Gila Basin. Thus, his research provides no specific findings that can be used to characterize material source areas or determine the origin of basaltic artifacts.

Previous Hohokam groundstone material provenance studies have found evidence of geochemical variation among the spatially-discrete basaltic formations. As discussed in Chapter 2, analysis of raw material from at least six known sources, including Lone Butte, Hedgpeth Hills, and the Adobe, McDowell, Moon, and West Wing Mountains did identify consistent geochemical differences among these source areas (Shackley 1994, 1995a, Skinner 2000a, 2000b, 2001). For example, the mid-Z elements of Rb, Ti, and Ni were found to exhibit different concentration levels among the McDowell Mountain, Moon Hills, and West Wing Mountain (McQuestion Quarry) quarries (Shackley 1994, 1995a). Bivariate plots of Rb and Sr could also be used to characterize and separate material from Adobe Mountain, Lone Butte, and the Hedgpeth Hills (Skinner 2000a, 2000b, 2001). Although these studies show some promise, analysts are currently unable to match artifact chemistry to any source area due to an insufficient understanding of the geochemical variability among the region's basaltic formations. Thus, in order to fulfill the Provenience Postulate and allow material sourcing analyses, a much more comprehensive understanding of regional basalt chemistry must first be ascertained.

Evaluation of Analytical Methodology

PXRF confers very practical advantages for Hohokam vesicular basalt provenance analysis. However, the analytical technique is not ideally suited for the nondestructive analysis of heterogeneous materials due to the adverse effect of variable sample morphology, texture, and composition on measurement reliability. The validity of PXRF for Hohokam groundstone material provenance analyses is also not well understood due to a limited knowledge of basalt geochemistry in the Salt-Gila Basin. Aware of these issues, this research study undertook three preliminary experiments to evaluate and improve the reliability of PXRF for Hohokam vesicular basalt provenance analyses. In particular, the aim of these experiments was to determine 1) the minimal analysis time required to yield a consistent geochemical measurement; 2) the minimum number of differently placed assays needed to produce a consistent characterization of single-sample chemistry; and 3) whether the minimum analysis requirements generated accurate geochemical data useful for vesicular basalt provenance analyses. The results of these three experiments were used to form an efficient and reliable data collection procedure for nondestructive analysis of the unmodified vesicular basalt material. The new data collection method was then employed to analyze the raw material sample and evaluate the Provenance Postulate. This final evaluation would determine whether nondestructive PXRF is a valid approach for Hohokam sourcing studies.

Evaluating Reliability

Objectives

The reliability of nondestructive PXRF for vesicular basalt provenance analyses was assessed by conducting three experiments. The objective of the first experiment was to identify the minimal assay time necessary to produce a sufficiently precise measurement of sample geochemistry. Measurement precision is in part a product of analysis time. Simply, the longer the assay, the more fluorescent radiation there is. Increased fluorescence in turn translates to improved precision because larger X-ray count samples act to better represent specimen chemistry than smaller ones (Jenkins 1999; Lachance and Claisse 1995; Williams-Thorpe 2008:178). Thus, the first step in assessing the reliability of nondestructive XRF involves identifying the minimal amount of analysis time required to produce a consistent geochemical measurement on an unprepared specimen of vesicular basalt.

Measurement precision also concerns the consistency of separate assays on the same sample. Again, uneven sample morphology, coarse surface texture, and variable mineralogy can negatively influence the reliability of nondestructive PXRF by altering the emission and detection of fluorescence X-rays (Davis et al. 2011; Forster et al. 2011; Lundblad et al. 2008; Lundblad et al. 2011; Markowicz 2008; Potts et al. 1997; Williams-Thorpe 2008). However, recent research demonstrates that invariable representation of sample chemistry can be produced if multiple assays are taken at different locations on a single specimen and then averaged together (e.g., Forster et al. 2011; Grave et al. 2012; Potts et al. 1997; Markowicz 2008). The number of analyses required differs for each material type and element of interest. A second experiment, therefore, was conducted to determine the minimum number of differently-located assays necessary to achieve an invariable measurement of sample geochemistry.

The third experiment sought to determine if the minimal assay time and number identified in the first two experiments could be used to generate geochemical data that are sufficiently accurate for geographic provenance analyses. Recently, analytical accuracy has been a contentious issue in archaeological provenance analysis (see Frahm 2013a, 2013b; Frahm and Doonan 2014; Shackley 2010; Speakman and Shackley 2013). At the heart of this debate is whether the goal of compositional analysis in archaeology is to generate objective, replicable, and inter-laboratory geochemical data or, alternatively, simply valid geographic provenance assignments for artifacts. The ability of nondestructive PXRF to accurately assess the geographic provenance of vesicular basalt groundstone artifacts is beyond the scope of the current experiment since the Provenance Postulate (Weigand et al. 1997) has not yet been evaluated for Hohokam groundstone sourcing studies. Indeed, the very purpose of this study is to develop an efficient and reliable technique capable of generating the large dataset that is necessary to even evaluate the Provenance Postulate. Thus, the accuracy of the nondestructive method was evaluated by comparing its geochemical measurements with data produced by other laboratories that used a destructive methodology and desktop XRF (Shackley 1994, 1995a; Skinner 2000a, 2000b, Shackley 2001).

Data Collection

All geochemical assays for the three experiments were conducted by the GRIC Materials Science Laboratory (MSL) using a Bruker Tracer III-V portable XRF spectrometer. The instrument was set to operate at 40keV and 12 µA using an external power supply. Additionally, a beam filter composed of 304 µm of aluminum, 25 µm of titanium, and 152 µm of copper was placed between the tube and the sample. This configuration provides efficient detection of several mid-Z elements (defined as those elements on the periodic table between Potassium [Z=19] and Molybdenum [Z=42]) commonly used in provenance studies of igneous rocks (Shackley 2005, 2011), and whose fluorescence radiation is energetic enough to not be significantly affected by physical and chemical matrix effects (Forster et al. 2011:393).

Following data collection, the x-ray count data were normalized using the inelastic (i.e., Compton) peak of the rhodium backscatter at 18.2–19.2 keV. This procedure helps to control for irregularities in sample morphology, density, and slight variance in the x-ray beam intensity (Feather and Willis 1976; Lachance and Claisse 1995:184; Willis 1989). The normalized counts for 14 mid-Z and high-Z fingerprinting elements (K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Ba) were then converted to elemental concentration data (parts-per-million [ppm]) using an empirical calibration developed from the analysis of seven different pressed-pellet reference standards with compositions similar to basaltic rock (AGV-2, BCR-2, BHVO-2, BIR-1, DNC-1, SRM-

278, and W-2). The calibration coefficient for each element was computed using Lucas Tooth and Pyne linear regression equations, a robust approach for quantifying sample chemistry because it takes into account X-ray absorption and enhancement effects (Lachance and Claisse 1995:166; Markowicz 2008; Potts et al. 1997:35).

<u>Experiment 1 – Minimum Analysis Time</u>

The objective of the first experiment was to determine the minimum analysis time necessary to achieve a precise geochemical measurement for a single location. In this effort, three different vesicular basalt samples were analyzed ten times in exactly the same spot at ten different time intervals (15, 30, 45, 60, 90, 120, 180, 240, 300 & 360 seconds). A pressed pellet of basaltic rock (USGS references standard BHVO-2) was also analyzed in the same manner for comparative purposes. The three raw material samples are from the Hedgpeth Hills, a well known source of groundstone material in the Hohokam cultural area (Bruder 1983a, 1983b). Samples from this source were selected because the material contains several macroscopic mineral inclusions, which have the potential to affect analytical precision. Thus, these samples were considered a “worst case” scenario for evaluating the precision of nondestructive assays. Analytical precision was considered to have been achieved when the chemical measurements for the 15 elements of interest exhibited a standard deviation of 10 percent or less from the mean.

The repeated analysis of vesicular basalt raw material and one pressed-pellet BHVO-2 reference standard at different time intervals revealed a continual decrease in the average standard deviation for the measured elements as the length of the assay increased from 15 to 360 seconds (Figure 6.6). The average standard deviation for both the prepared and unprepared specimens fell below 10.0 percent of the mean by the 90 second mark, after which there is only slight improvement in analytical precision until 180 seconds of analysis time, when the relative standard deviation flattens out around 5.0 percent. These results suggest that a sufficient degree of analytical precision can be ascertained in nondestructive analysis after 90 seconds of analysis time, and that there is no significant improvement in measurement stability after 180 seconds. Furthermore, there is no difference in the precision of nondestructive and destructive analyses. From these observations, it was determined that 120 seconds of analysis time, which represents the midpoint between 90 and 180 seconds in the experiment, is sufficient for achieving a stable measurement of sample geochemistry in unprepared, heterogeneous samples.

A more detailed examination of the data further justifies the use of 120-second exposures. It is well understood that longer analysis times are needed to reliably record trace-element concentrations compared to major or even minor concentrations (Jenkins 1999; Lachance and Claisse 1995; Speakman 2012). This phenomenon was observed in the current trial. For example, a precise measurement of Fe, which totals over 8,600 ppm in BHVO-2, is achieved after just 15 seconds of analyses time. In comparison, it takes

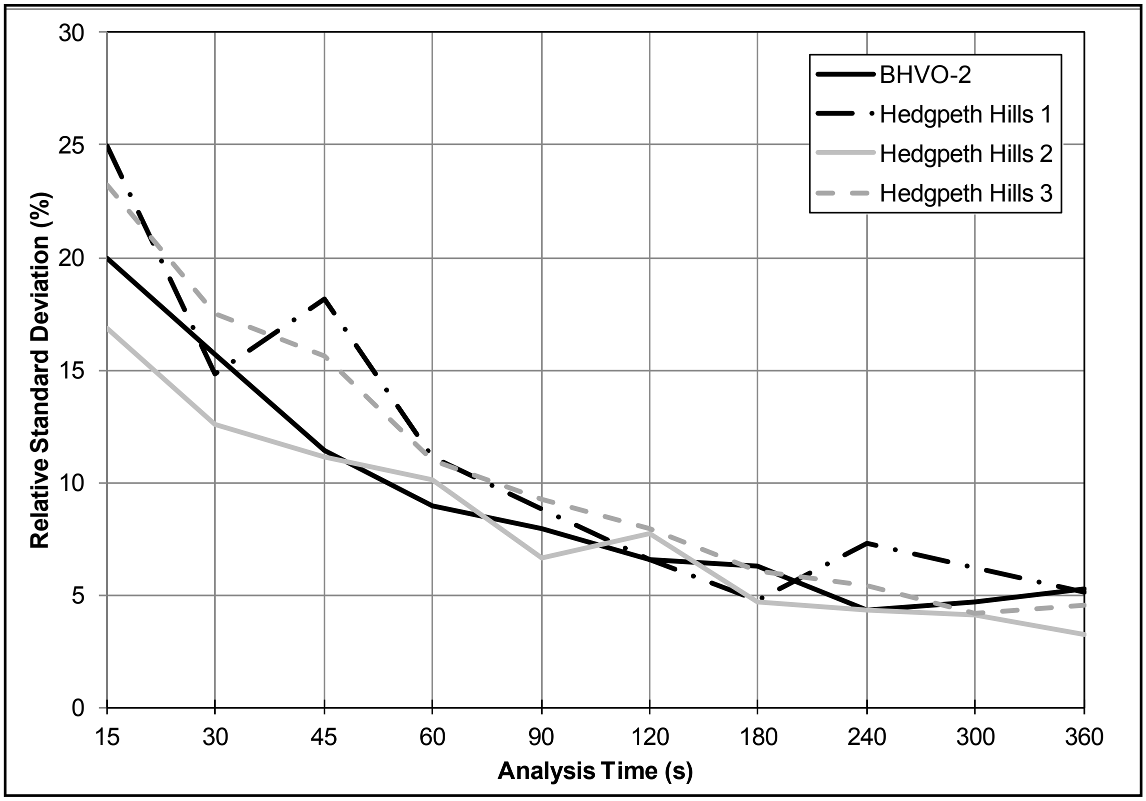

Figure 6.6. Relative Standard Deviation of Nondestructive and Destructive PXRF Analysis Versus Length of Assay.

120 seconds to achieve measurement stability for Nb at 18 ppm, and more than 180 seconds for Rb at 10 ppm (Table 6.3). However, efficiency of single assays is a concern for this study because it is also recognized that the analysis of chemically-heterogeneous samples requires multiple differently-placed assays (Forster et al. 2011; Grave et al. 2012; Potts et al. 1997, 2008). With this in mind, the slight improvement in measurement precision after the 120 second mark is not worth the additional analysis time for trace-element concentrations since a 1-5 percent improvement in measurement error at this

Table 6.3. Relationship Between Analytical Time and Measurement Stability (Relative Standard Deviation [%]) in USGS BHVO-2 Pressed-Powdered Pellet

		Analysis Time (s)									
Element	**Conc.**	**15**	**30**	**45**	**60**	**90**	**120**	**180**	**240**	**300**	**360**
K	4300	19.3	14.6	11.6	10.7	8.8	7.5	6.0	3.5	2.9	3.3
Ca	81700	11.9	14.3	8.8	5.8	3.8	3.0	3.9	1.9	2.8	2.6
Ti	16300	21.0	9.2	7.9	7.2	7.4	6.2	6.2	3.5	2.6	3.8
Mn	1290	22.3	17.5	12.0	11.7	6.7	6.7	6.3	4.7	5.6	4.9
Fe	86032	10.5	12.5	6.2	3.9	4.9	3.2	2.5	1.7	1.9	1.6
Ni	120	31.2	23.8	20.2	5.9	8.6	10.6	7.5	3.9	7.4	4.9
Cu	127	23.6	17.7	12.2	12.6	9.0	8.8	8.4	8.3	3.3	4.2
Zn	103	19.9	12.8	10.2	15.1	13.1	7.9	8.8	6.8	9.0	4.0
Rb	10	31.4	28.0	23.4	19.0	10.7	6.6	13.8	9.3	11.8	5.5
Sr	389	8.9	9.0	5.1	2.7	5.1	5.0	3.9	2.7	2.4	1.5
Y	26	29.1	16.8	15.4	12.5	10.2	12.4	7.8	4.8	6.8	2.8
Zr	172	9.7	10.5	7.9	5.2	8.0	4.5	4.0	2.9	2.6	3.1
Nb	18	28.8	21.1	12.7	9.1	8.8	5.1	6.1	5.3	4.5	2.3
Ba	130	11.7	11.4	6.3	3.9	6.1	4.4	2.9	1.4	1.8	1.7
Column Mean		19.9	15.7	11.4	8.9	7.9	6.6	6.3	4.3	4.7	3.3

scale translates to only a few parts-per-million, a degree of error that is unlikely to compromise the interpretation of artifact provenance. Thus, it was deemed that 120 seconds of analysis time is sufficient for achieving a stable geochemical measurement of unprepared and chemically-homogenous vesicular basalt samples.

Experiment 2 – Minimum Number of Assays

The aim of the second experiment was to determine the minimum number of differently-placed assays necessary to yield a stable geochemical measurement. For this task, five vesicular basalt specimens from the Hedgpeth Hills basalt quarry were subjected to ten differently located assays. Material from this source area, again, was ideal for the analysis because it contains several large mineral inclusions that have the potential to adversely affect analytical reliability. Once data collection was completed, the mean and standard deviation (SD) of the ten measurements were calculated, from which the minimum number of assays (n) needed to achieve an accurate representation of sample chemistry with a 95 percent confidence rate could be computed using the equation [$n = ((SD*1.96) / (ER))^2$]; where ER (Error Range) is equal to 0.10 of the mean (Drennen 1996:132; Markowicz 2008:27).

The results of the second experiment indicated that no less than six differently placed assays are required to achieve a sufficiently precise (<10% ER) characterization of sample geochemistry. In using the mean and standard deviation for the ten differently-placed geochemical measurements from a single specimen, the minimum number of assays needed to achieve a steady representation of sample chemistry with a 95 percent confidence rate was calculated to be just 5.1 (Table 6.4). Specifically, eleven elements (K, Ti, Mn, Ni, Cu, Zn, Sr, Y, Zr, Nb, Ba) required less than six assays, while only three elements (Ca, Fe, and Rb) required more. Similar to single-spot assays, better precision can be achieved if more assays are performed. However, the efficiency of XRF as an analytical technique is reduced by the addition of even just one more assay. Therefore, it was decided that obtaining a measurement within 10 percent of the statistical mean after just six differently-located 120-second assays was sufficient within the context of sourcing studies.

<u>Experiment 3 – Accuracy of Minimum Time and Assay Method</u>

In the third and final experiment, the results of the six differently-placed 120-second assay method was evaluated for analytical accuracy. This evaluation process involved verifying that the mean elemental concentration values obtained using the new data collection procedures were consistent with previously reported values generated using destructive, laboratory XRF. The former data group consisted of 120 samples from four source areas (Adobe Mountain, Hedgpeth Hills, Lone Butte, and West Wing Mountain). The latter sample was generated by the Northwest Research Obsidian Studies Laboratory (NWL), who previously completed a destructive geochemical analysis of 20

Table 6.4. Measurement Statistics for Ten Differently-Placed Nondestructive PXRF Assays on Five Different Vesicular Basalt Samples

Sample	K	Ca	Ti	Mn	Fe	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	Group Mean
							Mean								
HP1	12544	34307	3796	712	33851	63	96	72	26	537	7	146	11	899	
HP2	14627	31371	3698	666	30627	50	99	70	34	566	5	149	10	899	
HP3	14957	33663	3629	717	34486	59	87	72	37	529	10	155	11	915	
HP4	13123	34385	3564	685	31846	60	89	72	30	547	7	146	10	930	
HP5	14941	33671	3811	636	30498	48	71	72	37	545	18	161	11	985	
							Standard Deviation								
HP1	27.8	43.0	15.7	8.5	549.8	7.4	8.4	7.8	19.9	123.3	13.0	68.8	7.5	153.2	
HP2	21.3	211.0	21.2	23.9	1055.9	9.1	7.9	8.7	12.4	123.8	11.1	56.7	7.7	68.9	
HP3	15.3	29.0	9.6	7.3	312.2	5.7	7.2	14.3	15.3	357.9	12.6	80.8	6.2	115.1	
HP4	19.5	34.8	14.9	11.4	792.7	8.8	8.5	10.2	26.6	390.3	16.1	147.2	9.6	62.6	
HP5	21.0	56.8	27.5	15.5	1231.7	8.5	10.2	7.2	33.3	283.0	22.5	141.5	13.0	183.6	
Mean	21.0	74.9	17.8	13.3	788.5	7.9	8.5	9.7	21.5	255.7	15.1	99.0	8.8	116.7	
							N for 10% RSE w/ 95% Confidence								
HP1	2.6	5.0	2.7	2.5	7.3	1.7	2.7	2.0	7.5	1.0	2.9	1.3	1.1	1.0	
HP2	1.3	40.0	2.1	6.7	4.2	1.4	1.6	2.0	28.4	5.2	3.6	3.4	2.0	0.3	
HP3	0.7	2.3	1.1	2.2	2.7	1.0	2.2	5.0	2.6	10.1	2.5	1.8	0.7	0.6	
HP4	1.1	3.4	2.4	5.5	14.2	2.7	3.3	3.4	7.7	9.9	4.1	5.5	1.7	0.2	
HP5	1.3	7.6	8.8	9.9	40.1	2.3	4.6	2.0	14.6	4.3	9.0	5.3	3.7	1.5	**Group Mean**
Mean	1.4	11.7	3.4	5.4	13.7	1.8	2.9	2.9	12.2	6.1	4.4	3.5	1.8	0.7	5.1

vesicular basalt samples from the same four source areas (Skinner 2000a, 2000b, 2001). Though the samples in both sample groups are similar chemically, the nondestructive data collection procedure is not expected to be perfectly accurate. This expectation stems from the fact that samples in the earlier study were sawn flat with a lapidary trim saw, meaning the two groups differ in morphology, surface texture, and probably particle size. Thus, a certain degree of inaccuracy is expected between the values for the modified and unmodified sample groups. The important question, then, is not whether the newly produced geochemical data conform to values previously ascertained using the destructive method, but whether any predictable or systematic discrepancies in the nondestructive data exist. If so, the PXRF calibration program can be adjusted to output more accurate measurements by using correction coefficients generated through linear regression analysis (Neff 2001).

Comparison of elemental concentration data between the previous and current sample sets found that the nondestructive method employed in this study was consistent (as demonstrated above), but slightly inaccurate (Figures 6.7 and 6.8). Figure 6.7 exemplifies this situation. This figure is a bivariate plot of the elemental concentrations Rb and Sr from the two sample groups. As is evident in the graph, the nondestructive method and calibration program yielded consistently lower concentrations. This observation indicates that the six replicate assays produced stable geochemical measurements, but that the empirical calibration program consistently underestimated elemental concentration data among the unprepared sample groups. This undesirable

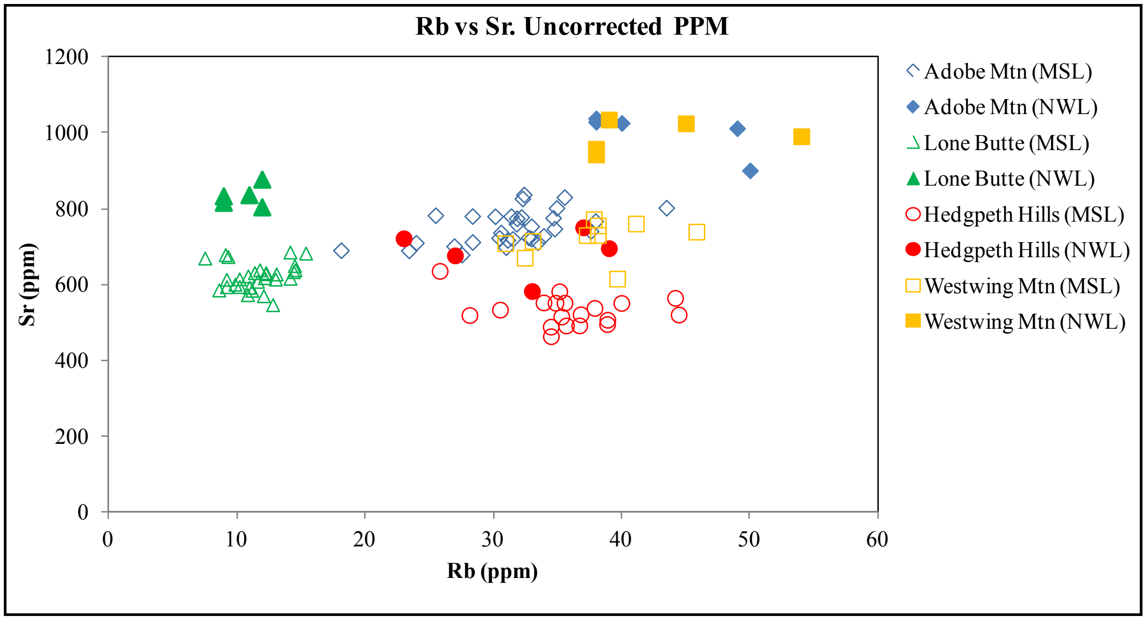

Figure 6.7. Rb and Sr Elemental Concentration Data for Destructive (NWL) and Nondestructive (MSL) PXRF Analyses before Calibration Correction Procedure.

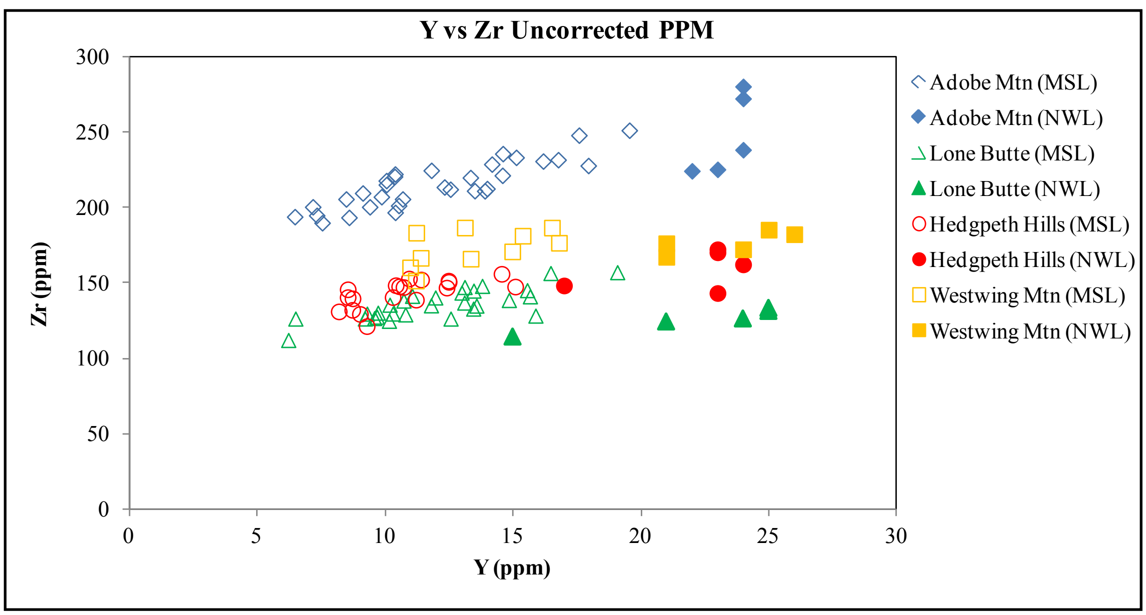

Figure 6.8. Y and Zr Elemental Concentration Data for Destructive (NWL) and Nondestructive (MSL) PXRF Analyses before Calibration Correction Procedure.

tendency is inferred to be the result of increased X-ray attenuation inherent in the nondestructive analysis of unprepared specimens (Jenkins 1999; Markowicz 2008; Potts et al. 1997).

To compensate for the increased X-ray attenuation and corresponding lower elemental concentrations, an additional correction coefficient was incorporated into the empirical calibration program. This adjustment was permissible because the calculated elemental concentrations for the unprepared samples exhibit consistent and predicable differences from the "true" measurements (Neff 2001:121). The correction coefficient was developed from a series of linear regression analyses for comparable elements between the two sample groups (Fe, Rb, Sr, Y, Zr, Nb). In the case of Sr, for example, the newly-developed data collection procedure was underreporting concentration values by about 150-300 ppm (see Figure 6.7). By producing a scatter plot for all of the Sr values produced using the destructive (Y-axis) and nondestructive methods (X-axis), it was possible to calculate the typical deviation between paired X and Y data points. Additionally, a software program (Microsoft Excel) was used to ascertain (through linear regression analysis) a liner slope equation (Y=bX+a) useful for making the X values more consistent with the Y values.

Application of the linear slope equations successfully corrected the elemental concentrations generated using nondestructive PXRF. Examination of Figures 6.9 and 6.10 shows that there is now considerable agreement in the elemental data between the two sample groups, with specimens from the previous and current analyses overlapping

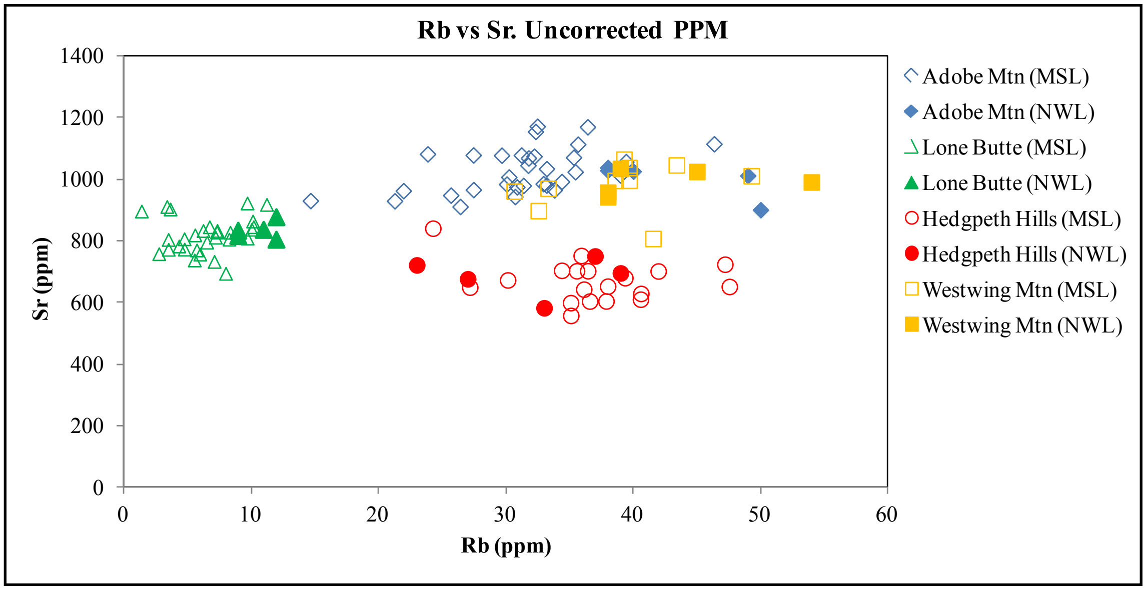

Figure 6.9. Rb and Sr Elemental Concentration Data for Destructive (NWL) and Nondestructive (MSL) PXRF Analyses after Calibration Correction Procedure.

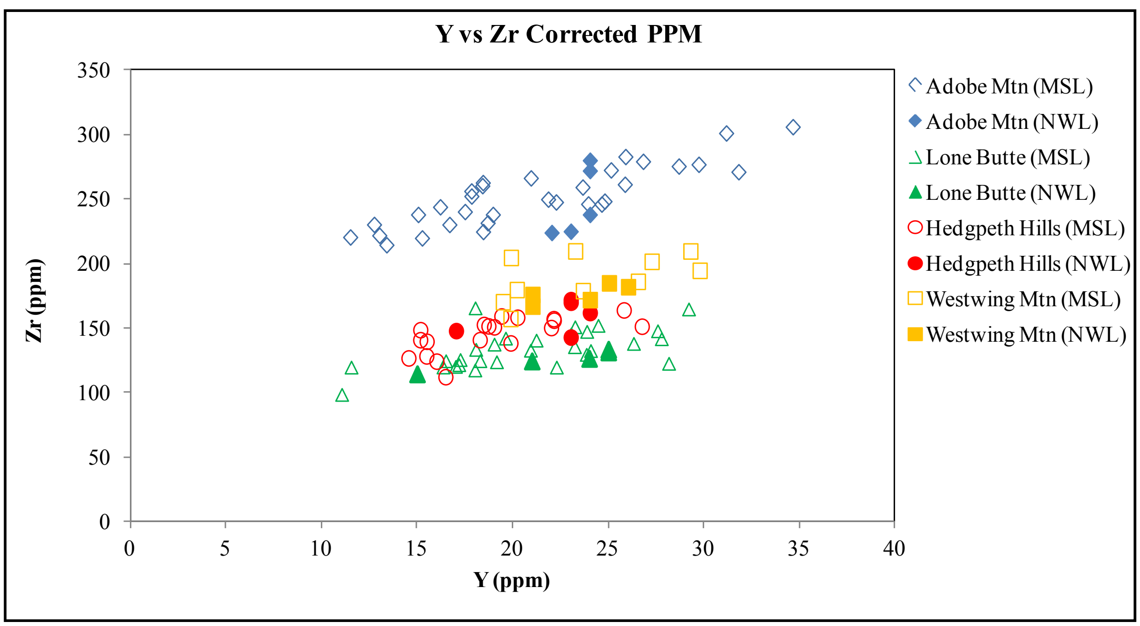

Figure 6.10. Y and Zr Elemental Concentration Data for Destructive (NWL) and Nondestructive (MSL) PXRF Analyses after Calibration Correction Procedure.

on the bivariate plots. Notably, corrections were only applied to some of the elements (Fe, Rb, Sr, Y, Zr, Nb). The procedure was not applied to other mid-Z elements (e.g., Ti, Mn, Ni, Cu, Zn) due to insufficient data. Although correction of these elements is not imperative for the current research owing to the precision of the nondestructive method, future destructive analyses should be undertaken to develop correction coefficients for these elements as well.

Evaluating Validity

Objectives

A technique is considered valid for geographic provenance studies if it can identify predictable geochemical variation among archaeological relevant spatially-discrete source areas, and if artifact composition can be confidently linked to these varieties (Hughes 1998; Neff 2002; Neff and Glowacki 2002; Weigand et al. 1977). The first component of validity thus involves satisfying the Provenance Postulate (Weigand et al. 1977), while the second is related to the specific task of sourcing artifacts (Shackley 2008). For this study, the Provenance Postulate was assessed by evaluating the raw material sample (n=738) for predictable inter-group geochemical variation. The sourcing potential of nondestructive PXRF for vesicular basalt provenance analyses was evaluated by determining if the majority of artifacts could be confidently matched with one of the represented source groups in the raw material sample. The following discussion presents evidence demonstrating that both conditions were satisfied, thereby validating the use of nondestructive PXRF for Hohokam vesicular basalt studies in the Salt-Gila Basin.

Data Collection

Based on the results presented earlier, all specimens were analyzed for a 120-second live-time count in six different locations using the aforementioned instrumental settings. X-ray count data were normalized to the inelastic (i.e., Compton) peak of the Rh backscatter to help control for irregularities in sample morphology, texture, density, and slight variance in the x-ray beam intensity (Feather and Willis 1976; Lachance and Claisse 1995:184; Willis 1989). The normalized counts for the 15 mid-Z and high-Z fingerprinting elements (K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, BP, Rb, Sr, Y, Zr, Nb, Ba) were then converted to elemental concentration data (ppm) using the Lucas Tooth and Pyne calibration program and the newly created correction curve that accounts for X-ray attenuation in nondestructive sample analysis (Lachance and Claisse 1995:166; Potts et al. 1997:35).

Data Analysis

Data analysis involved an assessment of the Provenance Postulate and also the success rate of artifact provenance classifications. Evaluation of the Provenance Postulate entailed two separate analyses of raw material geochemical data. First, the data for each source area were investigated for intra-group variability. This assessment was conducted because at least five characteristic basalt formations are present among the bedrock outcrops of the Hohokam region (Leighty 1997; Jagiello 1987; Richard et al. 2000). In some places, geological processes related to the Basin and Range Disturbance caused bedrock formations to tilt in such a manner that they now exhibit basalt from two different flow events (e.g., Deem Hills and Hedgpeth Hills). In other places, the bedrock tilting combined with subsequent erosion has caused material from separate flows to become mixed together in talus fields (e.g., Ludden Mountain). Intra-source geochemical variability, when not accounted for, has the capacity to obfuscate provenance determinations for artifact samples. Therefore, before evaluating the Provenance Postulate, the geochemical data for each sampled source area were examined for distinct geochemical subgroups (and outliers). This effort was completed using a combination of bivariate plots and hierarchical cluster analyses of all elemental concentration data collected during PXRF analysis.

The second evaluation of the raw material data involved an assessment of inter-group geochemical variability, the essence of the Provenance Postulate. This study attempted several multivariate techniques (i.e., bivariate plots, principal components analysis, canonical discriminant analysis, and hierarchal and nonhierarchical cluster analysis) to find the most optimal means for discriminating the raw material source groups. This exploration process revealed that Canonical Discriminant Analysis (CDA) performed the best in discriminating source (and subsource) groups. This multivariate classification technique is effective because it seeks variables (i.e., elemental concentrations) in the dataset that help to maximize inter-group variation while also minimizing intra-group variation. It then uses this information to develop a mathematical equation that optimally discriminates cases from known reference groups (i.e., raw material source area samples) and, more importantly, predicts group membership for unclassified cases (i.e., artifact samples) (Baxter 1994a, 1994b).

The variables used in the CDA to help define group membership for source samples (and later artifacts) included the log10 PPM values for K, Ti, Ni, Zn, Rb, Sr, Y, Zr, Nb, and Ba. These ten elements were selected because box-and-whisker plots and analysis of variance (ANOVA) tests indicate that they exhibit relatively minor intra-source variation and moderate to major inter-source variation. The log10 transformation was employed to help create a normal distribution for the elemental concentration data, reduce the affect of larger variables (i.e., concentration data) in pattern recognition procedures, and also effectively eliminate violations of correlations between group mean and variance (Drennen 1996:60; Glascock et al. 1998; Neff 2002:17). The strength of the CDA was further evaluated by conducting a parallel “jackknifing” or “leave-one-out” classification. This classificatory procedure omits specimens on a case-by-case basis prior to the calculation of group-membership and, therefore, serves as a blind check on the ability of the CDA to separate groups and predict group memberships (Baxter 1994b; Glascock et al. 1998; Neff 2002). Sufficient discrimination of source areas was considered achieved if 80 percent of all specimens were assigned by the CDA to the correct provenance group.

Finally, the sourcing potential of nondestructive PXRF was assessed by determining if the raw material database represented the geochemistry of Hohokam groundstone material procurement areas well enough to permit provenance classification for the majority of artifact samples. Artifact provenance assignments were assessed using the predictive formula of the CDA developed above and also with consideration of the Mahalanobis distance score assigned to each artifact sample during the multivariate analysis. The Mahalanobis distance score is a multidimensional generalization of the distance between a single case and a group mean. As such, it is a meaningful statistic for evaluating group membership when the reference group is a sample and not a complete population, as is the case for the present study (Neff 2002:35). In this study, all cases exhibiting a Mahalanobis distance score equal to or less than the value for other raw material specimens associated with a source group were classified as part of that source group. For those cases with a Mahalanobis distance score larger than the raw material specimens, a classification of "Unknown" was ascribed. The entire artifact provenance classification procedure was considered valid if more than 50 percent of the artifact samples could be assigned to specific source group. This success rate is considered as an acceptable start since it would mean that the majority of vesicular basalt source areas from which groundstone material was procured were sufficiently represented in the reference database.

<u>Results</u>

Evaluation of the Provenance Postulate for Hohokam vesicular basalt sourcing analyses began with an assessment of intra-source geochemical variability. This inspection revealed a single cluster of elemental data for 11 of the 17 source sample groups in the reference collection. These eleven source groups were thus considered comparatively homogenous and not split into two or more subsources. In contrast, distinct geochemical subgroups (labeled Subsources A–C) were found in six source groups, including the Deem Hills, Ludden Mountain, Moon Hill, Robbins Butte, the Santan Mountains, and West Wing Mountain (Figures 6.11–6.16). The two subsources in the Deem Hills group were expected given that sampling efforts were divided between two areas containing material from distinct igneous flows (Richard et al. 2000). The

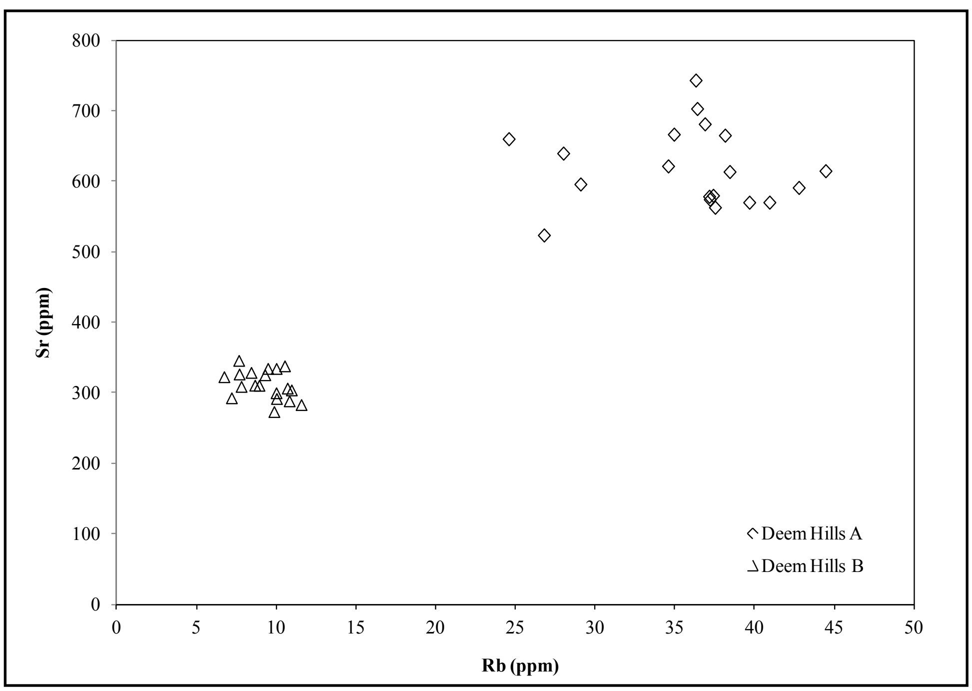

Figure 6.11. Deem Hills Source Area Geochemical Subgroups.

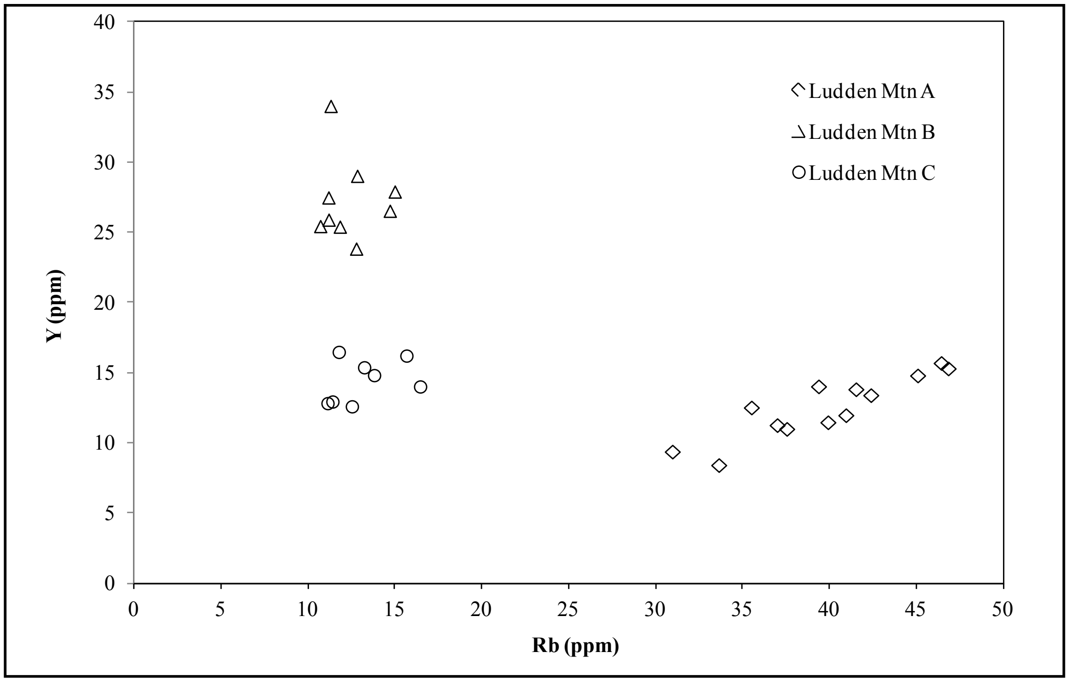

Figure 6.12. Ludden Mountain Source Area Geochemical Subgroups.

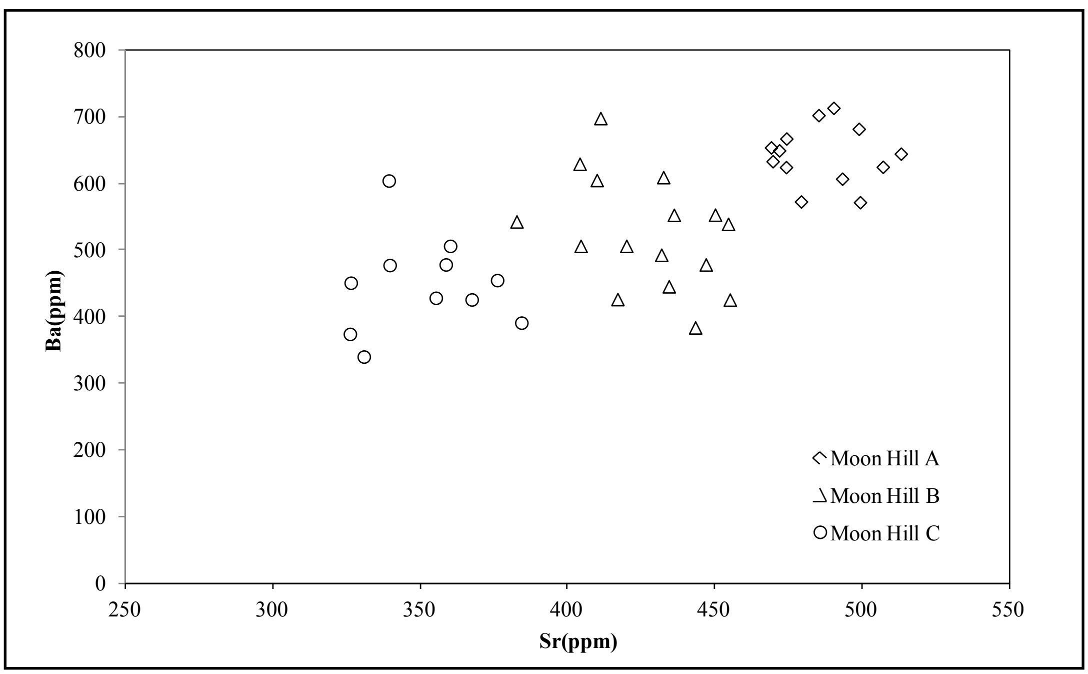

Figure 6.13. Moon Hill Source Area Geochemical Subgroups.

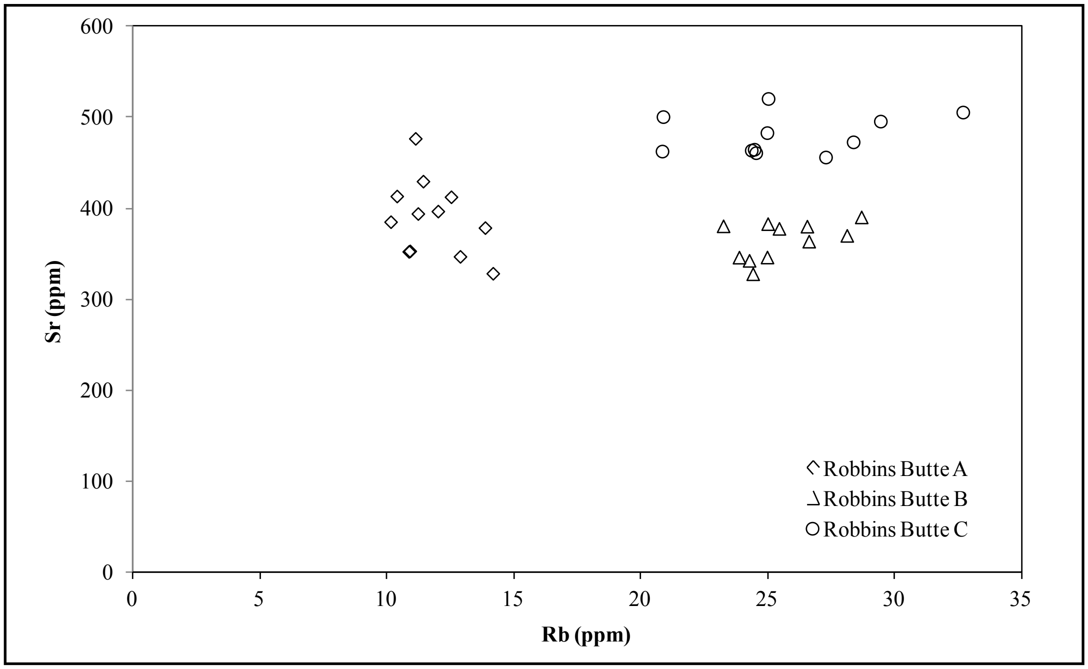

Figure 6.14. Robins Butte Source Area Geochemical Subgroups.

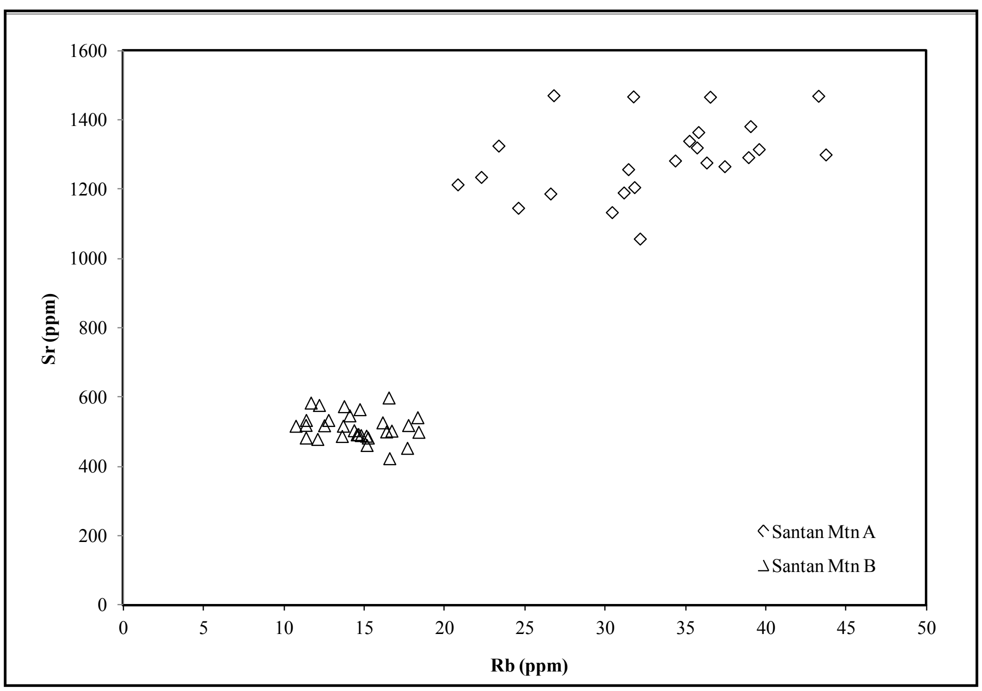

Figure 6.15. Santan Mountain Source Area Geochemical Subgroups.

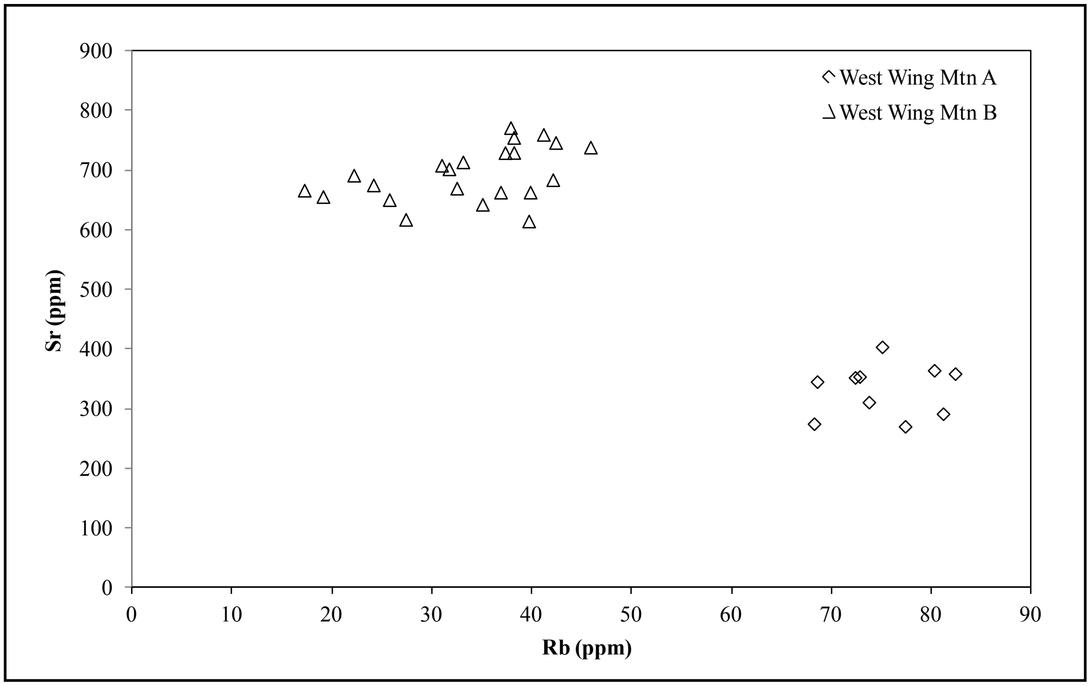

Figure 6.16. West Wing Mountain Source Area Geochemical Subgroups.

geochemical variability observed in the other five source areas most likely represents the mixing of temporally distinct basalt flows in the same talus debris field. In the end, a total of 26 geochemical source groups are represented among the 17 sampled basalt formations.

Examination of bivariate plots for each source group also identified a total of 25 outliers among the 738 raw material specimens in the reference collection, or approximately 3.4 percent of the entire database. An example of one such outlier is observable in Figure 6.17, which represents the Deem Hills raw material sample. These outliers are inferred to represent some type of measurement error as opposed to natural variation due to their overall low number within each source group and the broader

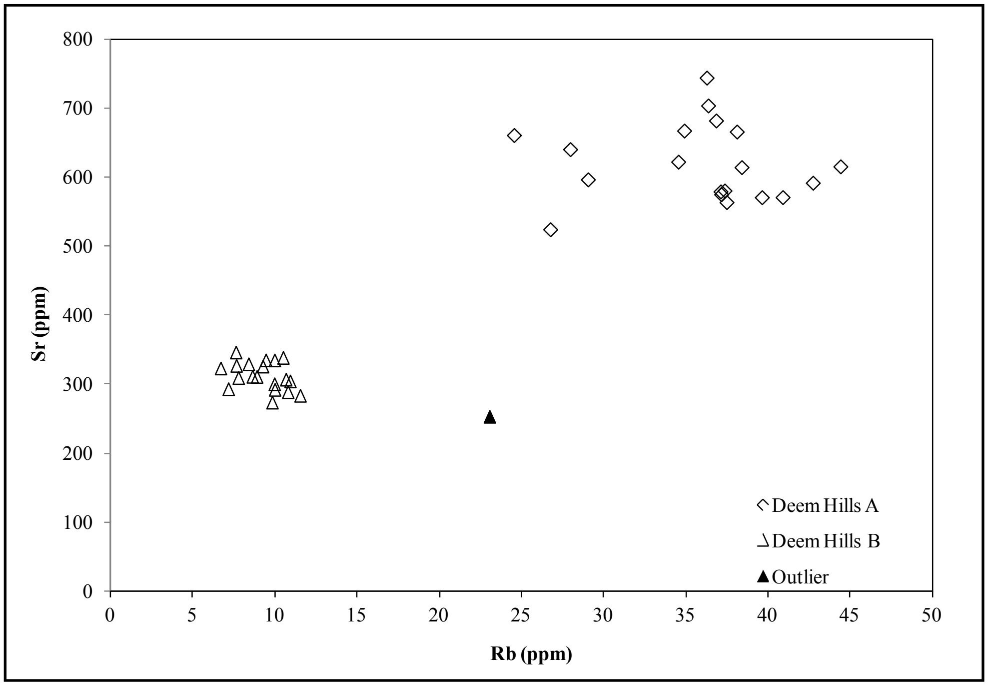

Figure 6.17. Geochemical Outlier in the Deem Hills Source Group.

reference database. Likely sources of measurement error include greater than average distance between the PXRF aperture and sample, extreme cases of weathering, amygdaloidal minerals, or sediment rich cavities. No matter the reason, these outliers were removed from the representative source database to limit intra-source geochemical variability and, improve the validity of artifact provenance assignments.

Following the intra-group assessment, all 26 raw material geochemical groups were evaluated for inter-source variability. The CDA proved to be successful in identifying consistent and predictable geochemical variation among the source groups, correctly classifying the geographic provenance for 648 of the 713 (90.9%) specimens

(Table 6.5). The results of the Jackknife analysis were quite similar. This test predicted group membership for 88.4 percent of the cases, indicating that the strength of the predictive formula used in the CDA is reliable (Table 6.6). The largest source of error in the analysis was the conflation of the Moon Hill and Ludden Mountain source groups. The Jackknife classification assigned 16 percent of the samples (n=5) from Ludden Mountain Subsources B and C to Moon Hill, and 20 percent (n=8) of the samples from Moon Hill to Ludden Mountain (see Table 6.6). The confusion between the Moon Hill and Ludden Mountain sources likely results from the fact that these two outcrops contain material from the same igneous flow event (Leighty 1997). Due to the geochemical overlap between these two sources, they were constituted as one geochemical group during artifact provenance analyses. Apart from this misclassification, group membership was generally correctly predicted with a success rate of greater than 90 percent. Overall, then, results of the CDA suggest that there is sufficient geochemical variability among the different vesicular basalt source areas exploited by the Hohokam to conduct geographic provenance analyses.

The CDA was also found to be effective in assigning provenance classifications to groundstone artifacts in the archaeological sample. In using the predictive formula of the CDA, as well as the Mahalanobis distance score for each unassigned artifact specimen, a provenance classification was assigned to nearly three-quarters (n=343/484; 71%) of the vesicular basalt groundstone tools in the current study sample (Table 6.7). This success rate was welcomed given the possibility (roughly 3.4 percent) of measurement error (e.g.

Table 6.5. Results of Discriminant Analysis

Actual Group	Predicted Group Membership																										
	Adobe Mtn	Deem Hills A	Deem Hills B	Florence Cinder	Hedgpeth Hills	Lone Butte	Ludden Mtn A	Ludden Mtn B	Ludden Mtn C	McDowell Mtn	Moon Hill A	Moon Hill B	Moon Hill C	Picture Rocks	Poston Butte	Robbins Butte A	Robbins Butte B	Robbins Butte C	Santan Mtns A	Santan Mtns. A	Shaw Butte	Union Hills	Vaiva Hills	Table Top Mtn	West Wing Mtns A	West Wing Mtns B	**Total**
Adobe Mtn	**32**																							1			33
Deem Hills A	1	**14**			3																					1	19
Deem Hills B			**20**																								20
Florence Cinder				**28**											1												29
Hedgpeth Hills					**84**													2									86
Lone Butte						**29**			1																		30
Ludden Mtn A							**13**																				13
Ludden Mtn B								**6**			3																9
Ludden Mtn C									**6**										2								8
McDowell Mtn										**88**													1				89
Moon Hill A									**3**		**8**								2				2				15
Moon Hill B									**4**		1	**10**															15
Moon Hill C			1									1	**7**									1					10
Picture Rocks														**35**													35
Poston Butte															**30**												30
Robbins Butte A											1					**12**											13
Robbins Butte B																	**11**										11
Robbins Butte C					5													**7**									12
Santan Mtns A									6	1	1								**48**								56
Santan Mtns B	1																			**44**							45
Shaw Butte		1	1								2										**5**		1				10
Union Hills											1											**25**					26
Vaiva Hills																							**30**				30
Table Top Mtn	1																							**31**		2	34
West Wing Mtns A																									**10**		10
West Wing Mtns B		5					4	1	1	1																**13**	25
Total	35	20	22	28	92	29	17	7	21	90	17	11	7	35	31	12	11	9	52	44	5	26	34	32	10	16	**713**

Table 6.6. Results of Jackknife Discriminant Analysis

	Predicted Group Membership																										
Actual Group	Adobe Mtn	Deem Hills A	Deem Hills B	Florence Cinder	Hedgpeth Hills	Lone Butte	Ludden Mtn A	Ludden Mtn B	Ludden Mtn C	McDowell Mtn	Moon Hill A	Moon Hill B	Moon Hill C	Picture Rocks	Poston Butte	Robbins Butte A	Robbins Butte B	Robbins Butte C	Santan Mtns A	Santan Mtns A	Shaw Butte	Union Hills	Vaiva Hills	Table Top Mtn	West Wing Mtns A	West Wing Mtns B	**Total**
Adobe Mtn	**32**																							1			33
Deem Hills A	1	**14**			3																					1	19
Deem Hills B			**20**																								20
Florence Cinder				**26**											3												29
Hedgpeth Hills		1			**82**													3									86
Lone Butte						**28**			2																		30
Ludden Mtn A							**13**																				13
Ludden Mtn B								**5**			4																9
Ludden Mtn C									**4**		1								3								8
McDowell Mtn										**88**													1				89
Moon Hill A									3		**6**								4				2				15
Moon Hill B									5		1	**9**															15
Moon Hill C			2									1	**5**									2					10
Picture Rocks														**35**													35
Poston Butte															**30**												30
Robbins Butte A											3					**9**			1								13
Robbins Butte B																	**11**										11
Robbins Butte C					6													**5**	1								12
Santan Mtns A									6	1	1								**48**								56
Santan Mtns B	1																			**44**							45
Shaw Butte		1	1								2										**5**		1				10
Union Hills											1											**25**					26
Vaiva Hills																							**30**				30
Table Top Mtn	1																							**31**		2	34
West Wing Mtns A																									**10**		10
West Wing Mtns B		5					4	1	1	1																**13**	25
Total	**35**	**21**	**23**	**26**	**91**	**28**	**17**	**6**	**21**	**90**	**19**	**10**	**5**	**35**	**33**	**9**	**11**	**8**	**57**	**44**	5	**27**	**34**	**32**	**10**	**16**	**713**

Table 6.7. Summary of Vesicular Basalt Groundstone Artifact Provenance Assignments

Source Area Name	Total (n)	Total (%)
Adobe Mountain	0	0%
Deem Hills	10	2%
Florence Cinder Mine	2	<1%
Hedgpeth Hills	13	3%
Lone Butte	2	<1%
McDowell Mountain	72	15%
Moon Hill/Ludden Mountain	23	5%
Picture Rocks	23	5%
Poston Butte	0	0%
Robbins Butte	5	1%
Santan Mountain	165	34%
Shaw Butte	0	0%
Table Top Mountain.	2	<1%
Union Hills	0	0%
Vaiva Hills	0	0%
West Wing Mountains	26	5%
Unknown	141	29%
Total	484	100%

outliers) and also the absence of representative material from all prehistoric Hohokam groundstone quarries in the Salt-Gila Basin. The results are also encouraging because a large proportion of the artifacts were assigned to the two largest and closest sources of vesicular basalt in the study area, the McDowell (n=72; 15%) and Santan Mountains (n=165; 34%). These observations suggest that the bulk of vesicular basalt artifact samples from Hohokam sites can be traced to specific source areas that are known to have been intensively exploited by the Hohokam. Thus, the raw material sample is adequately representative and the data collection and analysis procedures are sufficient for conducting geographic provenance analysis for Hohokam vesicular basalt groundstone artifacts. Certainly, though, the addition of raw material samples from other unsampled sections of vesicular basalt outcrops in the reference database and other unsampled outcrops in the Salt-Gila Basin will likely improve the success of the provenance method.

Summary

Current understandings of Hohokam vesicular basalt procurement and distribution practices have been limited as a result of the unavailability of an efficient and reliable technique for determining the geographic provenance of groundstone material. However, the findings of this study suggest that PXRF can be used to rapidly produce reliable geochemical data for unmodified and chemically-heterogenous vesicular basalt specimens. Additionally, evaluation of 738 raw material specimens from 17 geographically discrete vesicular basalt outcrops in the Hohokam cultural territory revealed that there is sufficient geochemical variability to successfully discriminate material from these source areas. The analysis of nearly 500 vesicular basalt groundstone artifacts also promotes the validity of the technique by demonstrating that nearly three-quarters of the artifact sample could be confidently assigned a geographic provenance classification. Altogether, the findings of this study serve to establish nondestructive PXRF as an effective analytical technique for Hohokam vesicular basalt sourcing studies.

CHAPTER 7: RESULTS OF ARTIFACT PROVENANCE ANALYSIS AND HYPOTHESIS TESTING

Geographic provenance assignments were determined for 484 groundstone tools from nine Hohokam sites using the analytical methods outlined in the previous chapter. These provenance data constitute the largest and most geographically precise vesicular basalt source dataset compiled to date in Hohokam archaeology. This chapter presents, first, the results of the geographic provenance analysis for each site in the study sample with reference to the data patterning expectations for each of the five hypotheses examined in this study. Second, the provenance data are considered in aggregate to evaluate the validity of the direct procurement, direct exchange, down-the-line exchange marketplace exchange, and elite-controlled exchange models. It is concluded from the hypothesis testing that direct procurement is a likely acquisition practice for some of the sites in the study sample, but that none of the other models account well for the observed archaeological patterns. Based on this result, a new model of Hohokam vesicular basalt provisioning practices is presented in the third and final section of this chapter.

Vesicular Basalt Groundstone Provenance Results

Casa Grande

The well-known prehistoric site of Casa Grande is located in the modern town of Coolidge on the south side of the middle Gila River (see Figure 1.3). It is the southern and easternmost sample context included in this study. The nearest vesicular basalt outcrops to Casa Grande are Chee Nee (i.e., Walker Butte) and the Hunt Highway Buttes.

However, these source areas were not sampled during the current investigation because recent archaeological survey of these formations has not found any evidence of groundstone manufacture at these sources (North et al. 2004). The closest known groundstone material quarries are found at the Florence Cinder Mine and Poston Butte source areas. These locations are a distance of 13 km and 14 km, respectively. Other exploited vesicular basalt outcrops within a 50 km radius of the site include the Santan Mountains (22 km), Picture Rocks (23 km), and the Vaiva Hills (49 km).

A total of 37 groundstone artifacts from Casa Grande were subject to geochemical analyses as part of this research (Table 7.1). The results of the analysis indicate that households at Casa Grande did not rely on the nearest available source area, the Florence Cinder Mine, for groundstone material (Figure 7.1). Vesicular basalt from the nearby Poston Butte source is also not observed during either the Preclassic or Classic periods. The inhabitants of this village instead acquired a considerable proportion of their material from the Picture Rocks source. Material from the Santan Mountains is also present in moderate quantities during both the Preclassic and Classic periods. So even if the provenance of many of the unknown artifacts is the Chee Nee or the Hunt Highway Buttes, the acquisition of material from the more distant Picture Rocks and Santan Mountain sources belies the notion that direct procurement was the primary means of material acquisition at Casa Grande during either period of investigation. Thus, the source provenance data provide evidence to reject the direct procurement hypothesis at Casa Grande during the Preclassic and Classic periods.

Table 7.1. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Casa Grande

	Preclassic		Classic		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**
Picture Rocks	7	47%	6	27%	13	35%
Santan Mtn	1	7%	2	9%	3	8%
Florence Cinder Mine			2	9%	2	5%
Hedgpeth Hills			1	5%	1	3$
Unknown	7	47%	11	50%	18	49%
Total	15	100%	22	100%	37	100%

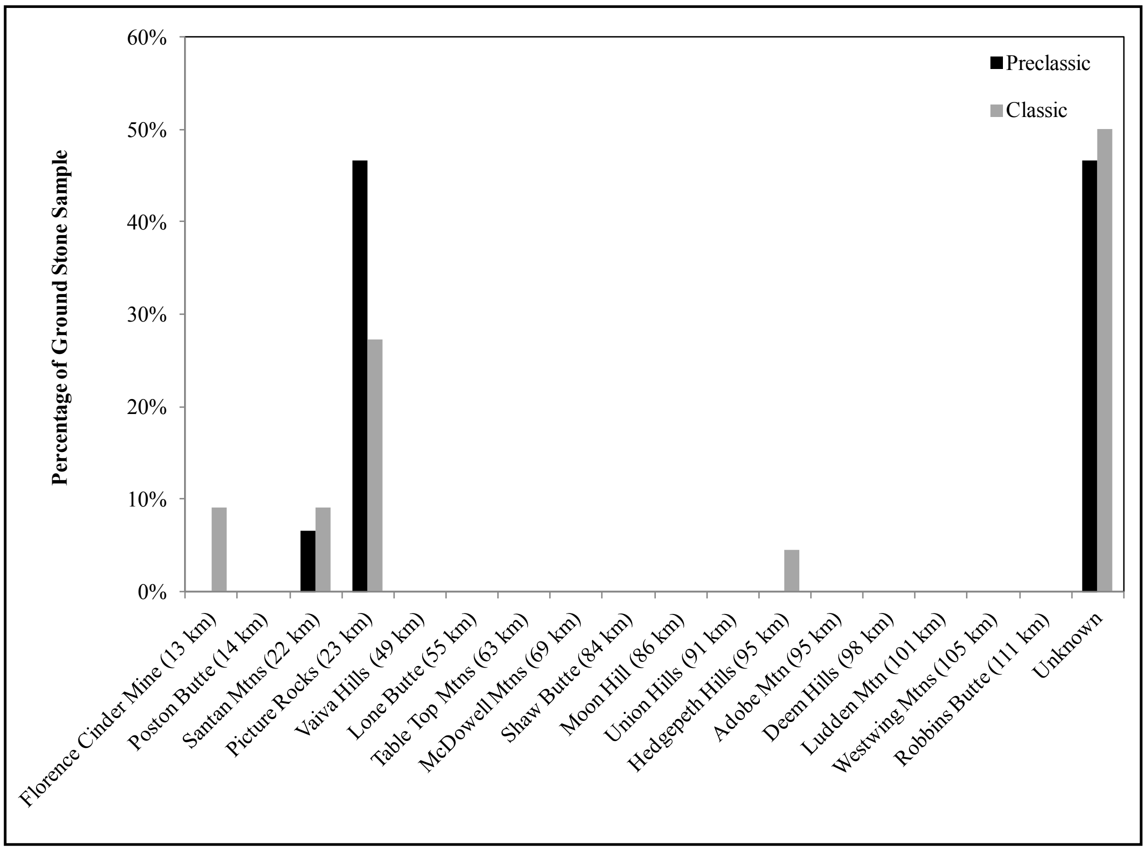

Figure 7.1. Relative Proportion of Vesicular Basalt Source Areas by their Distance from Casa Grande for Preclassic and Classic Period Contexts.

The provenance data patterning also lead to a rejection of the down-the-line exchange model. It is clear from the relative abundance of Picture Rocks material, relative to stone from the Santan Mountain and Florence Cinder Mine sources during both temporal intervals of investigation, that there is not a distance-decay trend in source frequency at the site. A Spearman rank-order correlation test confirms the absence of a strong and significant negative relationship during the Classic ($r_{s=}$ -0.316; p>0.05) periods. It is not possible to conduct a similar test for the Preclassic sample due to the fact that all of the known material derived from just two sources areas. However, this patterning itself is considered evidence contra to the expectations of the down-the-line exchange model.

The geographic provenance data from Casa Grande also give cause to reject the marketplace and elite-controlled exchange models. The sample from this site demonstrates a very strong and significant rank-order correlation in source preference between the Preclassic and Classic period contexts (r_s=0.892, p≤0.05). During both intervals, material from Picture Rock and Santan Mountain source areas constitute the bulk of the ceramic assemblage. There does appear to be an increase in direct procurement during the later period, as evidenced by the slight increase in use of material from the Florence Cinder Mine. However, this increase is not substantial enough to be significant. Thus, the temporal continuity in source preference over time indicates that the collapse of Hohokam markets at the end of the Sedentary period and the rise of platform mound communal activities in the Classic period had no significant impact on the acquisition of vesicular basalt at Casa Grande.

The provenance data provide no reason to reject the direct exchange model for vesicular basalt acquisition at Casa Grande. The bulk of the identified groundstone material at this site stems from either the Picture Rocks source, which is found slightly upstream of the site, or the Santan Mountains, which is located downstream from the site (see Figure 1.3). Notably, the Picture Rocks source is located near the head of the Casa Grande Canal System (see Figure 4.1). Hohokam social relations have been shown to be coterminous with irrigation systems, particularly during the Classic period (Abbott 2000, 2003c; Abbott et al.2006). Therefore, the substantial amount of vesicular basalt from Picture Rocks and other more distance source areas provides support for the idea that vesicular basalt was moved through direct exchanges between individuals.

Gila Crossing

The prehistoric to modern day village of Gila Crossing is located on the north bank of the Gila River near its confluence with the Santa Cruz drainage (see Figure 1.3). Lone Butte is the closest vesicular basalt quarry to the site at a distance of about 13 km to the east. Another ten sources are found within a 50 km radius of the site. The Santan Mountain (45 km) source area in the middle Gila River Valley and the Robbins Butte (47 km) source area along the lower Gila River are within this range. The other eight source areas, including Moon Hill (38 km), Hedgpeth Hills (44 km), and the McDowell Mountains (48 km), are located in the Salt River Valley. Shaw Butte is also not far from the site at a distance of roughly 36 km; however, no prehistoric quarries have been documented at this outcrop and no artifacts were traced to it as part of this study, thus making its status as a vesicular basalt source area questionable.

Given the proximity of the site to the Lone Butte source area, it was expected that the majority of the groundstone material would be traced to this location. However, the results were much different than expected (Figure 7.2; Table 7.2). Not one sample in the collection was traced to this source. Instead, the bulk of the identifiable material was traced to either the Santan Mountains (n=12; 29%) or the McDowell Mountain (n=7; 17%) source areas. The absence of material from the Lone Butte source area, along with the presence of various other source areas in the sample, indicates that the Preclassic households at Gila Crossing did not expend much effort procuring groundstone materials directly from the closest available source area. Instead, it appears that households at Gila Crossing obtained vesicular basalt groundstone though some form of exchange.

Table 7.2. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Gila Crossing

	Preclassic	
Geographic Provenance	**N**	**%**
Santan Mtn	12	29%
McDowell Mtn	7	17%
Robbins Butte	2	5%
Moon Hill/Ludden Mtn	1	2%
West Wing Mtn	1	2%
Unknown	19	45%
Total	42	100%

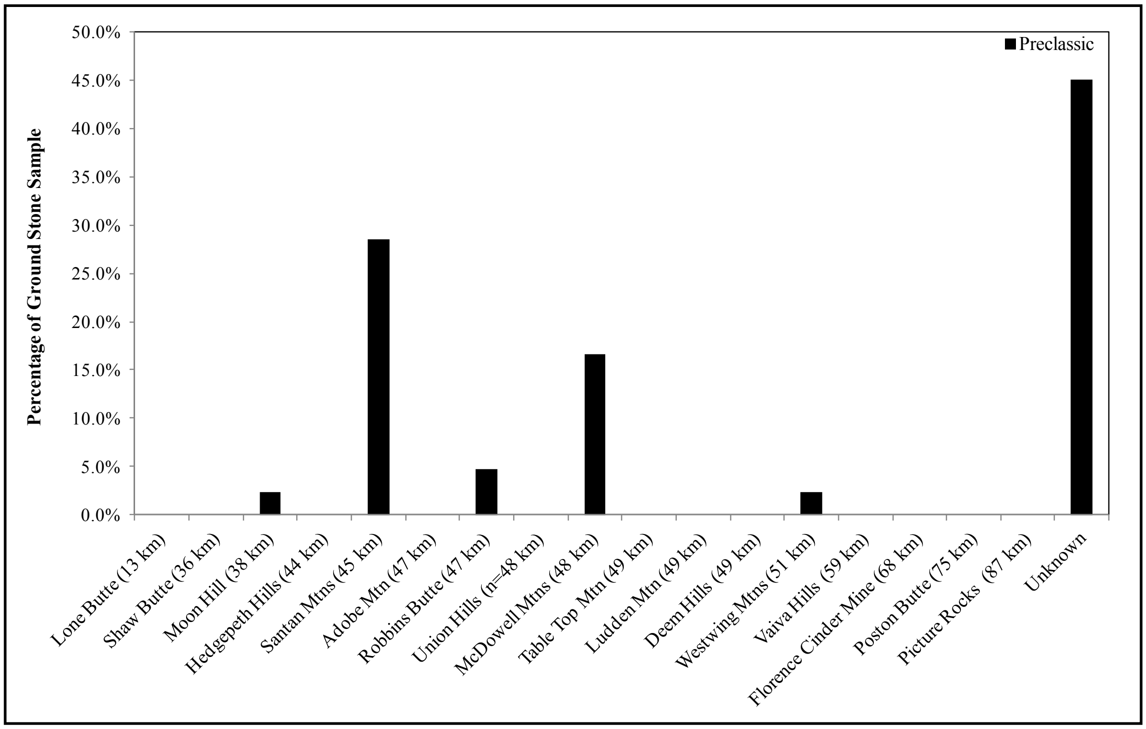

Figure 7.2. Relative Proportion of Vesicular Basalt Source Areas by their Distance from Gila Crossing for Preclassic Period Contexts.

It is unlikely that households at Gila Crossing acquired vesicular basalt through down-the-line exchange. Material from the Santan Mountain and McDowell Mountain source areas, which represent the second and fourth most distant sources areas represented in the site sample, are the most abundant source groups. In contrast, Moon Hill and Robbins Butte, both of which are closer to Gila Crossing than the Santan Mountains, together comprise less than eight percent of the groundstone sample. A Spearman rank-order correlation test confirms that there is a weak and insignificant negative relationship ($r_{s=}$ -0.103; $p>0.05$) between represented source frequency and the distance from the site to the represented source areas. Therefore, down-the-line material distribution model is not a valid explanation for vesicular basalt acquisition practices at Gila Crossing.

Unfortunately, it is not possible to differentiate between direct and marketplace exchange for this Preclassic sample due to the inability to discern different household areas and also the absence of comparative Classic period assemblage for the site. Thus, the direct procurement model and down-the-line exchange models can be rejected as a primary vesicular basalt acquisition practice during the Preclassic at Gila Crossing, while direct and market exchange remains viable explanations.

Hospital Site

The Preclassic village known as the Hospital Site is situated in the modern day community of Sacaton in the GRIC (see Figure 1.3). This village lies roughly six km south of the extensive vesicular basalt deposits in the Santan Mountains. At least six other source areas are located within 50 km of the Hospital Site. More notable sources within this range include the Florence Cinder Mine (26 km), Poston Butte (32 km), and Lone Butte (33 km). Similar to Casa Grande, the Chee Nee and Hunt Highway Buttes are located within the vicinity of the Hospital Site, but these sources are not represented in this study due to the absence of known groundstone quarries at these formations (North et al. 2004).

The geochemistry of 31 groundstone artifacts from Preclassic contexts at the Hospital Site was analyzed as part of this study (Table 7.3). The available data indicate that the Preclassic households relied on the closest available source for the bulk of their

Table 7.3. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from the Hospital Site

	Preclassic	
Geographic Provenance	**N**	**%**
Santan Mtn	23	74%
Picture Rocks	1	3%
Robbins Butte	1	3%
Unknown	6	19%
Total	31	31

groundstone material. The analysis found that approximately three-quarters of the vesicular basalt groundstone originated from the nearby Santan Mountains (n=23; 74%; Figure 7.3). Therefore, it is likely that households at the Hospital Site acquired vesicular basalt for groundstone tool production primarily through direct procurement. However, these data do not necessarily oppose the direct, down-the-line, or market exchange models, since it is possible that households from the site acquired material from related households or tool producers living at Upper Santan. The elite-controlled exchange model could not be evaluated at the Hospital site given the Preclassic association of the artifact sample.

La Plaza

La Plaza is located on the south bank of the Salt River in the modern day area of Tempe (see Figure 1.3). The two closest vesicular basalt source areas to the site are the McDowell Mountains (19 km) and Lone Butte (19 km); though Lone Butte is a bit further if one considers that a trip from La Plaza to the source would need to circumvent

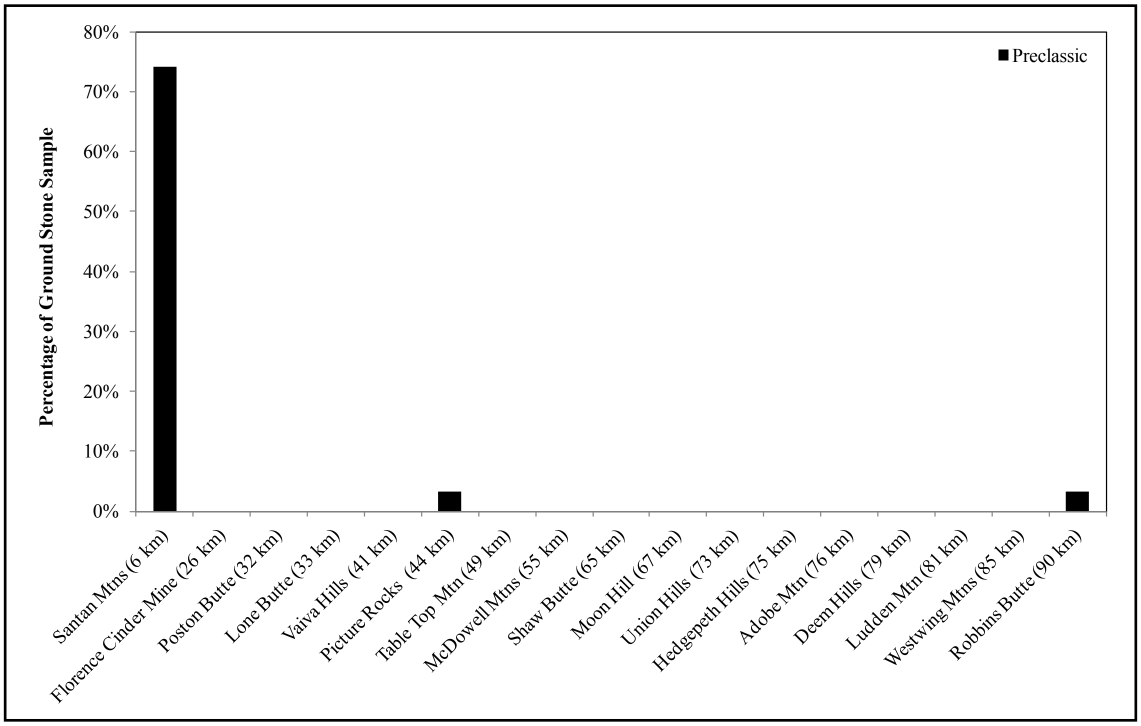

Figure 7.3. Relative Proportion of Vesicular Basalt Source Areas by their Distance from Hospital Site for Preclassic Period Contexts.

the eastern flank of South Mountain. At least nine other source areas with documented evidence of prehistoric groundstone manufacture occur within a 50 km radius of the site (see Figure 1.3; Figure 7.4). The more relevant of these outcrops include Moon Hill (27 km), the Hedgpeth Hills (35 km), the Santan Mountains (38 km), and the West Wing Mountains (46 km).

The geographic provenance data from La Plaza suggest that households at the site obtained a large proportion of their groundstone material from the McDowell Mountains, the nearest available source area if one takes into consideration the local topography (Figure 7.4; Table 7.4). Thus, the data do not stand in contrast to the direct procurement model. Yet, the results also are not in opposition to the direct or down-the-line exchange

Table 7.4. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from La Plaza

	Preclassic		Classic		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**
McDowell Mtn	9	45%	9	53%	18	49%
Santan Mtn	3	15%			3	8%
Lone Butte			1	6%	1	3%
Table Top Mtn			1	6%	1	3%
Unknown	8	40%	6	35%	14	38%
Total	20	100%	17	100%	37	100%

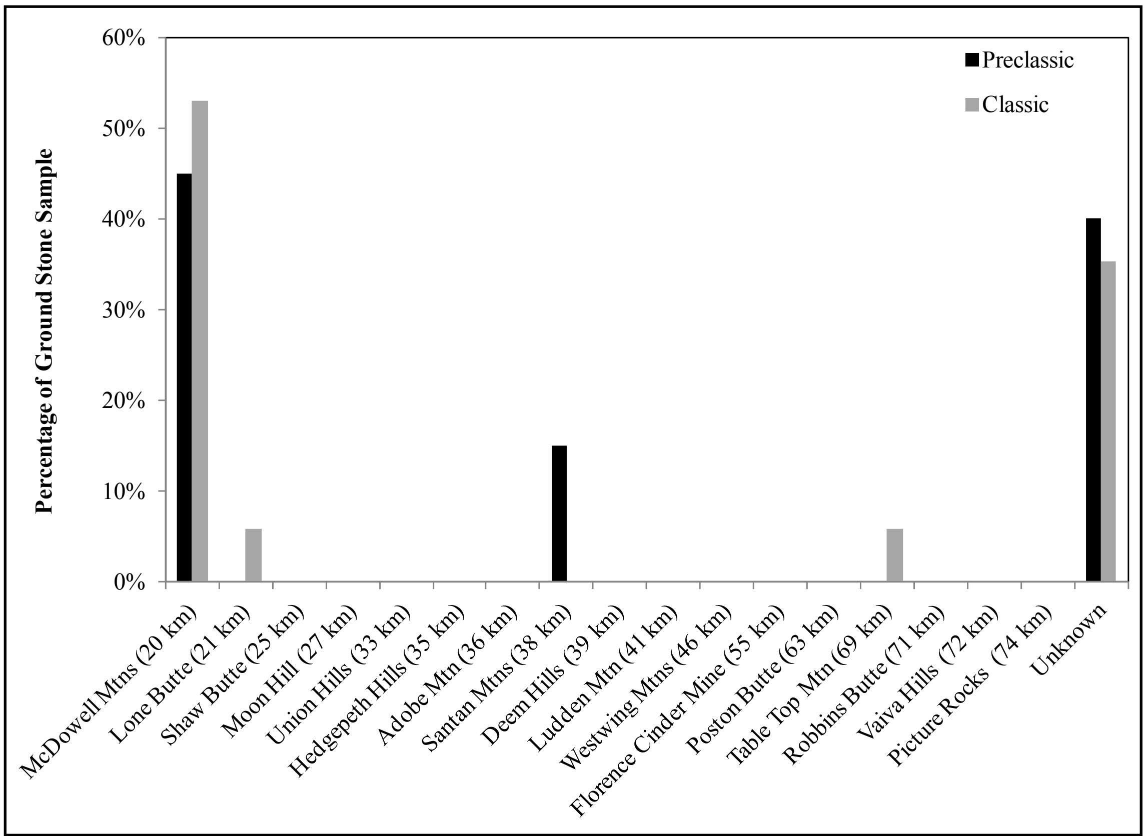

Figure 7.4. Relative Proportion of Vesicular Basalt Source Areas by their Distance from La Plaza for Preclassic and Classic Period Contexts.

models, because a large proportion of the assemblage is from one or more unknown source areas. If these unknowns stem from any source area other than the McDowell Mountains, then the provenance data would actually stand in contrast to the direct procurement model and instead support the direct or down-the-line exchange model. Additional research needs to be undertaken to determine the source of the unknown artifacts.

The marketplace and elite-controlled redistribution models also cannot be rejected from the La Plaza data. A Spearman's rank-order test revealed that there was a strong but insignificant positive correlation (r_s=0.6842, p>0.05) in source preference between the Preclassic and Classic periods. The absence of a significant positive correlation leaves in place the possibility that there was a change in source acquisition practices between the two intervals. This change may have involved a shift from Santan Mountain to the more local Lone Butte source area. The transition to a more proximate source area in the Classic period does fit in line with the expectations of a collapsed market economy and not the emergence of an elite-controlled economy. However, with so much of the artifact sample from an unknown source area, it is imprudent to dismiss (or give support to) either explanation.

In sum, the geographic provenance data from La Plaza are equivocal. There is reason to believe that direct procurement of vesicular basalt was the primary acquisition strategy, as evidenced by the high relative frequency of material from the McDowell

Mountains. However, with much of the vesicular basalt sample coming from an unknown source area, it is not possible to rule out other groundstone tool provisioning strategies.

Las Colinas

The prehistoric village of Las Colinas is located at the tail end of Canal System 2 on the north side of the Salt River (see Figure 1.3). The closest documented vesicular basalt groundstone quarry area to the site is Moon Hill at a distance of about 17 km. Shaw Butte is actually closer to the site (14 km), but no prehistoric quarries have been documented at the site and no artifacts were traced to this outcrop. Eight other source areas with documented prehistoric groundstone quarries are found within a 50 km radius from the site. In order of ascending distance, these sources consist of the Hedgpeth Hills (23 km), Lone Butte (24 km), Adobe Mountain (26 km), Union Hills (26 km), Deem Hills (28 km), Ludden Mountain (29 km), the McDowell Mountains (32 km), and the West Wing Mountains.

Ninety-five vesicular basalt artifacts from datable contexts at Las Colinas were analyzed for their geochemistry (Table 7.5). This sample is important because it contains artifacts from three different temporal intervals and spatially discrete habitation areas, thus allowing for an evaluation of source provenance patterns across both time and space at the site. The three temporal intervals from which the vesicular basalt sample stems are the middle Sacaton (n=31), the late Sacaton (n=33), and Classic period (n=31). The middle and late Sacaton period collections include groundstone from two distinct domestic habitation areas (Areas 4 and 5). The early Classic period sample includes artifacts from one domestic habitation area (Area 7) and also the platform mound compound (Area 3).

Table 7.5. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Las Colinas

	Middle Sacaton		Late Sacaton		Early Classic		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	
West Wing Mtn	7	23%	7	21%	4	13%	18	19%
McDowell Mtn	9	29%	4	12%	4	13%	17	18%
Moon Hill/Ludden Mtn	2	6%	8	24%	3	10%	13	14%
Deem Hills	2	6%	4	12%	1	3%	7	7%
Santan Mtn	2	6%			1	3%	3	3%
Hedgpeth Hills			1	3%	1	3%	2	2%
Robbins Butte			1	3%			1	1%
Unknown	9	29%	8	24%	17	55%	34	26%
Total (n)	31	100%	33	100%	3	31	95	100%

The vesicular basalt provenance data from Las Colinas do not exemplify patterning typical of direct procurement (Figure 7.5). At its peak in the late Sacaton, the closest available source area, Moon Hill, only constitutes about one-quarter of the groundstone material at the site. There is also little to no material from other nearby sources, such as the Hedgpeth Hills, Adobe Mountain or the Union Hills. Instead, a substantial proportion of the groundstone inventory consists of material from the more distant McDowell Mountain and West Wing Mountain source areas. Thus, the geographic provenance data from Las Colinas stand in contrast to the expectations of the direct procurement hypothesis. On this basis, then, the direct procurement model is rejected as the primary groundstone material procurement method at Las Colinas for all three temporal intervals under consideration.

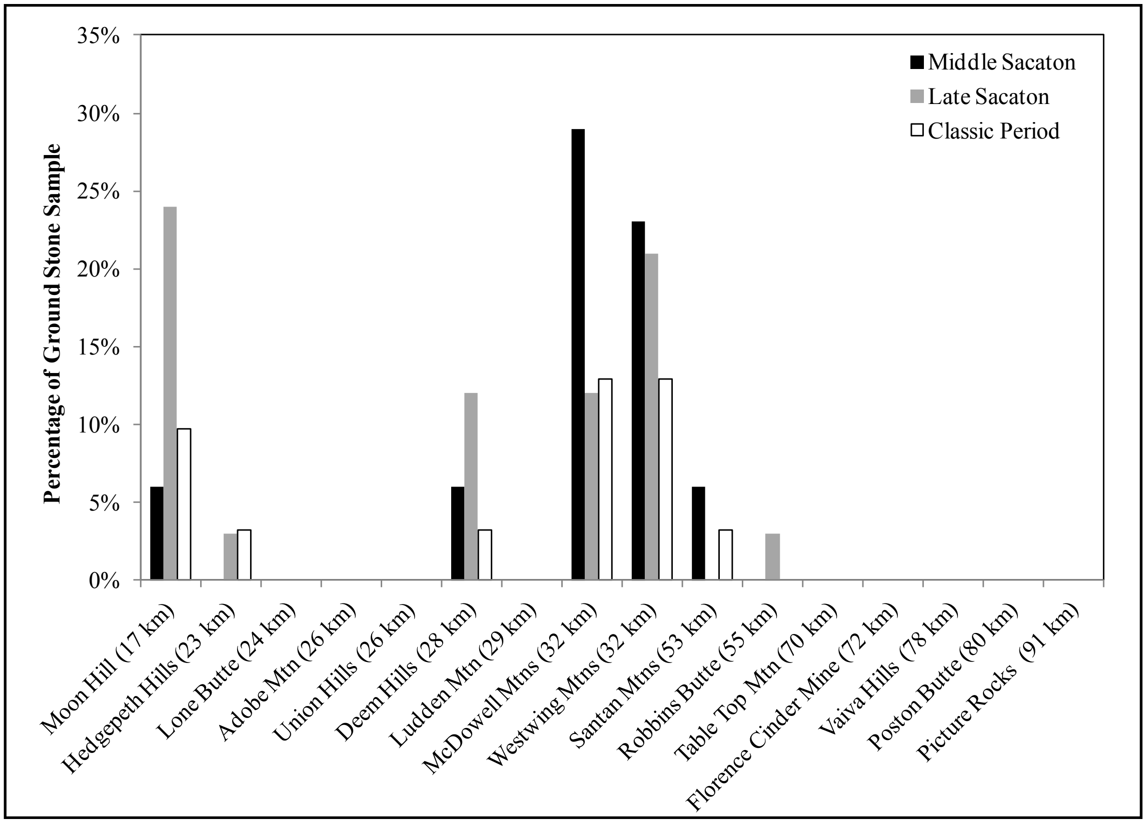

Figure 7.5. Relative Proportion of Vesicular Basalt Source Areas by their Distance from La Plaza for Preclassic and Classic Period Contexts.

The geographic provenance data for Las Colinas also provide justification to reject down-the-line exchange. None of the three temporal intervals exhibit a strong and significant distance-decay trend when taking into account the represented source areas in the sample. In fact, the only period to show a negative correlation was the late Sacaton sample ($r_{s}=$ -0.403; $p>0.05$). Both the middle Sacaton ($r_{s}=$ 0.287; $p>0.05$) and Classic ($r_{s}=$ 0.125; $p>0.05$) period samples displayed positive relationships between source frequency and distance from Las Colinas to the source. On this evidence, the down-the-line exchange model can be rejected as a possible vesicular basalt provisioning practice for households at Las Colinas.

An evaluation of source preference through time at Las Colinas found some support for marketplace exchange, but no evidence of elite control over vesicular basalt distributions. Spearman's rank-order correlation test failed to identify either a strong or significant relationship in source preference between the middle Sacaton and late Sacaton periods ($r_{s=}$ 0.591; $p>0.05$). As noted above, the relative frequency of Moon Hill, the closest available vesicular basalt source area to the site, increased substantially from just 6.0 percent of the groundstone sample to more than 24.0 percent. A difference of proportions tests confirms this increase is significant ($Z= -2.00$, $p<0.05$). In contrast, the Spearman's rank-order correlation test for source preference between the late Sacaton and Classic period sample found a strong and significant correlation ($r_{s=}$ 0.756; $p\leq0.05$). Thus, these results suggest that the collapse of the ballcourt network and marketplace exchange in the late Sacaton period may have affected the distribution of vesicular basalt. However, the rise of platform mound ceremonialism in the Classic period had no significant impact on vesicular basalt distributions.

The marketplace hypothesis is further supported by an evaluation of intra-site source provenance distribution patterns at Las Colinas. This examination did not reveal any significant differences in source preference between the two middle Sacaton household groups at Las Colinas (Table 7.6). A BR test run simultaneously with a Monte Carlo simulation procedure to take into account sample size (Peeples 2011) found no significant difference in source acquisition trends among the two middle Sacaton habitation areas (BR=125; p=0.55). This result indicates that at least two household groups at Las Colinas had equal access to the same source areas as other groups, which is a characteristic of market economies (Garraty 2009; Hirth 1998).

Table 7.6. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Middle Sacaton Household Groups at Las Colinas

	Area 4		Area 5		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**
Deem Hills	2	12%			2	6%
McDowell Mtn	4	24%	5	36%	9	29%
Moon Hill/Ludden Mtn			2	14%	2	6%
Santan Mtn	2	12%			2	6%
West Wing Mtn	3	18%	4	29%	7	23%
Unknown	6	35%	3	21%	9	29%
Total	17	100%	14	100	31	100%

Intriguingly, though, evaluation of intra-site patterning also failed to find significant variation between household groups during the later temporal intervals at the site (Tables 7.7 and 7.8). A BR test revealed the absence of significant variation between two house groups during the late Sacaton phase (BR=142; p=0.77). No significant difference was observed either between the platform mound compound (Area 3) and one domestic habitation group (Area 7) during the Classic period (BR=140; p=.75). These results again suggest that each household at Las Colinas had equal access to various source areas, which is a characteristic of redistribution from a central place.

In sum, the vesicular basalt groundstone provenance data from Las Colinas strongly suggest that neither direct procurement nor down-the-line exchange were the primary material acquisition methods practiced by households at the site. Instead, the data

Table 7.7. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Late Sacaton Household Groups at Las Colinas

	Area 4		Area 5		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**
Deem Hills	2	9%	2	20%	4	12%
Hedgpeth Hills					1	3%
McDowell Mtn	2	9%	2	20%	4	12%
Moon Hill/Ludden Mtn	6	27%	2	20%	8	24%
Robbins Butte	1	5%			1	3%
West Wing Mtn	6	27%	1	10%	7	21%
Unknown	5	23%	3	30%	8	24%
Total	22	100%	10	100%	33	100%

Table 7.8. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Early Classic Household Groups at Las Colinas

	Area 3		Area 7		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**
Deem Hills			1	8%	1	3%
Hedgpeth Hills			1	8%	1	3%
McDowell Mtn	1	8%	2	15%	4	13%
Moon Hill/Ludden Mtn	2	17%	1	8%	3	10%
Santan Mtn			1	8%	1	3%
West Wing Mtn	2	17%	1	8%	4	13%
Unknown	7	58%	6	46%	17	55%
Total	12	100%	13	100%	31	100%

suggest that the material was acquired primarily through exchange. Temporal and intra-site provenance data patterning at Las Colinas do conform to the expectations of the market exchange model during the middle Sacaton. However, the data are more supportive of direct exchange during both the late Sacaton and Classic periods, due to the absence of a temporal shift in provisioning activities between the late Sacaton and Early Classic periods.

Los Hornos

The Hohokam site of Los Hornos is located on the south side of the lower Salt River part way between the village of La Plaza and South Mountain (see Figure 1.3). The nearest documented vesicular basalt quarry to the site is Lone Butte, at a distance of just 15 km. Another nine basaltic outcrops that are in the representative source database are found within 50 km of Los Hornos, including the McDowell Mountains (26 km), Moon Hill (28 km), the Hedgpeth Hills (37 km), the Santan Mountains (37 km), and the West Wing Mountains (47) among others.

A total of 32 vesicular basalt groundstone artifacts from Preclassic sample contexts were submitted for geochemical analysis (Table 7.9). It is clear from the provenance data that households at La Plaza did not rely on the closest available source area, Lone Butte, for the bulk of their groundstone material (Figure 7.6). Instead, the data suggest that they preferred material from the McDowell Mountains. These data are in contrast to the expectations of the direct procurement hypothesis, which expects households to rely on the closest available source area. Therefore, this model of material acquisition can be rejected as the primary means of vesicular basalt procurement for the Preclassic households at Los Hornos.

Table 7.9. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Los Hornos

	Preclassic	
Geographic Provenance	**N**	**%**
Deem Hills	1	3%
Lone Butte	1	3%
McDowell Mtn	16	50%
Moon Hill/Ludden Mtn	2	6%
Santan Mtn	4	13%
West Wing Mtn	2	6%
Unknown	6	19%
Total	32	100%

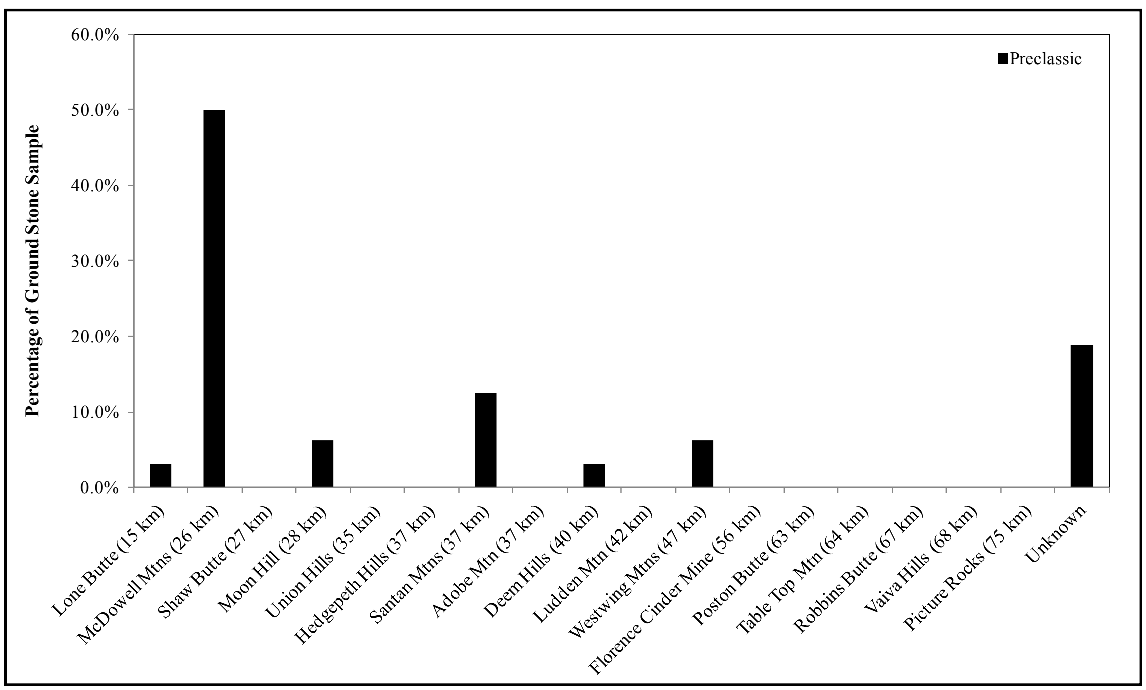

Figure 7.6. Relative Proportion of Vesicular Basalt Source Areas by their Distance from Los Hornos for Preclassic Period Contexts.

The geographic provenance data also serve to reject the down-the-line exchange model. Spearman's rank-order correlation test did not find a strong and significant negative relationship in the source frequency and the distance to sources areas. This result was true if all 17 source areas are considered in the calculation ($r_{s=}$ -0.584; p>0.05), and also if only those sources present in the site sample are used ($r_{s=}$ -0.059; p>0.05). Thus, the source provenance data from Los Hornos indicate that the Preclassic inhabitants of the site may have acquired the majority of their groundstone through either direct or market exchange.

The available data do conform to the expectations of the direct exchange model since a number of sources are present in the sample, and the relative frequency of these sources has no relationship with distance from Los Hornos to source areas. Unfortunately, intra-site and temporal comparisons of vesicular basalt provenance are unavailable for the Los Hornos sample. As a result, the direct exchange and market exchange models remain viable explanations for Preclassic vesicular basalt groundstone tool provisioning practices.

Lower Santan

The prehistoric village of Lower Santan is located on a river terrace on the north side of the Gila River (see Figure 1.3). At a distance of about three km, the nearby Santan Mountains are the closest available source of basaltic stone. Other sources within a 50 km radius of the site include Lone Butte (27 km), Florence Cinder Mine (29 km), Poston Butte (35 km), the McDowell Mountains (47 km), Picture Rocks (47 km), and the Vaiva

Hills (n-47). Lower Santan is located on the same canal alignment, the Santan Canal, as Upper Santan, which sits about four km upstream closer to the head of the water-distribution feature. The Hospital site, on the opposite side of the Gila River, is about seven km to the southeast.

A total of 100 vesicular basalt groundstone artifacts from Lower Santan were analyzed for their geochemistry (Table 7.10). The results of the analysis confirm that the majority of vesicular basalt from Lower Santan originates from the nearby Santan Mountains (Figure 7.7). Sixty-eight percent of the early/middle Sacaton phase material is from the source, as is 89 percent of the late Sacaton/early Soho period sample, and 61 percent of the Classic period sample. A lesser amount of material entered the site from Picture Rocks during all three temporal intervals. One artifact from the early/middle Sacaton sample was traced to the McDowell Mountains and one artifact from the Classic period sample appears to be from Moon Hill. Provenance assignments could not be determined for a handful of artifacts from each temporal context.

Table 7.10. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Lower Santan

	Early/Middle Sacaton		Late Sacaton/ Early Soho		Classic		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Santan Mtn	23	68%	31	89%	19	61%	73	73%
Picture Rocks	4	12%	2	6%	3	10%	9	9%
McDowell Mtn	1	3%					1	1%
Moon Hill/Ludden Mtn					1	3%	1	1%
Unknown	6	18%	2	6%	8	26%	16	16
Total	34	100%	35	100%	31	100%	100	100%

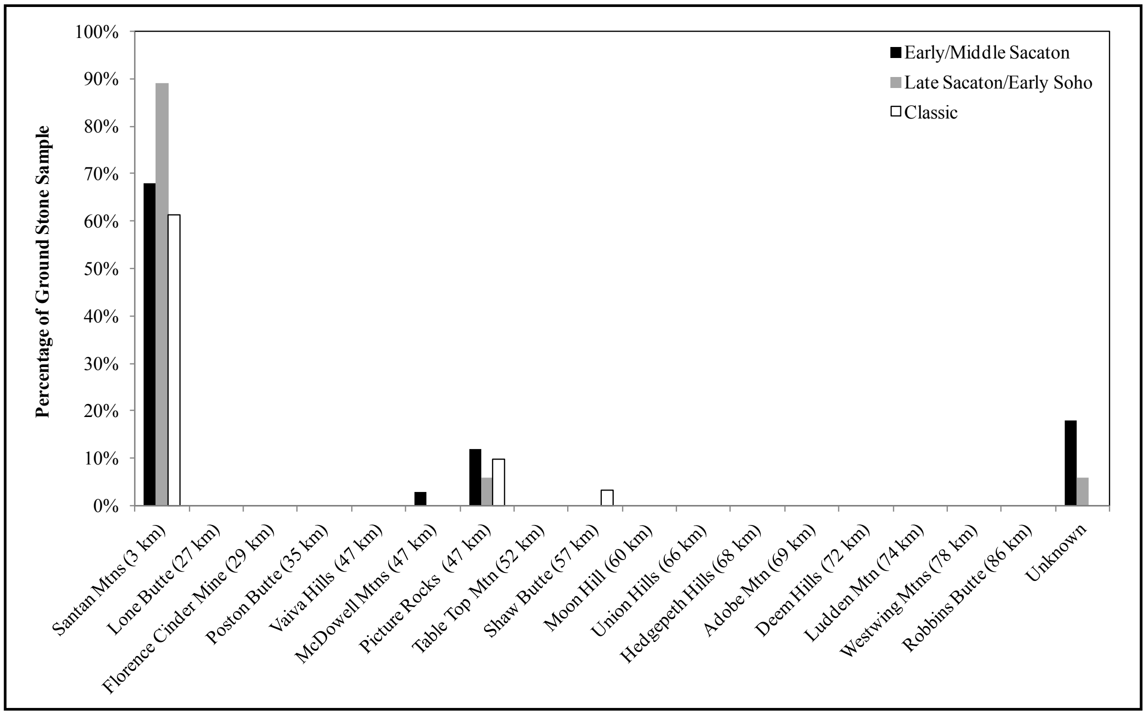

Figure 7.7. Relative Proportion of Vesicular Basalt Source Areas by their Distance from Lower Santan for Preclassic Period Contexts.

The geographic provenance data suggest that households at Lower Santan relied primarily on the nearby Santan Mountains for the majority of their groundstone material. The sheer prevalence of Santan Mountain basalt in the groundstone sample through time supports the direct procurement model for material acquisition. However, these data do not necessarily oppose the direct exchange model, since it is possible that households at Lower Santan acquired material through exchange with related households or tool producers located at Upper Santan. The direct exchange of vesicular basalt between social groups is also supported by the presence of material from the Picture Rocks source during all three temporal periods of investigations.

The vesicular basalt provenance data from Lower Santan do serve to reject the other three models of material distribution considered in this study. The acquisition of groundstone from practically just the Santan Mountains and the more distant Picture Rocks source defies the expectations of the down-the-exchange model. The provenance data also exhibit no change in source preference over time. Spearman's rank-order test found a strong and significant relationship in material acquisition patterns between the early/middle Sacaton and late Sacaton /early Soho ($r_{s=}$ 0.892; $p \leq 0.05$), as well as between the late Sacaton /early Soho to Classic period ($r_{s=}$ 0.892; $p \leq 0.05$). Therefore, the available data do not indicate a change in source distribution and acquisition practices at any point, thereby giving reason to reject the marketplace and elite-controlled exchange hypotheses for the Lower Santan sample.

Pueblo Grande

The prehistoric Hohokam village of Pueblo Grande was situated at the head of Canal System 2 on the north side of the Salt River (see Figure 1.3). The nearest vesicular basalt outcrop to households at this site was Shaw Butte, but again this outcrop is unlikely to have been a major source of vesicular basalt groundstone and is therefore not considered the closest source area to Pueblo Grande for analytical purposes. Lone Butte, at a distance of 20 km, is actually the closest material source area. However, as with most other Salt River sites in the sample set, a trip between Pueblo Grande and Lone Butte would be much greater due to having to circumvent South Mountain. In taking into account these considerations, the nearest vesicular basalt outcrop to Pueblo Grande is actually Moon Hill at a distance of 21 km, followed shortly thereafter by the McDowell Mountains at 23 km. Other basalt source areas within a 50 km radius of Pueblo Grande include the Union Hills (28 km), Hedgpeth Hills (28 km), Adobe Mtn (30 km), Deem Hills (33 km), Ludden Mountain (36 km) and West Wing Mountains in the northern periphery, and the Santan Mountains (43 km) to the southeast. Pueblo Grande and Las Colinas, which are found in the same irrigation cooperative (Canal System 2), are located approximately 12 km apart.

A sample of 65 vesicular basalt artifacts from Pueblo Grande was selected for geochemical analysis (Table 7.11). The vesicular basalt provenance data from Pueblo Grande suggest that Classic period households at the site consumed but did not rely entirely on the nearest available source area for groundstone material (Figure 7.8). Basalt from Moon Hill only constitutes about one-tenth of the inventory during both temporal

Table 7.11. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Pueblo Grande

	Early Classic		Late Classic		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**
McDowell Mtn	7	21%	6	19%	13	20%
Hedgpeth Hills	2	6%	8	26%	10	15%
Moon Hill/Ludden Mtn	3	9%	3	10%	6	9%
Santan Mtn	3	9%	3	10%	6	9%
West Wing Mtn	3	9%	2	6%	5	8%
Deem Hills	1	3%	1	3%	2	3%
Table Top Mtn	1	3%			1	2%
Unknown	14	41%	8	26%	22	34%
Total	34	100%	31	100%	65	100%

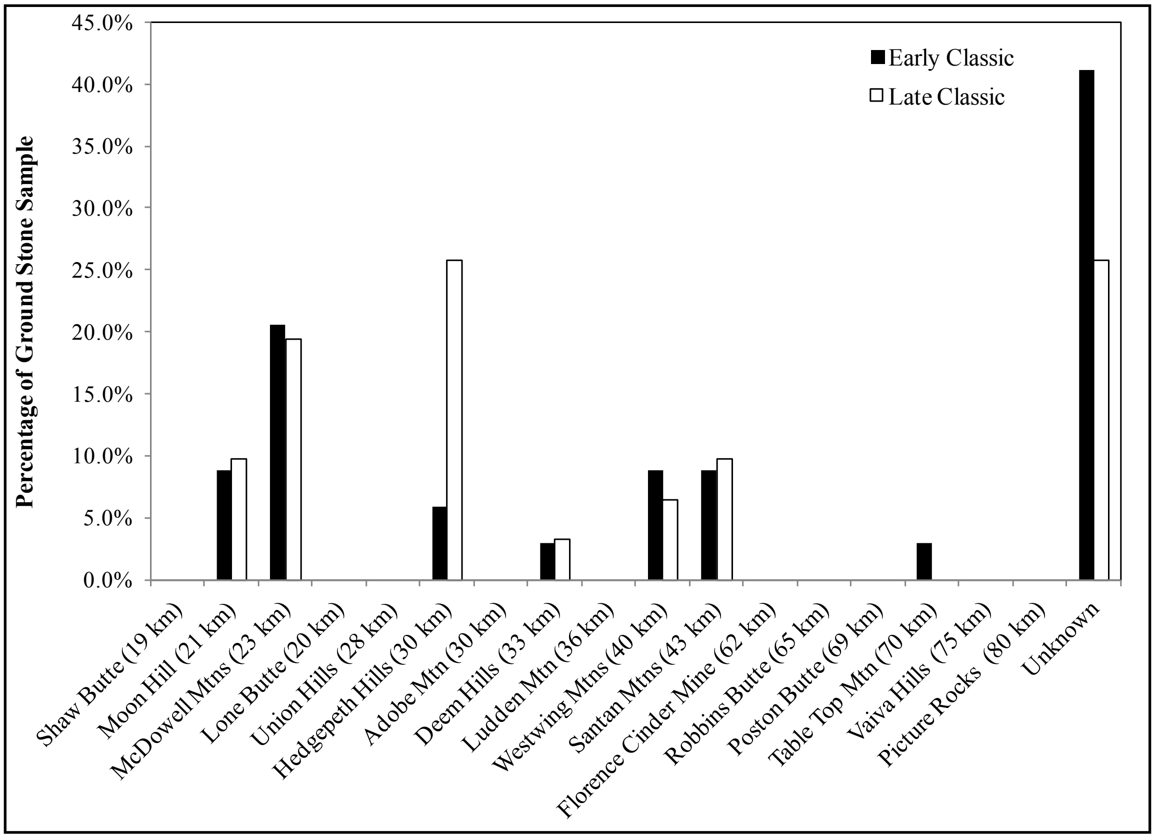

Figure 7.8. Relative Proportion of Vesicular Basalt Source Areas by their Distance from Pueblo Grande for Classic Period Contexts.

intervals analyzed. Material from at least six other source areas comprises the rests of the inventory. Therefore, these data serve to reject the notion that direct procurement from the nearest available source was the primary means of vesicular basalt provisioning at the site.

The geographic source provenance data also do not conform to the expectations of the down-the-line exchange model. Using only source areas represented in the sample groups, a Spearman rank-order correlation tests did not find a strong or significant distance-decay trend during either the Early Classic ($r_{s=}$ -0.468; p>0.05) or Late Classic

($r_{s=}$ -0.468; p>0.05). The association between source frequency and distance from site to source was even weaker for both sample groups when all 17 source areas were included in the analyses. The absence of a distance-decay relationship for the Pueblo Grande Classic period vesicular basalt collection, when so many source areas are represented, justifies dismissal of the down-the-line exchange model for this site.

The similarity in source preference through time at Pueblo Grande also provides a reason to reject the elite-controlled exchange model. The massive platform mound at Pueblo Grande was first constructed during the Early Classic period, but underwent a major expansion during the Late Classic period at the same time that there was increasing centralization of Hohokam economic and political authority (Bayman 2002; Downum and Bostwick 2003:10; Elson and Abbott 2002; Fish and Fish 2000; Harry and Bayman 2000). The continuity in source acquisition practices between the Early and Late Classic contexts, as indicated by a strong and significant correlation in source preference ($r_{s=}$ -0.921; p≤0.05), suggests that aspiring elites had little to no control of vesicular basalt acquisition practices at Pueblo Grande.

Lastly, an intra-site evaluation of source provenance data found no significant difference in source acquisition trends among any of the habitation areas during either the Early or Late Classic. Tables 7.12 and 7.13 show the relative frequency of representative vesicular basalt source areas for those household groups with more than five vesicular basalt samples during the Early and Late Classic periods, respectively. Although some minor differences in source consumption exist among the household groups during both temporal intervals, a BR test determined that none of these differences are significant

(Tables 7.14 and 7.15). From this perspective, the data serve to reject the direct exchange hypothesis.

In sum, the provenance data from Pueblo Grande are unique in that they exhibit patterning that reject all four vesicular basalt procurement and distribution models applicable to the Classic period. The presence and relative frequency of material from multiple source areas is contra to the expectations of the direct procurement and down-the-line exchange hypotheses; the absence of temporal shift in source preference between the Early and Late Classic gives reason to reject the elite-controlled exchange mode; and the lack of spatial differences in source diversity goes against the expectations of the direct exchange model.

Table 7.12. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Early Classic Household Groups at Pueblo Grande

	Area 3		Area 5		Area 7		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Deem Hills	1	9%					1	3%
Hedgpeth Hills			1	14%	1	9%	2	7%
McDowell Mtn	2	18%	2	29%	2	18%	6	21%
Moon Hill/Ludden Mtn	2	18%	1	14%			3	10%
Santan Mtn	1	9%					1	3%
Table Top Mtn	1	9%					1	3%
West Wing Mtn			1	14%	2	18%	3	10%
Unknown	4	36%	2	29%	6	55%	12	41%
Total	11	100%	7	100%	11	100%	29	100%

Table 7.13. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Late Classic Household Groups at Pueblo Grande

	Area 2		Area 5		Area 7		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Deem Hills			1	8%			1	4%
Hedgpeth Hills	1	17%	3	23%	2	29%	6	23%
McDowell Mtn	1	17%	3	23%	1	14%	4	19%
Moon Hill/Ludden Mtn			1	8%	2	29%	3	12%
Santan Mtn	1	17%			1	14%	2	8%
West Wing Mtn	1	17%	1	8%			2	8%
Unknown	2	33%	4	31%	1	14%	7	27%
Total	6	100%	13	100%	7	100	26	100%

Table 7.14. Brainerd Robinson Coefficient of Similarity and Probability Scores for Early Classic period Households Groups at Pueblo Grande

Household Group	Area 3	Area 5	Area 7
Area 3	200	122 (.69)	109 (.44)
Area 5		200	140 (.83)
Area 7			200

Table 7.15. Brainerd Robinson Coefficient of Similarity and Probability Scores for Late Classic period Households Groups at Pueblo Grande

Household Group	Area 2	Area 5	Area 7
Area 2	200	144 (.82)	119.0 (.31)
Area 5		200	119 (.76)
Area 7			200

Upper Santan

The prehistoric to modern day village of Upper Santan is located on the north bank of the Gila River along the same main canal alignment, the Santan Canal, as the village of Lower Santan (see Figure 1.3). The core section of Upper Santan is located about one kilometer from the Santan Mountains, the largest source of vesicular basalt in the middle Gila River Valley. The next closest basaltic outcrop is the Florence Cinder Mine at a linear distance of 25 km to the east. No other sources are found within a 30 km radius of Upper Santan. Lone Butte, another well-known outcrop in the region is approximately 32 miles to the northwest. The closest sample site to Upper Santan is the Hospital Site, which is located just 4 km to the south on the opposite side of the Gila River. Upper Santan and Lower Santan are separated by a distance of roughly five km.

A total 45 vesicular basalt groundstone artifacts from Upper Santan were subject to geochemical analyses (Table 7.16). The vast majority of the vesicular basalt was traced to the nearby Santan Mountains (Figure 7.9). This source area constitutes 87 percent of the Preclassic sample and 80 percent of the Classic period sample. A single artifact from the Preclassic period was found to be from Robbins Butte (n=1; 3%), a source area more than 90 km to the west. Ten percent of the Preclassic sample and 20 percent of the Classic period sample was not sourced to a specific outcrop. However, given the prevalence of Santan Mountain material during both temporal internals, it is likely that this material derives from an as of yet unrepresented portion of the nearby basaltic outcrop. The proximity of Upper Santan to the Santan Mountains source area, along with the overwhelming presence of this material in the vesicular basalt sample, strongly suggests that households at the Santan Mountains acquired groundstone material primarily through direct procurement during both the Preclassic and Classic periods.

Table 7.16. Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts from Upper Santan

	Preclassic		Classic		Total	
Geographic Provenance	**N**	**%**	**N**	**%**	**N**	**%**
Santan Mtn	26	87%	12	80%	38	84%
Robbins Butte	1	3%			1	2%
Unknown	3	10%	3	20%	6	13%
Total (n)	30	100%	15	100%	45	100%

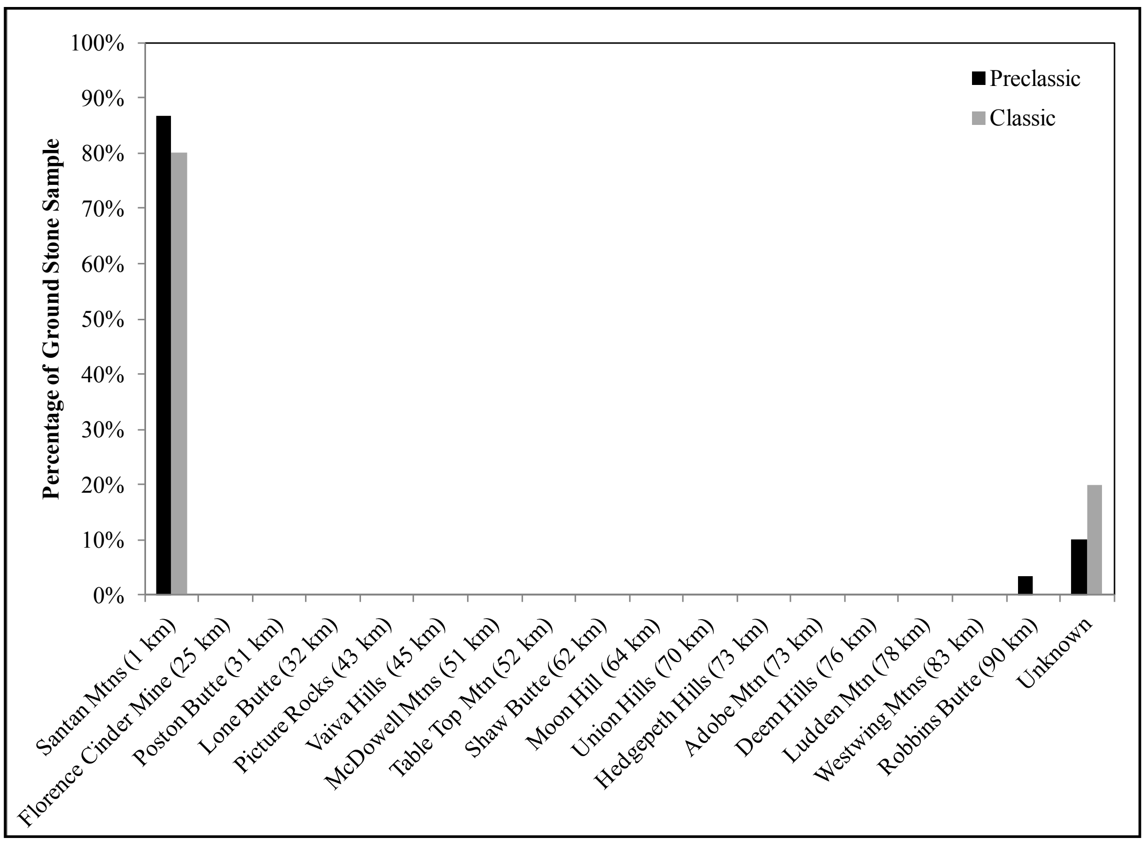

Figure 7.9. Relative Proportion of Vesicular Basalt Source Areas by their Distance from Upper Santan for Preclassic and Classic Period Contexts.

Evaluation of Research Hypotheses

The vesicular basalt provenance data from the nine sample sites provide a peek into Hohokam groundstone provisioning practices at each site. However, to better understand the organization of groundstone procurement and distribution in the Salt-Gila Basin, it is best to consider the study sample as a whole. This perspective allows a more comprehensive examination of spatial and temporal patterns, which in turn provides a better view on the movement of the textured stone in the study area. In using this approach, direct procurement model is found to be a possible explanation for some of the sites in the study sample, namely those that are located less than 10 km from a vesicular basalt outcrop. Direct exchange is considered an unlikely explanation, though it cannot be dismissed outright. The other three exchange hypotheses, down-the-line exchange, market exchange, and elite-controlled exchange, as defined in this study are rejected as plausible explanations.

Direct Procurement

The direct procurement model for vesicular basalt acquisition is supported by the observations at Upper Santan, Lower Santan, the Hospital Site, and possibly La Plaza. The first three of these sites all exhibit an exclusive preference for textured stone from the nearest available source area, the Santan Mountains. The inhabitants of La Plaza also exhibited a strong preference for material from the McDowell Mountain source areas, the closest source area to that site (see Figure 7.4). However, a large proportion of the sample from La Plaza is from an unknown source area. This material may be from an unsampled portion of the McDowell Mountains or from one or more different source areas. Thus, while the available data from La Plaza suggest reliance on the closest source area, the acquisition of material from multiple source areas cannot be dismissed. Since the exclusive acquisition of groundstone material from the closest source area is an expectation of the direct procurement model, it is likely that this provisioning practice was pursued by households at Upper Santan, Lower Santan, the Hospital Site, and potentially La Plaza.

Vesicular basalt provenance data patterning from the sites of Casa Grande, Gila Crossing, Los Hornos, Las Colinas, and Pueblo Grande lead to a rejection of the direct procurement model. None of these sites relied on the nearest available basaltic outcrop for groundstone material. Vesicular basalt from Lone Butte was not well represented in Preclassic contexts at Gila Crossing or Los Hornos, whose households chose instead to acquire material from the McDowell Mountain and Santan Mountain source areas. The Moon Hill source area, the closest vesicular basalt outcrop to the site of Las Colinas, never constitutes more than 24 percent of the site’s basalt inventory. Likewise, less than one-fifth of the entire Classic period sample at Pueblo Grande derives from Moon Hill. Lastly, both the Preclassic and Classic period inhabitants at Casa Grande avoided material from the two closest source areas in the representative database, Poston Butte and Florence Cinder Mine, and acquired material instead from the more distant Picture Rocks source area.

The acquisition of vesicular material from comparatively distant source areas is not considered to be a result of material preference by groundstone manufactures or consumers. All of the sources areas included in the representative geochemical database were specifically selected because material from these locations exhibit textural and mineralogical attributes favored in the production and use of groundstone tools (Hayden 1987:15; Horsfall 1987:344; Schneider 2002; Schneider and LaPorta 2008:24). Moreover, the raw material samples that comprise this database were collected primarily from locations with documented evidence of prehistoric groundstone manufacture. Therefore, it is imprudent to conclude that stone from any of the outcrops included in this study was undesirable to indigenous households. Some other factor must have promoted the acquisition of vesicular basalt from the more distant source areas. It is presumed, then, that source selection patterning at these sites indicates households preferred to acquire vesicular basalt through exchange rather than procure it themselves from the nearest available outcrop.

The preference to obtain vesicular basalt through exchange rather than direct procurement may simply be a matter of transport cost. It is notable that the three sites (Upper Santan, Lower Santan, and the Hospital Site) with substantial evidence for direct procurement are all located less than 10 km from a vesicular basalt source area. In contrast, those sites (Casa Grande, Gila Crossing, Las Colinas, and Pueblo Grande) that likely relied on exchange to acquire groundstone are situated more than 10 km from a basaltic outcrop. Ethnographic evidence reveals that prehistoric groups in the Southwest would travel up to 50 km to procure groundstone material (Schneider 2002:391). Though perhaps in the Hohokam case, a distance of 10 km was the point at which the effort of procuring and transporting groundstone material by oneself began to outweigh the cost of acquiring it through exchange relations. This division in provisioning practices is sensible for some households because not only does it help to reduce transport costs associated with movement of cumbersome manos and metates across large distances, but it would also save time and effort in not having to perform initial quarry and tool shaping. Thus, direct procurement may only have been a reasonable provisioning practice for households located less than 10 km from a vesicular basalt source area; those households located more than 10 km from a source perhaps found it more efficient to acquire raw material or finished tools through exchange.

Direct Exchange

The vesicular basalt geographic provenance data from Casa Grande, Gila Crossing, and Los Hornos all provide tentative support for the direct exchange model. None of these sites show an abundance of material from the most proximate source area or a strong and significant distance-decay trend in relative source frequency. Rather, households at these sites acquired material from multiple, differently located source areas. The inhabitants of Casa Grande, for instance, did not acquire much textured stone from the proximate Florence Cinder Mine, but instead preferred material from the Picture Rocks to the east and the Santan Mountains to the west. The dearth of vesicular basalt from the most immediate source, along with the inclusion of stone from source areas in opposite directions, suggests that various exchange relations likely account for the importation of groundstone material. A similar pattern and therefore interpretation is applicable for Gila Crossing and Los Hornos.

The provenance data from Las Colinas and Pueblo Grande at first also appear to conform to the expectations of the direct exchange model. However, a more nuanced look at the data paints a different picture. At these two sites, the relative frequency of vesicular basalt source areas is not related to geographic distance, which is expected for the direct exchange model and similar to other sites in the study sample that are located more than 10 km from a vesicular basalt outcrop. Though, in contrast to the test expectations for direct exchange, an evaluation of intra-site source diversity variance found no significant differences among any of the contemporaneous habitation groups at either site during any time period. For example, household groups at Las Colinas acquired material from the same four or five source areas during the middle Sacaton, late Sacaton, and Early Classic period. Therefore, the direct exchange hypothesis, which expects individual social units to engage in their own unique exchange networks, is not entirely satisfied for the sites of Las Colinas and Pueblo Grande.

The geographic provenance data patterning for Lower Santan and the Hospital site are also not directly supportive of the direct exchange model, but this acquisition model cannot be dismissed outright in these cases. As discussed earlier, these two sites acquired the bulk of their vesicular basalt for groundstone tool production from the nearby Santan Mountain source area. This data patterning is consistent with the direct procurement model. However, it is still possible that households from these sites chose to receive the textured stone through exchange with their neighbors at Upper Santan, who were located immediately adjacent to several known groundstone quarries. Source homogeneity at these sites is thus a matter of the short distance to tool producers at Upper

Santan, and not the result of direct procurement. Therefore, while the provenance data from Lower Santan and the Hospital site lean towards the notion that households from these sites acquired vesicular basalt through direct procurement, the exchange of raw material or finished tools with kin or trade partners at Upper Santan cannot be ruled out entirely.

The village of La Plaza also appears to have relied on direct procurement to acquire vesicular material, but the direct exchange model cannot be eliminated for this site due to insufficient source characterization of the artifact sample. The available provenance data from this site suggest that its inhabitants relied heavily on the McDowell Mountains for groundstone material, the closest source area to the site. Still, like the inhabitants of Lower Santan and the Hospital site, it is possible that individuals from La Plaza obtained vesicular basalt from the McDowell Mountains through direct exchange. This notion is supported by the presence of material from other source areas, such as the Santan Mountains and potentially other unknown outcrops. Additionally, La Plaza is located more than 10 km from the McDowell Mountains, which may be an approximate cut-off point for effective direct procurement. Thus, the relatively high proportion of vesicular basalt from the McDowell Mountain source area at La Plaza is not a sufficient reason to reject the direct exchange model at this site.

In sum, there is reason to consider direct exchange as a plausible model for vesicular basalt acquisition at Casa Grande, Gila Crossing, Los Hornos, and La Plaza during the Preclassic and Classic periods. However, the data from Las Colinas and Pueblo Grande do not entirely fit the test expectations for direct exchange. For though these two sites contain vesicular basalt from a variety of sources, they show no intra-site variability in vesicular basalt source types. This finding calls into question the viability of the direct exchange model for Casa Grande, Gila Crossing, Los Hornos, and La Plaza. If an evaluation of intra-site vesicular basalt source type patterns was also possible for these sites, there might then be evidence to refute the direct exchange hypothesis at these locations. For now, the direct exchange model remains a possible but unlikely explanation for vesicular basalt movements in the Hohokam territory. Future investigations should focus on resolving this matter.

Down-the-Line Exchange

The down-the-line exchange model for vesicular basalt distributions is rejected given the data at hand. Of the nine sites in the study sample, not one showed evidence of a distance-decay relationship in source frequency during any temporal period. Thus, the patterning that is exemplar of down-the-line exchange was not observed among a total of 17 different spatial-temporal contexts. The relative frequency of vesicular basalt source areas at a site instead seemed to reflect reliance on the closest available source area (i.e., direct procurement) or the selective acquisition of material from multiple differently-located sources. The latter trend is more consistent with other forms of exchange, such as direct, marketplace, and elite-controlled exchange. Therefore, there is abundant evidence to suggest that the down-the-line exchange model is not a credible explanation for the movement of vesicular basalt raw material or finished groundstone tools during the Hohokam Preclassic and Classic periods.

Market Exchange

An evaluation of regional patterning in source provenance data has found equivocal support of the market exchange hypothesis. One line of evidence that supports this explanation is intra-site source type diversity. At Las Colinas, the only Preclassic site in the study sample for which an intra-site comparison of vesicular basalt distribution was possible, statistical analyses found no significant difference in source diversity between two household groups during the middle Sacaton phase (see Table 7.6). Though this sample is rather small, the result indicates that these two household units at Las Colinas had equal access to the same source areas as other groups, which is an expectation of market exchange.

A second piece of evidence that supports the market exchange hypothesis is the observed temporal shift in source type frequency between the middle and late Sacaton contexts at Las Colinas. Spearman's rank-order correlation test failed to identify both a strong or significant relationship in source preference between these two periods ($r_{s=}$ 0.591; $p>0.05$). A major contributing factor to this weak association was a significant increase in the acquisition of the closest available source, Moon Hill, and a corresponding decrease from the more distant McDowell Mountain source area. This trend provides support for the notion that the collapse of the ballcourt network and the associated market-like distribution system in the late Sacaton may have also affected the distribution of vesicular basalt, specifically the long-distance movement of the stone from communities near the McDowell Mountains to Las Colinas.

However, this distribution of vesicular basalt through markets can be discredited on two accounts. First, households at Las Colinas continued to import material from several source areas during the late Sacaton and Early Classic, including material from outcrops in the northern periphery (Deem Hills, Hedgpeth Hills, and West Wing Mountain). If the movement of groundstone material was part of a highly-specialized and regionally-integrated market economy, then we should expect material from more distant source areas, not just the local McDowell Mountain source area, to decrease significantly in the late Sacaton. However, a difference of proportions test reveals that there was no significant decline in the proportion of vesicular basalt from the Hohokam northern periphery between the middle and late Sacaton periods ($Z=1.587$; $p=.06$). Thus, the increased importation of Moon Hill was potentially the result of decreased exchange with tool producers in the McDowell Mountain area only, and not a response to economic disintegration in the Salt-Gila Basin.

A second reason for rejecting the market exchange model is the lack of regional homogeneity in source type diversity. The market exchange hypothesis expects substantial regional homogeneity in the distribution of goods (Garraty 2009; Hirth 1998). In contrast to this expectation, there is measurable variability among the archaeological sample sites. A BR test of similarity for geographic provenance assignments among the Preclassic sample reveals that 17 of the 28 (61%) possible site comparisons were more dissimilar than they were alike, and five of these differences were found to be significant ($p < 0.05$) (Table 7.17). Further consideration of the provenance data and test results

Table 7.17. Brainerd Robinson Coefficient of Similarity and Probability Scores for Provenance Assignments among Preclassic Archaeological Site Samples

	Gila Crossing	Hospital Site	La Plaza	Las Colinas[1]	Los Hornos	Lower Santan	Upper Santan
Casa Grande	104 (.74)	**58** (.19)	**93** (.43)	**59** (.49)	**51** (.14)	**54** (.43)	**33 (.01)**
Gila Crossing		102 (.65)	143 (.89)	105 (.69)	105 (.65)	**83** (.54)	**84** (.48)
Hospital Site			**69** (.25)	**48** (.16)	**63** (.17)	178 (.99)	175 (.97)
La Plaza				100 (.77)	153 (.91)	**56** (.37)	**50** (.08)
Las Colinas					116 (.75)	**32 (.01)**	**29 (.02)**
Los Hornos						**51** (.15)	**45 (.03)**
Lower Santan							177 (.99)

[1] Includes only middle Sacaton Phase Sample

suggest the presence of three different distribution and consumption spheres that are coterminous with geographic areas. One of these areas encompasses the distribution of Picture Rocks material in the Florence area as evidenced at Casa Grande; the second area includes sites in the western section of the middle Gila River Valley (Upper Santan, Lower Santan, and the Hospital Site) that relied on material from the Santan Mountains; and the third consist of a mix of McDowell Mountain, Moon Hill, and northern Periphery sources in the lower Salt River Valley (La Plaza, Las Colinas, Los Hornos, Pueblo Grande). Notably, these distribution areas are not discrete boundaries, as exemplified by the consumption of Santan Mountain and McDowell Mountain material at Gila Crossing near the confluence of the Salt and Gila Rivers. The identification of multiple overlapping distribution spheres discredits the notion of a single, wide-spread, and integrated market exchange economy for the production and distribution of vesicular basalt groundstone tools.

Elite-Controlled Exchange

Evaluation of the elite-controlled exchange model also led to mixed results. The primary line of data supporting this provisioning model is the lack of intra-site difference in source type among Classic period households at Las Colinas and Pueblo Grande. At Las Colinas, a BR test found no significant difference between the platform mound compound (Area 3) and one domestic habitation group (Area 7; see Table 7.8). Similar patterning was observed among the Early and Late Classic period households at Pueblo Grande (see Tables 6.14 and 6.15). Because elite-controlled exchange can result in the mixing of source material among households, and direct exchange relations often leads to spatially-discrete differences, the data patterns at Las Colinas and Pueblo Grande give no reason to reject the elite-controlled exchange model.

An inspection of temporal trends in source preference, however, does provide justification for discrediting the elite-controlled exchange hypothesis. The vesicular basalt provenance data at Las Colinas revealed a strong and significant correlation in source preference between the late Sacaton and Classic periods ($r_{s=}$ 0.756; $p \leq 0.05$). At this site, then, there was no indication that the rise of platform mound ceremonies at the start of the Classic period had any influence on vesicular basalt distribution practices. Furthermore, an evaluation of Early and Late Classic period contexts at the site of Pueblo Grande found a very strong significant correlation in the rank-order of vesicular basalt source areas between the two temporal intervals ($r_{s=}$ -0.921; $p \leq 0.05$). If elite-controlled exchange was integral to the Hohokam economy, it most likely would have been during the Late Classic period when compound walls and room structures began to be constructed at ceremonial platform mounds (Bayman 2002; Downum and Bostwick 2003:10; Elson and Abbott 2002; Fish and Fish 2000; Harry and Bayman 2000). Together, then, the absence of a temporal shift in vesicular basalt source acquisition trends between the Preclassic and Classic at Las Colinas, and again between the Early Classic and Late Classic at Pueblo Grande, provides reason to reject the elite-controlled exchange hypothesis.

A New Model for Vesicular Basalt Groundstone Tool Production and Distribution

The models of vesicular basalt distribution practices as defined and tested in this study do not fully account for Hohokam household groundstone provisioning practices. Direct procurement may be applicable for some households, but certainly not all of them since the majority of Hohokam settlements in the Salt-Gila Basin were located more than 10 km from a vesicular basalt quarry. The direct exchange model is supported by the variety of sources present at some sites, but not by intra-site distribution patterns in Preclassic and Classic contexts. Down-the-line exchange clearly is not an acceptable explanation. The Preclassic market exchange and Classic period elite-controlled exchange hypotheses are supported by homogenous intra-site source distribution patterns. However, the market exchange hypothesis is questionable due to the fact that most peripheral sources present in middle Sacaton contexts at Las Colinas continue to flow into the site during the late Sacaton and Early Classic periods. Similarly, elite-controlled distribution is discredited by continuity in source preference through time between the late Sacaton and Classic period at Las Colinas, and the Early to Late Classic transition at Pueblo Grande. Thus, aside from direct procurement at Upper Santan (and possibly Lower Santan and the Hospital Site), the hypotheses do not adequately fit the observed archaeological patterns.

Based on these results, a new model of vesicular basalt procurement and distribution is offered. The revised hypothesis is most similar to the market exchange model as defined in this study in that it suggests that vesicular basalt groundstone tools were produced at select locations by specialists. It differs, though, in that rather than periodic marketplaces (see Abbott 2006, 2009, 2010; Abbott et al. 2001; Abbott et al. 2007a; Abbott et al. 2007b), finished groundstone tools were acquired through either workshop procurement or perhaps local distributers. Further, it argues that this organization existed not only during the Preclassic period, but the Classic period as well. Overall continuity in vesicular basalt groundstone provisioning practices from the Preclassic to Classic periods is contrary to findings related to other classes of goods (e.g., ceramics, shell, and obsidian) and therefore should be met with some skepticism. However, evidence for specialists is not completely absent during the Classic period, and it is possible that the limited availability of vesicular basalt promoted the concentrated production of groundstone tools throughout the Hohokam sequence. The following paragraphs elaborate on the supporting evidence for the revised model.

The first line of evidence in support of the alternative groundstone provisioning model is the production and distribution of select vesicular basalt source areas. The geographic provenance data from this study suggest that the manufacture of groundstone tools for regional distribution was concentrated at a handful of locations in the Salt-Gila Basin. Preliminary research efforts for this study identified 40 prehistoric vesicular basalt quarries among 23 spatially-discrete basaltic outcrops in the Salt Gila Basin. Raw material collection efforts for this study were conducted at a total of 27 quarry sites found among 17 different formations (see Table 4.1). Geochemical analysis of 484 groundstone artifacts from the nine archaeological sites revealed that only 11 of the 17 sampled source areas were represented in cultural contexts (Table 7.18). Two of these eleven sources areas, the Santan Mountain (n=165; 34%) and McDowell Mountain (n=72; 14.9) areas,

Table 7.18. Complete Geographic Provenance Assignments for Vesicular Basalt Groundstone Artifacts

Geographic Provenance	Frequency	Proportion
Santan Mountains	165	34.1%
McDowell Mtns	72	14.9%
West Wing Mtns	26	5.4%
Picture Rocks	23	4.8%
Moon Mountain	23	4.8%
Hedgpeth Hills	13	2.7%
Deem Hills	10	2.1%
Robbins Butte	5	1.0%
Table Top Mountain	2	0.4%
Lone Butte	2	0.4%
Florence Cinder Mine	2	0.4%
Adobe Mtn	0	0.0%
Ludden Mountain	0	0.0%
Poston Butte	0	0.0%
Union Hills	0	0.0%
Vaiva Hills	0	0.0%
Unknown	141	29.1%
Total	484	100.0%

comprise about half of the total inventory. Another three source areas, the West Wing Mountains in the northern periphery; the Picture Rocks source near Casa Grande; and the Moon Hill source in central Phoenix; combine to account for another 15 percent of the artifact sample. Thus, the majority of vesicular basalt groundstone artifacts consumed by Hohokam households were traced to just 5 of the 23 outcrops within the Salt-Gila Basin.

Again, differences in material quality are not considered a likely explanation for source preference because the reference material is from areas that were exploited by the Hohokam, and thus were selected by prehistoric tool producers, if only for minimal local use. Therefore, it is inferred from the present data that groundstone tools for the majority of households in the Salt-Gila Basin were being manufactured at only a handful of the available resource areas within the Hohokam core territory. This observation is argued to be evidence for the concentrated production of groundstone tools and also the distribution of finished products between non-related persons.

A second line of evidence in support of the new groundstone provisioning model is the spatial distribution of vesicular basalt. The market exchange hypothesis, as originally defined and tested in the study, expected a substantial degree of homogeneity in the regional distribution of goods due to the existence of periodic, rotating marketplaces. This expectation was based on the results of ceramic production and distribution studies, which have found abundant evidence that during the middle Sedentary period, tool producers in just five locations were responsible for producing nearly all of the earthenware containers found at households throughout the lower Salt River Valley (Abbott 2009). Abbott (2006, 2009, 2010; Abbott et al. 2007a; Abbott et al. 2007b) has inferred from this scale of concentrated production that periodic marketplaces attached to communal ballcourt festivals were functionally necessary to distribute the large quantities of earthenware containers from the small number of producers to the large body of consumers. Contrary to this patterning, this study found at least three different vesicular basalt distribution spheres that appear to be largely coterminous with the different river valleys, or segments thereof. Again, these distributional areas include the Picture Rocks material in eastern middle Gila River Valley; the Santan Mountain source area in the western section of the middle Gila River Valley; and the McDowell Mountain, Moon Hill, and northern periphery sources in the lower Salt River Valley. The provenance data therefore indicate that a regionally-integrated system of revolving marketplaces, if ever present, was not responsible for the distribution of vesicular basalt throughout the Salt-Gila Basin. Yet, the data suggest the scale of specialization and material transfers was greater than that which could have been achieved through socially-based exchanges. From this understanding, it is suggested that specialists produced vesicular basalt groundstone tools that were then acquired by households through either workshop procurement or from distribution specialists in their own community. This arrangement is reasonable because it would have effectively minimized distribution costs from the point of view of tool producers, while also serving to minimize tool production or acquisition efforts for the consumer (Watts 2013).

A third line of evidence supporting the new vesicular basalt provisioning hypothesis is the similar distribution of manos and metates. If the production and distribution of vesicular basalt groundstone tool were organized at the regional level, then the average distance manos and metates traveled before reaching a site would be expected to differ since tool makers in different source areas would have been responsible for producing different types of grinding tools. We can also expect the movement of manos and metates to be slightly different if vesicular basalt was acquired through direct exchange with kin or known trade partners. One reason for the divergent paths in this scenario would have been the ease of gifting manos compared to metates. However, if groundstone tools were produced by specialists at a handful of locations, and if tools were acquired through workshop procurement or from individuals who specialized in the local distribution of these tools, then it can be expected that the spatial distribution of manos and metates would be similar. This expectation is based on the premise that tool producers would be responsible for the manufacture of both manos and metates for distribution in their local sphere. Additionally, material transfers are occurring independently of social relations, meaning that manos moved no less frequently than metates between persons. An examination of the vesicular basalt source areas by tool type at each of the sites in study area that contained material from multiple sources found no difference in the median distance traveled by manos and metates (Table 7.19). These results are therefore more consistent with the expectations of a specialist based production and exchange economy than one in which goods are moving through social networks or regional marketplaces.

Table 7.19. Mann-Whitney Wilcoxon Test Results for Mano and Metate Distributional Distance by Site

	Median Distance (km)			
Site Name	**Mano**	**Metate**	**Z**	**p**
Casa Grande	23	22	1.236	0.216
La Plaza	19	19	0.567	0.571
Las Colinas	32	32	0.465	0.642
Los Hornos	26	27	0.431	0.667
Pueblo Grande	30	30	0.162	0.871

The fourth and final piece of evidence that supports the new groundstone provisioning model is intra-site source type diversity during the Preclassic and Classic periods. The Preclassic and Classic period households at Las Colinas and also the Classic period households at Pueblo Grande were able to acquire vesicular basalt from a number of source areas, and there was no significant difference in access to these sources among spatially-discrete social units. For instance, even during the late Sacaton, a time of supposed economic collapse and reorganization (Abbott 2003a, 2003b, 2003c, 2009, 2010; Abbott et al. 2001; Abbott et al. 2007a; Abbott et al. 2007b), Areas 4 and 5 at Las Colinas contained material from at least five sources, four of which are the same. It is reasoned from these observations that groundstone tool production was an economic pursuit. Moreover, unrelated households or distribution specialists could visit these production workshops to acquire finished groundstone tools. This explanation is sensible because the demand for vesicular basalt trough metates and two-handed manos would have persisted through time due to the Hohokam's consistent dependence on irrigation agriculture. Additionally, economically-motivated production and distribution specialists would not have been greatly affected by the broader social, ritual, and potentially political transformations that characterized the Preclassic to Classic transition (Abbott 2003a, 2003b; Bayman 2001; Doyel 1980; 2000). Thus, the temporal continuity in source diversity at Hohokam villages might be explained by the presence of economically-motivated tool production and distribution specialists as well as the practice of workshop procurement.

Admittedly, a model of Hohokam economic organization that posits overall continuity between the Preclassic and Classic period is likely to be treated with some skepticism given that the Preclassic-Classic transition is regarded as a hinge-point in the Hohokam cultural sequence. This transformative interval marks the disintegration of the regionally-integrative ballcourt network, a shift in mortuary and ritual practices, demographic upheaval, and a reorganization of the ceramic, obsidian, and marine shell economies (Abbott 2003a, 2003b, 2009, 2010; Bayman 2001; Crown 1991; Doyel 1980, 1991a, 1991b, 2000; Fertelmes et al. 2012; Kelly 2013; Neitzel 1991; Nelson 1991; Sires 1987; Teague 1984; Watts 2013). Furthermore, scholars generally agree that the Classic period was a time of decreased social interaction and economic disintegration in the Salt-Gila Basin. The primary line of evidence for this view comes from ceramic studies, which show a shift from a highly specialized, regionally interdependent production and exchange economy in the late Preclassic, to an economy characterized by local production and more spatially restrictive, preferential exchange networks in the Classic period (Abbott 2000, 2009; Abbott et al. 2006).

However, it is argued that two factors promoted continuity in groundstone production and distribution practices from the Preclassic to Classic. The first factor is the limited availability of vesicular basalt. Unlike the production of ceramics, the manufacture of vesicular groundstone tools required material that was not locally available to most Hohokam households. Because vesicular basalt is naturally concentrated at specific locations, there was a fitting context for the emergence of tool production specialists, no matter the time period. A second and related reason for continuity is due to limitations in transporting heavy and bulky groundstone tools. It was perhaps not realistic for producers in just one or two communities to service the entire basin, and therefore multiple tool production locations could coexist. Thus, upon the collapse of the highly-specialized ceramic production and integrated exchange economy at the end of the Sedentary period, a similar shift from regional to local distribution was not possible for vesicular basalt due to the limited availability of vesicular basalt in the Salt-Gila Basin on the one hand, and also the potential limits of effective material distributions on the other.

The presence of concentrated production during the Classic period is also without precedent. One area of the Hohokam economy in which specialists were still present was the ceramic realm. Despite the disintegration of specialized plain and buff ware production at the end of the Sedentary period, the manufacture of painted red ware bowls and jars continued to be concentrated at communities located along the eastern flank of South Mountain and in some part of the middle Gila River Valley (Abbott 2003c). The distribution of these vessels exceeded those for plain ware pots in the Classic period, suggesting to Abbott (2003c:155) that they “circulated in a wider sphere of exchange that probably also included parties who were socially distant from one another.” In other words, the artisans pursued an economic rather than social reward for their effort. Given the nonubiquitous distribution of vesicular basalt outcrops in the Salt-Gila Basin, it is likely that there was also an economic motivation to continue producing vesicular basalt groundstone tools for extra-local exchange. In fact, it is even possible that one reason why potters near South Mountain produced red wares for extra-local distribution is because they were not in a prime location to acquire vesicular basalt.

To recap, there is evidence for concentrated production of vesicular basalt groundstone tools, the exchange of finished tools between socially distant peoples, and also continuity in production and distribution practices from the Preclassic through Classic period. It is inferred from these patterns that periodic marketplaces associated with ballcourt festivals were not responsible for moving finished groundstone tools around the Salt-Gila Basin, nor was there any elite involvement in the production and exchange of vesicular basalt. Instead, it is suspected there were specialists at a handful of communities that produced groundstone tools for an economical reason, and that individuals or households from elsewhere would come to these locations to acquire finished groundstone tools and bring them back to their own communities for use or secondary exchange.

Summary

Evaluation of the five research hypothesis resulted in the rejection of three models of Hohokam vesicular basalt provisioning practices, including down-the-line exchange, market exchange, and elite-controlled exchange. Direct exchange is also an unlikely model, though it cannot be dismissed outright based on the available sample and it probable that some sites in the Hohokam area pursued this provisioning method. Direct procurement survives as a possible explanation, but only for those sites located in proximity to a vesicular basalt outcrop. Thus, an improved understanding of Hohokam groundstone provisioning practices has been achieved through the elimination of potential explanations for the prehistoric movement of vesicular basalt.

The results of the hypothesis testing were also used to develop new model of Hohokam groundstone provisioning practices that better accounts for the observed archaeological patterns. This new model suggests that vesicular basalt groundstone tool production was concentrated at select locations and that the finished tools were acquired by households through either workshop procurement or from local distributers who specialized in acquiring material for the community. This alternative model of Hohokam groundstone provisioning practices is consistent with several provenance data patterns observed in this study, including the select acquisition of vesicular basalt from a handful of locations, homogenous intra-site source diversity variance, temporal continuity in source preference, and similar spatial distribution of different tool forms from the same source areas. Future testing of the model will certainly be needed to assess its validity.

CHAPTER 8: CONCLUSIONS

This study has improved current understandings of Hohokam vesicular basalt groundstone provisioning practices by eliminating possible hypotheses concerning material movements and also providing a new model of groundstone tool production and distribution. These results are significant because they have implications for scholarly conceptions of the Hohokam domestic economy and also broader anthropological theory on sociocultural evolution. The study is further significant because the PXRF provenance methods developed and used in this study demonstrate the efficacy of nondestructive analytical techniques for sourcing chemically heterogeneous lithic material. In the closing chapter of this dissertation, the implications of this study for Hohokam archaeology, anthropological theory, and sourcing methods are discussed.

Vesicular Basalt and Hohokam Domestic Economy

Knowledge of the Hohokam domestic economy is largely informed from studies of ceramic and obsidian provenance and distribution patterns. Analysis of local ceramic production and circulation tendencies in the Salt-Gila Basin reveals that Hohokam communities were interdependent for the supply of utilitarian goods and possibly comestibles during much of the Preclassic period (Abbott 2009, 2010; Kelly 2013; Watts 2013). By the beginning of the Classic period, though, the ceramic data suggest that households "took a step back from the sophisticated supply-and-demand arrangements of the Sedentary period by producing, at a local level, the full complement of vessel shapes and sizes" (Abbott 2003a:209). Thus, there was a major reorganization of the Hohokam domestic economy from one characteristic of household and community interdependence, to one of independence and self-sufficiency.

Analysis of nonlocal obsidian distributions also suggests a reorganization of Hohokam economic and social interactions between the Sedentary and Classic periods. During the Preclassic period, obsidian from source areas to the north, east, south, and especially west (e.g., Superior obsidian) entered the Salt-Gila Basin (Bayman and Shackley 1999; Fertelmes et al. 2012; Loendorf 2010; Marshall 2002; Mitchell and Shackley 1995; Shackley 2005). However, during the Classic period, several obsidian sources were no longer accessed by Hohokam core households as there was a shift in emphasis to volcanic glass from areas located to the south (e.g., Sauceda and Los Vidrios obsidian). Thus, similar to the ceramic analyses, the regional exchange of obsidian also appears to have transitioned in the Classic period from widespread to preferential exchange relations.

In contrast to the ceramic and obsidian distribution patterns, this analysis found the Preclassic to Classic period transition had no profound effect on vesicular basalt movements in the Hohokam territory. The data suggest instead that groundstone tool production was concentrated at the same locations during both temporal intervals. In addition, there is no indication that there was a dramatic change in the organization and direction of distribution networks between the two periods. These findings are important because they provide a new perspective on the Hohokam domestic economy and regional social relations. Specifically, they suggest that the perception of the Hohokam Classic period economy as one typified by self-sufficient communities, is slightly misleading.

The vesicular basalt data patterning reveal instead that communities located more than 10 km from a vesicular basalt outcrop were still dependent on others for groundstone tools. Perhaps, then, the movement of vesicular basalt in the Salt-Gila Basin was something that potentially tied different Hohokam communities together during the Classic period.

Vesicular Basalt and Hohokam Political Economy

The results of this study also afford some opportunity to comment on the causes and mechanisms correlated with the development of socially stratified societies and institutionalized political organizations (Earle 2002; Johnson and Earle 2000; Service 1962; Trigger 1998). A myriad of variables related to the rise of social inequality have been presented and tested by archaeologists and anthropologists over the past half century, the breadth of which is not reviewed in this discussion. A popular theory, though, is that a primary driver of cultural change is control over economic processes (Earle 1977, 1987, 1997, 2002; Brumfiel and Earle 1987b; Johnson and Earle 2000; Rousseau 2006). This position, labeled the “materialist” or “political” approach, presumes that every society has ambitious individuals who seek to create and maintain prestige and power. These individuals may elevate their status through several different ways, but control over the production and exchange of subsistence and wealth goods is regarded as a basic factor because it restricts others from accessing key resources necessary for social reproduction (Earle 1997:12). Status rivalries among competing individuals, groups, or classes result in ever increasing efforts to maximize economic advantage (i.e., control), which in turn leads to greater elaborations (or collapse) of social, political, and even religious institutions that reinforce the interests of elites (Johnson and Earle 2000:26). The manner by which surpluses are mobilized and allocated to support political activities, lifestyles, and the operations of social institutions and their leaders is termed "political economy" (Earle 2002:9).

The archaeological literature is replete with examples that link the monopolization of economic resources with the rise of social inequality. Many of these studies emphasize the role that material wealth (i.e., prestige goods, social valuables) plays in the political economy and increasing social differentiation (e.g., Bayman 1995, 2002; Brumfiel and Earle 1987a; Brunton 1975; Clark and Blake 1994; Earle 1987, 1997, 2002; Graves and Spielmann 2000; Healan 1993; Helms 1992; McGuire and Howard 1987; Rathje 1972; Rousseau 2006; Saitta 2000). Material wealth, which includes items of personal adornment or display, typically serve as means of payment, symbols of status or legitimate power, and evidence of sanctity in traditional societies (Earle 1987; Earle 2002:161). The comparative value of such items stems from the fact that they are made of nonlocal and rare raw materials, require much labor in their production, or require the skills of a highly trained specialist (Earle 2002). Because wealth items are generally compact, durable, rare, and costly to acquire, their production and exchange are easily subject to economic control. The restricted distribution of material wealth consequently leads to economic, social, and potentially political advantage for some.

Although many anthropologists might not consider groundstone tools as items of particularly high value in traditional societies, it is possible that these artifacts were an integral part of the Hohokam political economy. This idea is borrowed from the work of

Brian Hayden (1987) and his investigation of traditional groundstone manufacture among the Mayan Highlands of western Guatemala and southern Mexico. Here, during the pre-Contact era, households required three basic resources for successful maize agriculture: 1) stone for effective grinding tools; 2) obsidian for cutting tools, and 3) salt for dietary requirements (Rathje 1972:368). The distribution of these resources was highly localized within the highlands, with each commodity relegated to one or a few spatially-discrete locations in the region (Hayden 1987:106). Due to transportation difficulties in the mountainous terrain and a dispersed settlement pattern, individuals were not always capable of independently obtaining these basic commodities. Thus, households likely had to give up some of their autonomy to other individuals or suprahousehold organizations that specialized in the procurement and distribution of these basic necessities. Based upon the political model of human behavior, it follows than that those persons who could successfully tap into long-distance trade would enjoy restricted access to important resources and, consequently, potentially use this position to elevate their social or political status. To test this presumption, Hayden (1987) presents several hypotheses, including two of which are relevant for our current research. These hypotheses state:

1. When the local population density of an important resource area is comparatively high, and extra-local demand for the resource is moderate or high, local persons involved in exploiting the resource or capable of controlling production beyond immediate community needs will acquire an unusual amount of wealth and power, leading to socioeconomic differentiation.

2. When the local population density of an important resource area is comparatively low, and extra-local demand for the resource is moderate or high, local persons involved in exploiting the resource or capable of controlling production beyond immediate community needs will first acquire an unusual amount of wealth and power,

> leading to socioeconomic differentiation. However, because the neighboring communities have greater populations, they will take over distributional control and as a result shift almost all of the wealth derived from exploitation of the localized resources to the larger neighboring community.

A cursory review of ethnohistoric and archaeological data for the Mayan region by Hayden found tentative support for both hypotheses. Regarding the first hypothesis, Hayden (1987:107) noted that prior to the construction of modern roads and the availability of cheap industrially produced salt, salt from the village of San Mateo was the a major source of wealth for the community. Although the salt mines were owned cooperatively by community members, it was primarily the village administrators who had the right to draw salt from wells. Others in the village could draw salt, but only if they paid the administrators a fee. Intriguingly, the village of San Mateo contained the first evidence of monumental architecture in the region and, until the introduction of cheap salts, was one of the richest and most socially stratified communities in the area (Hayden 1987:108). Hayden (1987), therefore, surmised that there was a correlation between the initial appearance of stratified communities and control over extremely localized important resources in moderate to high demand (Hayden 1987:110).

Hayden's (1987) overview also found support for the second hypothesis. Archaeological surveys observed that pre-Contact villages in the vicinity of modern- day Pucal contained substantial architectural remains that "seem out of place" in relation to the agricultural potential of the area (Hayden 1987:108). However, the Pucal village was located near several vesicular basalt groundstone quarries that constituted the only major source of good quality stone in the region. Hayden again suggested that the monumental structures near Pucal were built by powerful individuals or groups using wealth accumulated from the extraction and distribution of a vesicular basalt grinding tools. Notably, the economic success of Pucal didn't last long, as administrative control over the quarries was usurped by larger social groups in the neighboring Malacatancito Valley. Hayden (1987:109) speculates that the appropriation of the quarries and their associated source of wealth was the primary reason for driving the pre-Contact villages near Pucal "backwards" into economically impoverished and non-stratified communities.

Although the environmental context of the western Mayan Highlands is a far cry from the Sonoran Desert, the present research on Hohokam vesicular basalt acquisition practices allows us to further investigate the link between groundstone tools and political economy. Three key similarities exist between the prehistoric Hohokam and pre-Conquest settlements in the Highland Maya. First, both culture groups were heavily invested in maize agriculture. Therefore, hard grinding stones were an important domestic commodity for Mayan and Hohokam households. Second, like suitable groundstone material in the Mayan region, vesicular basalt is a nonubiquitous but economically important resource in the Salt-Gila Basin. Third, the demand for vesicular basalt grinding stones was high enough among the Hohokam to promote its long-distance distribution from raw material source to residential settlements.

In addition to these similarities, the present Hohokam case study is fitting for the analysis because it features at least one Hohokam village (Upper Santan) that had the potential to use its position adjacent to a vesicular basalt quarry for economic and consequently political advantage. This study includes data from two temporal intervals that feature distinct socially-integrative institutions (Preclassic ballcourt and Classic period platform mounds) that had the potential to facilitate the movement of vesicular basalt. Thus, the application of Hayden's (1987) hypothesis to this study may also provide insight on the political underpinnings of Hohokam integrative social institutions.

The findings of this study provide little support for the idea that locally-scarce vesicular basalt was important to the Hohokam political economy. One key finding negating this possibility is the temporal continuity in the distribution and acquisition of vesicular basalt source material. As noted earlier, the small changes in source acquisition noted at some sample sites between the Preclassic and Classic periods is most likely the result of change in social relations between one or two communities, and not an overhaul of the organization of groundstone production and distribution systems. Additionally, there was no evidence of a change in vesicular basalt acquisition and distribution practices between the Early and Late Classic period at Pueblo Grande. It is inferred from these observations that neither the collapse of the ballcourt network nor the rise of platform mound ceremonialism influenced the distribution of vesicular basalt groundstone. Thus, even though both ceremonial institutions would have provided a context for certain individuals or groups to manage the distribution of nonlocal vesicular basalt, there is no indication that this role was ever fulfilled.

Source area preference at sites provides further evidence that vesicular basalt was not part of the Hohokam political economy. It was mentioned above that most Hohokam households did not receive vesicular material from the nearest available basaltic outcrop. Recall that the inhabitants of Gila Crossing, La Plaza, and Los Hornos did not exploit material from the nearby Lone Butte source area, choosing instead to acquire material from the Santan Mountains and McDowell Mountains. Households in traditional societies tend to seek autonomy and self-sufficiency (Hagstrum 1999, 2001; Netting 1989; Netting et al. 1984; Sahlins 1972; Wilk 1989). Therefore, if vesicular basalt was a component of the Hohokam political economy, and an elite segment of the these villages was importing material from distant contacts for their own benefit, then we should expect some households to opt out of this imbalanced exchange relationship and instead procure material directly from nearby source areas. Several vesicular basalt outcrops in the Salt-Gila Basin are well within the groundstone material procurement range for many traditional societies without beasts-of-burden (Binford 1979; Hayden 1987; Huckell 1986; Schneider 1992, 1994; Schneider and Altschul 2000). Therefore, the dearth of material from local source areas in some site assemblages suggests that the movement of vesicular basalt in the Hohokam territory was not politically manipulated.

Finally, there is no evidence that communities with preferential access to vesicular basalt source areas controlled the distribution of the material for political gain. The large irrigation village of Upper Santan, which was located immediately adjacent to the Santan Mountains basalt source area, was undeniably an important Hohokam village. This site was occupied throughout much of the Hohokam sequence and contained scores of habitation areas, a Preclassic ballcourt, and at least one large platform mound (Neily et al. 1999a; Thompson and Fertelmes 2011; Wilcox 1977). However, there is no indication that the longevity and prominence of Upper Santan was a direct product of its location near a vesicular basalt source as expected under Hayden's (1987) hypothesis. If Upper

Santan attempted to use their location for economic advantage, consumers may have turned elsewhere, thereby cutting many economic and social networks that helped sustain the village. Therefore, the longevity and prominence of Upper Santan is more likely attributed to its location near the head of a primary irrigation canal than a controlling agent in the vesicular basalt exchange economy (Woodson 2010; Woodson 2013)

In sum, this study of Hohokam vesicular basalt acquisition practices offered a chance to provide some insight into the correlation between the management of regionally-scarce resources and the institutionalization of social and political inequality (Hayden 1997). An examination of vesicular basalt source provenance data within the Hohokam Salt-Gila Basin found no evidence to suggest that the production or distribution of vesicular basalt was ever manipulated by a small group of people. Hence, it is difficult to imagine a scenario in which certain groups, such as those at Upper Santan, used their position adjacent to a vesicular basalt source to elevate their economic, social, or political clout. This interpretation appears to be true for the Preclassic period, when ballcourt festivals would have provided an ideal context to conduct communal displays of wealth, and also the Classic period, when comparatively private and centralized platform mound ceremonies may have allowed for a small segment of the population to acquire and distribute material resources. Thus, the findings of this study find no reason to support Hayden's (1987) suggestion that there is a correlation between control over the management of regionally-scarce material resources and social and political processes. Furthermore, the findings are in agreement with a previous model of Hohokam society, which emphasizes corporate leadership, ritual authorities, and diminutive social hierarchies (Elson and Abbott 2002; Fish and Fish 2002; Harry and Bayman 2002).

Nondestructive PXRF for Vesicular Basalt Provenance Analysis

It was mentioned in the beginning of this dissertation that if a primary objective of this study was to determine how the Hohokam provisioned themselves with vesicular basalt groundstone tools, then a secondary goal of this research must be the development of an efficient and reliable sourcing methodology. The findings of this research indicate that nondestructive PXRF can provide an efficient and reliable method for determining the geochemistry of chemically-heterogeneous vesicular basalt specimens. Additionally, the results reconfirm that there is substantial geochemical variability among many of the vesicular basalt outcrops exploited by the prehistoric Hohokam. PXRF is therefore argued to be a very practical method for sourcing Hohokam vesicular basalt groundstone. Still, the analytical potential of this technique can be even further improved by collecting data from other vesicular basalt source areas not included in the raw material sample, such as the Agua Fria and New River terraces, as well as from unsampled portions of large outcrops already included in this study (e.g., Santan and McDowell Mountains). Thus, the analytical potential of nondestructive PXRF for Hohokam vesicular basalt sourcing is only beginning to be unlocked.

The development of nondestructive PXRF for Hohokam vesicular basalt sourcing studies is perhaps even more important because studies such as this one have the potential to yield a new insight on Hohokam domestic economies and the broader social and political organization of the Hohokam. Prior to this study, the proposed hypotheses for Hohokam vesicular basalt provisioning practices were based on general anthropological theories such as direct procurement or direct exchange (Bruder 1982, 1983a; Doyel 1985a; Euler 1989; Marshall 2007; Mitchell 1989; Stone 1994a, 2003). Not only were these theories generic, but they were also largely unevaluated due to an underdeveloped representative geochemical database and small archaeological sample sets. The development and then application of nondestructive PXRF made possible a larger, spatially-precise artifact provenance dataset. As a result, more meaningful spatial and temporal patterning in vesicular basalt provisioning practices could be observed, from which a newer, refined model of groundstone provisioning practices could be developed. Furthermore, this new model of Hohokam vesicular basalt provisioning practices has led to fresh perspective on Hohokam social and political organizations. The continuous development and application of nondestructive PXRF provenance methods may therefore help to refine scholarly understandings of the Hohokam.

The geochemical data collection methods developed in this study are also significant for archaeologists working beyond the Hohokam Salt-Gila Basin. There are several places throughout the world, including Central and South America as well as the Near East, where vesicular basalt was an important raw material for groundstone tool production. Compositional characterization of the textured stone in these regions is still being done using costly and destructive analytical methods (e.g., Antonelli and Lazzarin 2012; Drüppel et al. 2011; Gluhak and Hofmeister 2011; Gluhak and Rosenberg 2013; Gluhak and Schwall 2014). This study demonstrates that PXRF can provide an efficient, reliable, and nondestructive analytical technique for vesicular basalt sourcing studies. Furthermore, use of this technique allows for the production of larger artifact provenance datasets, which in turn have the potential to provide a more nuanced understanding of production and distribution practices. Altogether, this study makes an excellent case for the use of nondestructive PXRF as a practical analytical technique in other research areas.

Final Thoughts

In closing, I would like to return to the quintessential image of the Hohokam village that was described in the opening chapter (see Figure 1.1); the one that focuses on a group of women who are grinding corn with vesicular basalt manos and metates. I asked then, by what means did this family acquire these goods? The results of this study perhaps provide more information on what methods they did not use, rather than the actual provisioning practice. For it is now known that down-the-line exchange, periodic marketplaces, and elite-controlled exchange are unlikely explanations. Direct procurement from the nearest available outcrop may possibly have been the reason, but only if the village was located less than 10 km from a vesicular basalt outcrop. If the community was located more than 10 km, it is possible that direct exchange relations were used to acquire groundstone tools, though the data do not entirely support this theory. Another idea is that a family member or someone else in their village traveled to a groundstone workshop and acquired finished tools from tool production specialists.

The idea that there were specialists producing and possibly distributing groundstone tools in the Hohokam Salt-Gila Basin is sensible for many reasons. First, the limited availability of vesicular basalt outcrops within the Salt-Gila Basin would have permitted the concentrated production of groundstone tools, no matter the timeframe. Second, a specialist-based production and distribution economy minimizes the efforts individual households must spend in producing groundstone tools, while also minimizing the distribution costs of tool producers. Third, the presence of individuals or groups in a village who specialized in procuring finished tools for secondary distributions in their own village conforms with the observed archaeological patterning of shared access to a number of source areas. Fourth, the production and exchange of basic domestic tool items made by specialists in select locations has the potential to be less effected by the rise and fall of various ritual ceremonies and political organizations, which would explain the apparent continuity in vesicular basalt source provisioning practices through time.

If the observed provenance data patterns from this study are representative of other Hohokam communities in the Salt-Gila Basin, and the new model vesicular basalt provisioning practices is accurate, then the findings of this study also have implications for the cultural context in which the households that are depicted in Figure 1.1 existed. Perhaps most notable, it is suggested that Hohokam households were not self-sufficient during the Preclassic or Classic periods. While this interpretation is consistent with current conceptions of the Hohokam Preclassic (Abbott 2009, Kelly 2013; Watts 2013), it is adding to a small body of evidence (e.g., red ware ceramics) that indicates Classic period groups were not as economically independent and socially "balkanized" as previously thought (Abbott 2003b). Perhaps, then, the economic and social integration of

Hohokam households and communities via the production and distribution of vesicular basalt grinding stones was something that was "classic" about the Hohokam.

The new interpretation of vesicular basalt provisioning practices is further significant because it suggests a distinction between Hohokam economic and political realms. If Hohokam political authority was vested in self-interested economic processes (i.e., centralized, hierarchical, or network oriented leadership), then a transformation in groundstone exchange practices would have likely occurred at some point in time, whether the Preclassic-Classic transition or the later Early Classic to Late Classic interval. The absence of temporal change in groundstone production and distribution practices reinforces, instead, the alternative idea that the cultural changes characteristic of the Hohokam Preclassic-Classic transition were primarily changes in ritual ideology and practice rather than the emergence of centralized political institutions and their supportive economic systems. It is suggested, then, that Hohokam leadership was probably largely independent of economic processes and organized in a corporate or hierarchical fashion. Further improvement of the vesicular basalt provenance database and on-going analysis of groundstone artifacts will likely continue to contribute to scholarly understandings of Hohokam domestic, political, and even ritual economies, as part of the social and political organization of the Hohokam.

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APPENDIX A

DATA TABLES

Table A.1. Average Elemental Concentration Data (ppm) for Vesicular Basalt Source Areas

Source Area	Count	K	Ti	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba
Adobe Mtn.	33	17209	3946	51	83	31	747	13	216	15	1123
Deem Hills A	19	17640	4516	61	83	36	619	14	167	11	1123
Deem Hills B	20	9532	5565	113	77	9	311	16	96	5	527
Florence Cinder Mine	29	10177	11015	96	90	12	378	17	158	26	507
Hedgpeth Hills	86	16723	3039	50	72	35	522	10	144	8	965
Lone Butte	30	11203	5582	89	89	12	622	13	136	8	735
Ludden Mtn. A	13	18933	3511	40	80	40	758	13	189	13	1146
Ludden Mtn. B	9	10410	6337	75	90	12	463	27	156	9	500
Ludden Mtn. C	8	10882	4887	84	80	13	500	14	138	8	703
McDowell Mtn	59	15198	4253	75	84	23	724	11	156	14	1073
Moon Hill A	15	11318	4971	79	82	15	487	18	142	8	642
Moon Hill B	15	11082	5246	89	93	14	427	26	151	8	529
Moon Hill C	10	10481	4543	86	81	11	351	19	119	6	449
Picture Rocks	35	12550	5494	67	95	14	701	23	264	21	847
Poston Butte	30	11740	10606	100	91	17	429	18	207	41	588
Robbins Butte A	13	10757	3937	87	78	12	391	25	139	10	593
Robbins Butte B	11	13682	3116	55	69	26	365	11	128	8	665
Robbins Butte C	12	14218	4327	68	82	25	482	16	150	10	841
Santan Mtns. A	56	15961	5725	101	119	33	1280	4	239	17	1543
Santan Mtns. B	45	11604	4604	80	80	14	504	14	141	10	658
Shaw Butte	10	12667	5921	117	86	18	471	16	133	7	589
Table Top Mountain	26	16434	5738	106	99	24	809	16	208	14	1264
Union Hills	30	9833	3880	110	77	10	401	18	104	5	515
Vaiva Hills	34	20040	7273	94	113	31	1134	15	224	18	1640
West Wing Mtns. A	10	25132	1834	22	64	75	334	14	130	11	1154
West Wing Mtns. B	25	17930	5766	69	92	33	692	18	204	14	1221

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Casa Grande	46	Metate	0	Nonfeature	Sedentary, undefined	Santan Mtn
Casa Grande	76	Mano	0	Nonfeature	Sedentary, undefined	Unknown
Casa Grande	89	Metate	0	Nonfeature	Sedentary, undefined	Unknown
Casa Grande	127	Ind.	1	Pithouse	Sedentary, undefined	Unknown
Casa Grande	130	Mano	1	Pithouse	Sedentary, undefined	Picture Rocks
Casa Grande	206	Mano	14	Pit, undefined	Sedentary, undefined	Picture Rocks
Casa Grande	236	Ind.	20	Pithouse	Sedentary, undefined	Picture Rocks
Casa Grande	332	Ind.	0	Nonfeature	Classic, undefined	Unknown
Casa Grande	377.01	Ind.	0	Nonfeature	Classic, undefined	Picture Rocks
Casa Grande	377.02	Ind.	0	Nonfeature	Classic, undefined	Unknown
Casa Grande	429	Ind.	25	Pithouse	Sedentary, undefined	Picture Rocks
Casa Grande	448	Ind.	23	Pithouse	Sedentary, undefined	Unknown
Casa Grande	451	Mano	23	Pithouse	Sedentary, undefined	Unknown
Casa Grande	477	Ind.	25	Pithouse	Sedentary, undefined	Unknown
Casa Grande	477	Ind.	25	Pithouse	Sedentary, undefined	Picture Rocks
Casa Grande	518	Ind.	0	Pit, undefined	Classic, undefined	Unknown
Casa Grande	572	Ind.	25	Pithouse	Sedentary, undefined	Picture Rocks
Casa Grande	614	Mano	23	Pithouse	Sedentary, undefined	Unknown
Casa Grande	629	Ind.	25	Pithouse	Sedentary, undefined	Picture Rocks
Casa Grande	739	Metate	106	Pit, undefined	Classic, Soho Phase	Unknown
Casa Grande	792	Metate	114	Trash Mound	Classic, undefined	Hedgpeth Hills
Casa Grande	826	Metate	26	Pit, thermal	Classic, undefined	Picture Rocks
Casa Grande	827	Metate	26	Pit, thermal	Classic, undefined	Unknown

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Casa Grande	910	Ind.	45	Plaza	Classic, undefined	Picture Rocks
Casa Grande	912.01	Metate	45	Plaza	Classic, undefined	Unknown
Casa Grande	912.02	Metate	45	Plaza	Classic, undefined	Unknown
Casa Grande	995	Ind.	38	Pit Room	Classic, undefined	Florence Cinder
Casa Grande	1082	Metate	41	Pit room	Classic, undefined	Santan Mtn
Casa Grande	1102	Ind.	38	Pit room	Classic, undefined	Unknown
Casa Grande	1186.01	Ind.	106	Pit, undefined	Classic, Soho Phase	Picture Rocks
Casa Grande	1186.02	Ind.	106	Pit, undefined	Classic, Soho Phase	Unknown
Casa Grande	1229	Metate	128	Midden	Classic, undefined	Unknown
Casa Grande	1304	Ind.	27	Pithouse	Classic, Soho Phase	Picture Rocks
Casa Grande	1397	Metate	23	Pit, undefined	Classic, undefined	Florence Cinder
Casa Grande	1433	Metate	128	Midden	Classic, undefined	Santan Mtn
Casa Grande	1534.01	Mano	45	Plaza	Classic, undefined	Unknown
Casa Grande	1543.02	Mano	45	Plaza	Classic, undefined	Picture Rocks
Gila Crossing	1413.01	Ind.	238	Trash Mound	Sedentary, undefined	Unknown
Gila Crossing	1413.02	Mano	238	Trash Mound	Sedentary, undefined	Robbins Butte
Gila Crossing	1419.01	Ind.	238	Trash Mound	Sedentary, undefined	Santan Mtn
Gila Crossing	1419.02	Ind.	238	Trash Mound	Sedentary, undefined	Unknown
Gila Crossing	1419.03	Ind.	238	Trash Mound	Sedentary, undefined	Unknown
Gila Crossing	1419.04	Ind.	238	Trash Mound	Sedentary, undefined	Unknown
Gila Crossing	1419.05	Ind.	238	Trash Mound	Sedentary, undefined	Unknown
Gila Crossing	1445.01	Metate	276	Midden	Sedentary, undefined	McDowell Mtn
Gila Crossing	1484.01	Ind.	238	Trash Mound	Sedentary, undefined	Unknown

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Gila Crossing	1484.02	Metate	238	Trash Mound	Sedentary, undefined	West Wing Mtn
Gila Crossing	1490	Metate	238	Trash Mound	Sedentary, undefined	Santan Mtn
Gila Crossing	3195.01	Ind.	426	Artifact cache	Sedentary, undefined	Robbins Butte
Gila Crossing	3195.02	Metate	426	Artifact cache	Sedentary, undefined	Unknown
Gila Crossing	3195.03	Metate	426	Artifact cache	Sedentary, undefined	McDowell Mtn
Gila Crossing	3195.04	Metate	426	Artifact cache	Sedentary, undefined	Unknown
Gila Crossing	3210	Ind.	417	Pit, undefined	Sedentary, undefined	McDowell Mtn
Gila Crossing	3258	Mano	424	Midden	Sedentary, undefined	Santan Mtn
Gila Crossing	3332.01	Metate	446	Pithouse	Sedentary, undefined	McDowell Mtn
Gila Crossing	3402.02	Ind.	384	Trash Mound	Sedentary, undefined	Unknown
Gila Crossing	3402.03	Ind.	384	Trash Mound	Sedentary, undefined	Unknown
Gila Crossing	3402.2	Ind.	384	Trash Mound	Sedentary, undefined	Santan Mtn
Gila Crossing	3418.01	Mano	384	Trash Mound	Sedentary, undefined	Moon Hill/Ludden Mtn
Gila Crossing	3425	Metate	824	Pit, undefined	Sedentary, undefined	Unknown
Gila Crossing	3594.01	Ind.	468	Pit, undefined	Sedentary, undefined	Santan Mtn
Gila Crossing	3594.02	Ind.	468	Pit, undefined	Sedentary, undefined	Unknown
Gila Crossing	3968.01	Metate	509	Pithouse	Sedentary, undefined	Unknown
Gila Crossing	4025.01	Mano	474	Pithouse	Sedentary, undefined	Unknown
Gila Crossing	4028.01	Mano	474.02	Pit, undefined	Sedentary, undefined	Santan Mtn
Gila Crossing	4811.01	Ind.	570	Midden	Sedentary, undefined	Unknown
Gila Crossing	4811.02	Ind.	570	Midden	Sedentary, undefined	Unknown
Gila Crossing	4811.03	Ind.	570	Midden	Sedentary, undefined	Santan Mtn
Gila Crossing	4927.01	Ind.	646	Pit, undefined	Sedentary, undefined	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Gila Crossing	4927.02	Ind.	646	Pit, undefined	Sedentary, undefined	Santan Mtn
Gila Crossing	4938.01	Metate	646	Pit, undefined	Sedentary, undefined	Unknown
Gila Crossing	4944.01	Metate	646	Pit, undefined	Sedentary, undefined	Unknown
Gila Crossing	5108	Mano	630	Pithouse	Sedentary, undefined	Santan Mtn
Gila Crossing	5128	Mano	717	Pit, undefined	Sedentary, undefined	Unknown
Gila Crossing	5723	Metate	820	Pit, undefined	Sedentary, undefined	McDowell Mtn
Gila Crossing	5847	Metate	836	Pit, undefined	Sedentary, undefined	McDowell Mtn
Gila Crossing	5850	Metate	824	Pit, undefined	Sedentary, undefined	Santan Mtn
Gila Crossing	5981.01	Ind.	856	Pit, undefined	Sedentary, undefined	Santan Mtn
Gila Crossing	5983.02	Metate	856	Pit, undefined	Sedentary, undefined	McDowell Mtn
Hospital Site	662.01	Ind.	72	Midden	Sedentary, undefined	Unknown
Hospital Site	662.02	Ind.	72	Midden	Sedentary, undefined	Unknown
Hospital Site	662.03	Mano	72	Midden	Sedentary, undefined	Santan Mtn
Hospital Site	662.04	Metate	72	Midden	Sedentary, undefined	Santan Mtn
Hospital Site	672.01	Metate	72	Midden	Sedentary, undefined	Unknown
Hospital Site	683.01	Mano	72	Midden	Sedentary, undefined	Santan Mtn
Hospital Site	693.01	Mano	72	Midden	Sedentary, undefined	Santan Mtn
Hospital Site	1380.01	Ind.	143	Pit, Thermal	Sedentary, undefined	Unknown
Hospital Site	1380.02	Ind.	143	Pit, Thermal	Sedentary, undefined	Santan Mtn
Hospital Site	1417.01	Ind.	142	Midden	Sedentary, undefined	Santan Mtn
Hospital Site	1567.01	Ind.	160	Pit, undefined	Sedentary, undefined	Santan Mtn
Hospital Site	2183.01	Mano	235	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2324.01	Ind.	217	Pithouse	Sedentary, undefined	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Hospital Site	2334.01	Mano	151	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2334.02	Mano	151	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2480.01	Mano	278	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2493.01	Ind.	278	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2508.01	Mano	151	Pithouse	Sedentary, undefined	Picture Rocks
Hospital Site	2510.01	Metate	151	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2513.01	Mano	151	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2514.01	Metate	151	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2515.01	Mano	151	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2516.01	Mano	151	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2582.01	Ind.	113	Pit, undefined	Sedentary, undefined	Santan Mtn
Hospital Site	2661.01	Mano	151	Pithouse	Sedentary, undefined	Unknown
Hospital Site	2876.01	Mano	313	Pithouse	Sedentary, undefined	Santan Mtn
Hospital Site	2937.01	Ind.	340	Pit Room	Sedentary, undefined	Santan Mtn
Hospital Site	3030.01	Ind.	342	Pit, undefined	Sedentary, undefined	Santan Mtn
Hospital Site	3030.02	Ind.	342	Pit, undefined	Sedentary, undefined	Santan Mtn
Hospital Site	3030.03	Ind.	342	Pit, undefined	Sedentary, undefined	Unknown
Hospital Site	3353.01	Ind.	125	Pit, undefined	Sedentary, undefined	Robbins Butte
La Plaza	002335.003.001	Mano	75	Trash Pit	Classic, undefined	McDowell Mtn
La Plaza	002335.003.001	Mano	75	Trash Pit	Classic, undefined	Unknown
La Plaza	002335.003.001	Mano	75	Trash Pit	Classic, undefined	McDowell Mtn
La Plaza	002335.003.009	Mano	75	Trash Pit	Classic, undefined	McDowell Mtn
La Plaza	002584.001.004	Mano	94	Trash Pit	Sedentary, undefined	Unknown

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
La Plaza	002584.001.004	Mano	94	Trash Pit	Sedentary, undefined	McDowell Mtn
La Plaza	002827.007.003	Metate	171	Pithouse	Colonial/Sedentary	Unknown
La Plaza	002827.010.002	Metate	171	Pithouse	Colonial/Sedentary	Santan Mtn
La Plaza	002840.001.008	Metate	169	Pithouse	Sedentary, Late Sacaton	Unknown
La Plaza	002925.001.010	Metate	404	Room, Massive Walled Adobe	Classic, undefined	Unknown
La Plaza	002925.003.022	Ind.	404	Room, Massive Walled Adobe	Classic, undefined	Unknown
La Plaza	005304.001.007	Metate	424	Trash Pit	Colonial	McDowell Mtn
La Plaza	005319.001.003	Metate	171.05	Posthole	Colonial/Sedentary	Unknown
La Plaza	005343.001.003	Metate	171.1	Pit, undefined	Colonial	McDowell Mtn
La Plaza	005343.001.003	Metate	171.1	Pit, undefined	Colonial	McDowell Mtn
La Plaza	005343.001.008	Mano	171.1	Pit, undefined	Colonial	McDowell Mtn
La Plaza	005343.002.004	Mano	171.1	Pit, undefined	Colonial	McDowell Mtn
La Plaza	005343.003.004	Metate	171.1	Pit, undefined	Colonial	McDowell Mtn
La Plaza	005361.003.002	Metate	209	Pithouse	Pioneer	Santan Mtn
La Plaza	005408.003.006	Metate	389	Pit, undefined	Colonial/Sedentary	McDowell Mtn
La Plaza	005414.005.002	Mano	276	Pit, undefined	Colonial	Unknown
La Plaza	005414.005.002	Mano	276	Pit, undefined	Colonial	Santan Mtn
La Plaza	005456.004.003	Other	280	Pit, undefined	Classic, undefined	McDowell Mtn
La Plaza	005499.006.004	Other	300	Pithouse	Sedentary, undefined	Unknown
La Plaza	005718.001.004	Metate	287	Pit, undefined	Sedentary, undefined	Unknown
La Plaza	008121.001.003	Metate	457	Room, Massive Walled Adobe	Classic, undefined	McDowell Mtn
La Plaza	008121.011.004	Mano	457	Room, Massive Walled Adobe	Classic, undefined	Unknown
La Plaza	008138.021.002	Other	292	Room, Massive Walled Adobe	Classic, undefined	McDowell Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
La Plaza	008139.001.004	Metate	288	Room, Massive Walled Adobe	Classic, undefined	Table Top Mtn
La Plaza	008159.001.006	Mano	478	Room, Massive Walled Adobe	Classic, undefined	McDowell Mtn
La Plaza	008169.002.001	Metate	477.01	Storage Pit	Classic, Civano Phase	McDowell Mtn
La Plaza	008169.002.005	Metate	477.01	Storage Pit	Classic, Civano Phase	Unknown
La Plaza	008169.002.006	Metate	477.01	Storage Pit	Classic, Civano Phase	McDowell Mtn
La Plaza	008222.001.004	Mano	437	Pithouse	Pioneer	Unknown
La Plaza	008230.001.001	Mano	450	Pit Room	Classic, Soho Phase	Lone Butte
La Plaza	008230.001.002	Metate	450	Pit Room	Classic, Soho Phase	Unknown
La Plaza	008327.001.001	Mano	355	Trash Pit	Colonial/Sedentary	McDowell Mtn
Las Colinas	30461	Ind.	M19	Pit Room	Classic, Soho Phase	Unknown
Las Colinas	30496	Mano	M36	Pit Room	Classic, Soho Phase	Unknown
Las Colinas	30512	Ind.	M28	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Las Colinas	30578	Mano	M37	Pit Room	Classic, Civano Phase	Unknown
Las Colinas	30579	Mano	M37	Pit Room	Classic, Civano Phase	McDowell Mtn
Las Colinas	30584	Metate	M37	Pit Room	Classic, Civano Phase	Unknown
Las Colinas	30586	Metate	M37	Pit Room	Classic, Civano Phase	West Wing Mtn
Las Colinas	30588	Ind.	M37	Pit Room	Classic, Civano Phase	Moon Hill/Ludden Mtn
Las Colinas	30589	Metate	M37	Pit Room	Classic, Civano Phase	West Wing Mtn
Las Colinas	30617	Ind.	M31	Room, Massive Walled Adobe	Classic, Civano Phase	Moon Hill/Ludden Mtn
Las Colinas	30842	Ind.	M32	Pit Room	Classic, Soho Phase	Unknown
Las Colinas	31159	Mano	M37	Pit Room	Classic, Civano Phase	Unknown
Las Colinas	40894	Mano	Structure 142	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	40936	Metate	Structure 124	Pithouse	Sedentary, Middle Sacaton	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Las Colinas	40988	Metate	Structure 143	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	41004	Metate	Structure 136	Unknown	Sedentary, Middle Sacaton	West Wing Mtn
Las Colinas	41012	Mano	Structure 136	Unknown	Sedentary, Middle Sacaton	Unknown
Las Colinas	41029	Metate	Structure 124	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	41064	Metate	Pit 161	Borrow Pit	Sedentary, Late Sacaton	Moon Hill/Ludden Mtn
Las Colinas	41070	Metate	Pit 161	Borrow Pit	Sedentary, Late Sacaton	West Wing Mtn
Las Colinas	41216	Mano	Pit 162	Borrow Pit	Sedentary, Late Sacaton	McDowell Mtn
Las Colinas	41221	Metate	Pit 162	Borrow Pit	Sedentary, Late Sacaton	West Wing Mtn
Las Colinas	41294	Metate	Structure 133	Pithouse	Sedentary, Middle Sacaton	West Wing Mtn
Las Colinas	41319	Metate	Structure 133	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	41329	Metate	Structure 148	Pithouse	Sedentary, Late Sacaton	West Wing Mtn
Las Colinas	41333	Metate	Structure 148	Pithouse	Sedentary, Late Sacaton	Unknown
Las Colinas	41339	Ind.	Structure 148	Pithouse	Sedentary, Late Sacaton	Deem Hills
Las Colinas	41340	Metate	Structure 148	Pithouse	Sedentary, Late Sacaton	Unknown
Las Colinas	41341	Mano	Structure 148	Pithouse	Sedentary, Late Sacaton	Moon Hill/Ludden Mtn
Las Colinas	41493	Mano	Structure 137	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	41541	Metate	Structure 123	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	41600	Mano	Pit 162	Borrow Pit	Sedentary, Late Sacaton	Moon Hill/Ludden Mtn
Las Colinas	41641	Metate	Structure 123	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	41666	Mano	Pit 409	Horno	Sedentary, Late Sacaton	West Wing Mtn
Las Colinas	41667	Mano	Pit 409	Horno	Sedentary, Late Sacaton	Moon Hill/Ludden Mtn
Las Colinas	41698	Mano	Pit 409	Horno	Sedentary, Late Sacaton	McDowell Mtn
Las Colinas	41710	Metate	Pit 409	Horno	Sedentary, Late Sacaton	West Wing Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Las Colinas	41745	Mano	Pit 409	Horno	Sedentary, Late Sacaton	Robbins Butte
Las Colinas	41972	Metate	Structure 131	Pithouse	Sedentary, Middle Sacaton	Deem Hills
Las Colinas	41995	Ind.	Pit 342	Pit, undefined	Classic, Soho Phase	Unknown
Las Colinas	42044	Metate	Pit 341	Pit, undefined	Sedentary, Late Sacaton	Deem Hills
Las Colinas	42047	Mano	Structure 142	Pithouse	Sedentary, Middle Sacaton	Santan Mtn
Las Colinas	42212	Metate	Structure 146	Pithouse	Sedentary, Late Sacaton	Unknown
Las Colinas	42214	Metate	Structure 146	Pithouse	Sedentary, Late Sacaton	Unknown
Las Colinas	42302	Ind.	Structure 150	Pithouse	Sedentary, Late Sacaton	Unknown
Las Colinas	42304	Ind.	Structure 150	Pithouse	Sedentary, Late Sacaton	West Wing Mtn
Las Colinas	42316	Mano	Pit 141	Borrow Pit	Sedentary, Late Sacaton	Moon Hill/Ludden Mtn
Las Colinas	42349	Mano	Structure 142	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	42350	Metate	Structure 131	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	42393	Mano	Structure 131	Pithouse	Sedentary, Middle Sacaton	Deem Hills
Las Colinas	42414	Mano	Structure 137	Pithouse	Sedentary, Middle Sacaton	West Wing Mtn
Las Colinas	42431	Ind.	Structure 150	Pithouse	Sedentary, Late Sacaton	Moon Hill/Ludden Mtn
Las Colinas	50325	Metate	Structure 79	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	50326	Metate	Structure 79	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	50328	Ind.	Structure 79	Pithouse	Sedentary, Middle Sacaton	West Wing Mtn
Las Colinas	50337	Metate	Structure 54	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	50353	Ind.	Structure 58	Pithouse	Sedentary, Late Sacaton	Deem Hills
Las Colinas	50358	Mano	Structure 58	Pithouse	Sedentary, Late Sacaton	Unknown
Las Colinas	50359	Ind.	Structure 58	Pithouse	Sedentary, Late Sacaton	Moon Hill/Ludden Mtn
Las Colinas	51314	Metate	Structure 71	Pithouse	Sedentary, Middle Sacaton	West Wing Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Las Colinas	51316	Ind.	Structure 71	Pithouse	Sedentary, Middle Sacaton	West Wing Mtn
Las Colinas	51320	Metate	Structure 71	Pithouse	Sedentary, Middle Sacaton	West Wing Mtn
Las Colinas	51327	Ind.	Structure 71	Pithouse	Sedentary, Middle Sacaton	Moon Hill/Ludden Mtn
Las Colinas	51404	Mano	Structure 63	Unknown	Classic, Soho Phase	Unknown
Las Colinas	51410	Ind.	Structure 63	Unknown	Classic, Soho Phase	Unknown
Las Colinas	51469	Metate	Structure 79	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	51502.01	Ind.	Structure 63	Unknown	Classic, Soho Phase	West Wing Mtn
Las Colinas	51502.02	Ind.	Structure 63	Unknown	Classic, Soho Phase	Unknown
Las Colinas	51503	Metate	Structure 63	Unknown	Classic, Soho Phase	McDowell Mtn
Las Colinas	51506	Metate	Pit 121	Borrow Pit	Sedentary, Late Sacaton	Deem Hills
Las Colinas	51507	Metate	Pit 121	Borrow Pit	Sedentary, Late Sacaton	West Wing Mtn
Las Colinas	51646	Metate	Structure 54	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	51671	Metate	Structure 54	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	51674	Metate	Structure 54	Pithouse	Sedentary, Middle Sacaton	Moon Hill/Ludden Mtn
Las Colinas	52034	Metate	Structure 54	Pithouse	Sedentary, Middle Sacaton	McDowell Mtn
Las Colinas	52035	Metate	Structure 54	Pithouse	Sedentary, Middle Sacaton	Unknown
Las Colinas	52135	Metate	Pit 117	Borrow Pit	Sedentary, Late Sacaton	Unknown
Las Colinas	52136	Metate	Pit 117	Borrow Pit	Sedentary, Late Sacaton	McDowell Mtn
Las Colinas	52140	Mano	Pit 117	Borrow Pit	Sedentary, Late Sacaton	McDowell Mtn
Las Colinas	52172	Metate	Pit 121	Borrow Pit	Sedentary, Late Sacaton	Unknown
Las Colinas	71012	Mano	Structure 4	Pithouse	Sedentary, Late Sacaton	Hedgpeth Hills
Las Colinas	72345	Metate	Pit 400	Horno	Classic, Soho Phase	Deem Hills
Las Colinas	72355	Metate	Pit 400	Horno	Classic, Soho Phase	Hedgpeth Hills

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Las Colinas	72356	Metate	Pit 400	Horno	Classic, Soho Phase	Unknown
Las Colinas	72490	Metate	Pit 400	Horno	Classic, Soho Phase	McDowell Mtn
Las Colinas	72492	Metate	Pit 400	Horno	Classic, Soho Phase	McDowell Mtn
Las Colinas	72493	Metate	Pit 400	Horno	Classic, Soho Phase	Unknown
Las Colinas	72573	Metate	Pit 400	Horno	Classic, Soho Phase	Unknown
Las Colinas	72574	Metate	Pit 400	Horno	Classic, Soho Phase	Unknown
Las Colinas	72575	Metate	Pit 400	Horno	Classic, Soho Phase	Unknown
Las Colinas	72576	Mano	Pit 400	Horno	Classic, Soho Phase	Moon Hill/Ludden Mtn
Las Colinas	72576	Mano	Pit 400	Horno	Classic, Soho Phase	Unknown
Las Colinas	72578	Mano	Pit 400	Horno	Classic, Soho Phase	Santan Mtn
Las Colinas	72579	Mano	Pit 400	Horno	Classic, Soho Phase	West Wing Mtn
Los Hornos	288	Mano	37	Pithouse	Colonial/Sedentary	Santan Mtn
Los Hornos	931	Mano	56	Trash Pit	Colonial/Sedentary	McDowell Mtn
Los Hornos	937	Metate	56	Trash Pit	Colonial/Sedentary	Unknown
Los Hornos	937	Mano	56	Trash Pit	Colonial/Sedentary	Unknown
Los Hornos	1239	Ind.	76	Pithouse	Sedentary, undefined	McDowell Mtn
Los Hornos	1467	Metate	7	Pithouse	Sedentary, undefined	Santan Mtn
Los Hornos	1467	Ind.	7	Pithouse	Sedentary, undefined	McDowell Mtn
Los Hornos	1467	Ind.	7	Pithouse	Sedentary, undefined	West Wing Mtn
Los Hornos	1493	Ind.	7	Pithouse	Sedentary, undefined	Santan Mtn
Los Hornos	1561	Ind.	37	Pithouse	Colonial/Sedentary	McDowell Mtn
Los Hornos	1748	Mano	7	Pithouse	Sedentary, undefined	Deem Hills
Los Hornos	1748	Mano	7	Pithouse	Sedentary, undefined	Moon Hill/Ludden Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Los Hornos	1749	Mano	7	Pithouse	Sedentary, undefined	West Wing Mtn
Los Hornos	1750	Mano	7	Pithouse	Sedentary, undefined	Unknown
Los Hornos	1750	Mano	7	Pithouse	Sedentary, undefined	Unknown
Los Hornos	1753	Ind.	7	Pithouse	Sedentary, undefined	Unknown
Los Hornos	1893	Mano	37	Pithouse	Colonial/Sedentary	McDowell Mtn
Los Hornos	1903	Metate	37	Pithouse	Colonial/Sedentary	McDowell Mtn
Los Hornos	1915	Ind.	37	Pithouse	Colonial/Sedentary	McDowell Mtn
Los Hornos	2040	Ind.	78	Pithouse	Sedentary, undefined	McDowell Mtn
Los Hornos	2161	Metate	10	Pithouse	Colonial/Sedentary	Moon Hill/Ludden Mtn
Los Hornos	2285	Mano	133	Pithouse	Sedentary, undefined	McDowell Mtn
Los Hornos	2342	Mano	136	Pithouse	Colonial/Sedentary	McDowell Mtn
Los Hornos	2350	Mano	136	Pithouse	Colonial/Sedentary	McDowell Mtn
Los Hornos	2376	Metate	136	Pithouse	Colonial/Sedentary	Lone Butte
Los Hornos	2432	Mano	136	Pithouse	Colonial/Sedentary	McDowell Mtn
Los Hornos	2440	Mano	6	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Los Hornos	2440	Mano	6	Pithouse	Sedentary, Late Sacaton	McDowell Mtn
Los Hornos	2463	Ind.	133	Pithouse	Sedentary, undefined	Unknown
Los Hornos	2604	Mano	133	Pithouse	Sedentary, undefined	McDowell Mtn
Los Hornos	2652	Ind.	133	Pithouse	Sedentary, undefined	McDowell Mtn
Los Hornos	2662	Ind.	133	Pithouse	Sedentary, undefined	McDowell Mtn
Lower Santan	1254.01	Mano	141	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	1254.01	Mano	141	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	1254.02	Metate	141	Pithouse	Sedentary, Late Sacaton	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Lower Santan	1321.01	Mano	160	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	1330.01	Metate	161	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	2099.01	Mano	323	Pit, Thermal	Classic, Soho phase	Santan Mtn
Lower Santan	2123.01	Mano	328	Rock-filled pit	Classic, undefined	Picture Rocks
Lower Santan	2179.01	Mano	356	Rock-filled pit	Classic, undefined	Santan Mtn
Lower Santan	2179.02	Ind.	356	Rock-filled pit	Classic, undefined	Santan Mtn
Lower Santan	2179.03	Mano	356	Rock-filled pit	Classic, undefined	Santan Mtn
Lower Santan	2179.04	Ind.	356	Rock-filled pit	Classic, undefined	Santan Mtn
Lower Santan	2179.05	Ind.	356	Rock-filled pit	Classic, undefined	Santan Mtn
Lower Santan	2179.06	Ind.	356	Rock-filled pit	Classic, undefined	Santan Mtn
Lower Santan	2179.07	Ind.	356	Rock-filled pit	Classic, undefined	Santan Mtn
Lower Santan	2913.01	Ind.	375	Room, Freestanding Room	Classic, Civano Phase	Picture Rocks
Lower Santan	2974.04	Mano	383.01	Pit Room	Classic, Civano Phase	Unknown
Lower Santan	3221.02	Mano	384	Pit Room	Classic, Civano Phase	Unknown
Lower Santan	3272.01	Mano	375	Room, Freestanding Room	Classic, Civano Phase	Moon Hill/Ludden Mtn
Lower Santan	3317	Mano	401	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	3404.02	Ind.	410	Pit, undefined	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	3441.01	Mano	247	Pit Room	Classic, Soho phase	Picture Rocks
Lower Santan	3441.02	Metate	247	Pit Room	Classic, Soho phase	Unknown
Lower Santan	3444.01	Ind.	407	Pit, undefined	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	4133.01	Mano	374.03	Room, Freestanding Room	Classic, Soho phase	Unknown
Lower Santan	4133.02	Mano	374.03	Room, Freestanding Room	Classic, Soho phase	Unknown
Lower Santan	4179.1	Mano	373	Room, Freestanding Room	Classic, Civano Phase	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Lower Santan	4262.01	Mano	383	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4315.01	Metate	383	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4524.01	Mano	384	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4580.01	Mano	383.01	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4607.01	Mano	378	Room, Freestanding Room	Classic, Civano Phase	Unknown
Lower Santan	4622.01	Ind.	384	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4697.01	Metate	383.05	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4697.02	Metate	383.05	Pit Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4828.01	Metate	375	Room, Freestanding Room	Classic, Civano Phase	Santan Mtn
Lower Santan	4832.01	Metate	375	Room, Freestanding Room	Classic, Civano Phase	Unknown
Lower Santan	5013.01	Metate	497	Pit, undefined	Sedentary, undefined	Santan Mtn
Lower Santan	5520	Metate	122.01	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	5631.01	Metate	231	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	5856.01	Mano	231	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	6122.01	Mano	231	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	6213.01	Metate	617	Pit, Thermal	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	6213.02	Metate	617	Pit, Thermal	Sedentary, Late Sacaton	Picture Rocks
Lower Santan	6278.01	Ind.	613	Borrow Pit	Sedentary, Late Sacaton	Picture Rocks
Lower Santan	6456.01	Mano	161	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	6456.02	Metate	161	Pithouse	Sedentary, undefined	Unknown
Lower Santan	6491.01	Mano	161	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	6499.01	Mano	161	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	6672.01	Metate	688	Pit, undefined	Sedentary, Late Sacaton	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Lower Santan	6888.01	Mano	739	Pithouse	Sedentary, undefined	Picture Rocks
Lower Santan	7074.01	Mano	738	Borrow Pit	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	7097.01	Mano	191	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	7223.01	Metate	209	Pithouse	Sedentary, undefined	Picture Rocks
Lower Santan	7263.01	Mano	756	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	7404.01	Mano	262	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	7589.01	Metate	108	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	7593.01	Ind.	1050	Pit, undefined	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	7642.01	Mano	792	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	7681.01	Mano	187	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	7720.01	Metate	792	Pithouse	Sedentary, undefined	Unknown
Lower Santan	7723.02	Metate	209	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	7723.03	Metate	209	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	7723.04	Metate	209	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	7723.05	Metate	209	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	7754.01	Metate	141	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	7758.01	Ind.	141	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	7969.01	Mano	187	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	8065.01	Mano	979	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	8122.01	Mano	979	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	8122.02	Mano	979	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	8122.02	Mano	979	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	8155.01	Metate	108	Pithouse	Sedentary, undefined	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Lower Santan	8178.01	Mano	979	Pithouse	Sedentary, Late Sacaton	Unknown
Lower Santan	8403.01	Mano	203	Pit, undefined	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	8543.01	Metate	867	Pithouse	Sedentary, undefined	McDowell Mtn
Lower Santan	8801.01	Mano	1050	Pit, undefined	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	9177.01	Mano	262	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	9177.02	Metate	262	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	9418.01	Mano	868	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	9460.01	Metate	868.03	Pithouse	Sedentary, undefined	Unknown
Lower Santan	9569.01	Metate	109	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	9712.01	Mano	867	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	9842.02	Metate	867	Pithouse	Sedentary, undefined	Picture Rocks
Lower Santan	9889.01	Metate	1089	Pithouse	Sedentary, undefined	Unknown
Lower Santan	9899.01	Metate	1089	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	9905.01	Mano	1089	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	9950.1	Metate	1093	Pithouse	Sedentary, undefined	Unknown
Lower Santan	9960.01	Metate	867	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	10069.01	Mano	191	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	10077.01	Metate	1089	Pithouse	Sedentary, undefined	Unknown
Lower Santan	10203.01	Mano	1093	Pithouse	Sedentary, undefined	Picture Rocks
Lower Santan	10271.01	Metate	160.05	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	10350.01	Mano	785	Pit Room	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	10356.01	Ind.	968	Borrow pit	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	10393.01	Mano	635	Pithouse	Sedentary, Late Sacaton	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Lower Santan	10666.01	Mano	635	Pithouse	Sedentary, Late Sacaton	Santan Mtn
Lower Santan	10730.01	Metate	785	Pit Room	Sedentary, Late Sacaton	Unknown
Lower Santan	10926.01	Metate	1296	Borrow Pit	Classic, Soho phase	Santan Mtn
Lower Santan	11415.01	Metate	868	Pithouse	Sedentary, undefined	Santan Mtn
Lower Santan	11420.01	Ind.	1296	Borrow Pit	Classic, Soho phase	Unknown
Pueblo Grande	1919	Metate	900	Room, Massive Walled Adobe	Classic, Civano Phase	West Wing Mtn
Pueblo Grande	1951	Mano	902	Room, Massive Walled Adobe	Classic, Civano Phase	Santan Mtn
Pueblo Grande	1981	Mano	144	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	1998	Mano	520	Pithouse	Classic, Soho Phase	Santan Mtn
Pueblo Grande	2134	Mano	901	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Pueblo Grande	3432	Mano	601	Room, Massive Walled Adobe	Classic, Civano Phase	McDowell Mtn
Pueblo Grande	3532	Metate	520	Pithouse	Classic, Soho Phase	Moon Hill/Ludden Mtn
Pueblo Grande	4001	Metate	520	Pithouse	Classic, Soho Phase	Table Top Mtn
Pueblo Grande	4026	Mano	641	Room, Massive Walled Adobe	Classic, Civano Phase	Moon Hill/Ludden Mtn
Pueblo Grande	4031	Mano	641	Room, Massive Walled Adobe	Classic, Civano Phase	McDowell Mtn
Pueblo Grande	4032	Metate	641	Room, Massive Walled Adobe	Classic, Civano Phase	Deem Hills
Pueblo Grande	4364	Metate	1000	Pithouse	Classic, Soho Phase	Hedgpeth Hills
Pueblo Grande	4406	Metate	1091	Room, Massive Walled Adobe	Classic, Civano Phase	Moon Hill/Ludden Mtn
Pueblo Grande	4448	Metate	1018	Pithouse	Classic, Soho Phase	McDowell Mtn
Pueblo Grande	4458.01	Mano	1049	Room, Massive Walled Adobe	Classic, Civano Phase	Santan Mtn
Pueblo Grande	4458.02	Mano	1049	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Pueblo Grande	4460	Metate	1049	Room, Massive Walled Adobe	Classic, Civano Phase	McDowell Mtn
Pueblo Grande	5196	Mano	641	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Pueblo Grande	5619	Metate	1049	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills
Pueblo Grande	5700	Metate	1018	Pithouse	Classic, Soho Phase	West Wing Mtn
Pueblo Grande	5909	Mano	1000	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	6240	Mano	1015	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	6709	Metate	1072	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills
Pueblo Grande	7362	Mano	1209	Room, Massive Walled Adobe	Classic, Civano Phase	Moon Hill/Ludden Mtn
Pueblo Grande	8501	Mano	1409	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	10106	Metate	958	Pithouse	Classic, Soho Phase	McDowell Mtn
Pueblo Grande	12035	Mano	993	Room, Massive Walled Adobe	Classic, Civano Phase	McDowell Mtn
Pueblo Grande	12945	Metate	1938	Pithouse	Classic, Soho Phase	McDowell Mtn
Pueblo Grande	13086	Mano	622	Room, Massive Walled Adobe	Classic, Civano Phase	McDowell Mtn
Pueblo Grande	13234	Mano	674	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills
Pueblo Grande	13692	Metate	674	Room, Massive Walled Adobe	Classic, Civano Phase	West Wing Mtn
Pueblo Grande	15922	Metate	2406	Pithouse	Classic, Soho Phase	Moon Hill/Ludden Mtn
Pueblo Grande	17177	Mano	257	Pithouse	Classic, Soho Phase	Santan Mtn
Pueblo Grande	19997	Mano	1128	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills
Pueblo Grande	22424	Mano	651	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills
Pueblo Grande	23659	Mano	2056	Pithouse	Classic, Soho Phase	McDowell Mtn
Pueblo Grande	23931	Mano	3109	Room, Freestanding Room	Classic, Soho Phase	Santan Mtn
Pueblo Grande	24255	Mano	674	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Pueblo Grande	24408	Metate	2406	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	24417	Metate	2014	Room, Massive Walled Adobe	Classic, Soho Phase	Unknown
Pueblo Grande	24547	Metate	1799	Room, Massive Walled Adobe	Classic, Civano Phase	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Pueblo Grande	24926	Metate	1799	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills
Pueblo Grande	28170	Mano	2015	Pithouse	Classic, Soho Phase	McDowell Mtn
Pueblo Grande	28170	Metate	2015	Pithouse	Classic, Soho Phase	West Wing Mtn
Pueblo Grande	29051	Mano	3160	Room, Freestanding Room	Classic, Soho Phase	Unknown
Pueblo Grande	29224	Mano	3517	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	29240	Mano	1797	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills
Pueblo Grande	41260	Mano	674	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Pueblo Grande	41571	Mano	144	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	42126	Mano	144	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	42135	Metate	144	Pithouse	Classic, Soho Phase	West Wing Mtn
Pueblo Grande	43127.01	Metate	520	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	43127.02	Metate	520	Pithouse	Classic, Soho Phase	Deem Hills
Pueblo Grande	43128.01	Metate	520	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	43128.02	Metate	520	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	43840	Metate	520	Pithouse	Classic, Soho Phase	McDowell Mtn
Pueblo Grande	45317	Mano	674	Room, Massive Walled Adobe	Classic, Civano Phase	McDowell Mtn
Pueblo Grande	45960	Metate	601	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Pueblo Grande	46754	Mano	520	Pithouse	Classic, Soho Phase	McDowell Mtn
Pueblo Grande	47813	Mano	630	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Pueblo Grande	48868	Mano	901	Room, Massive Walled Adobe	Classic, Civano Phase	Unknown
Pueblo Grande	49050	Metate	2056	Pithouse	Classic, Soho Phase	Moon Hill/Ludden Mtn
Pueblo Grande	49050	Mano	2056	Pithouse	Classic, Soho Phase	Unknown
Pueblo Grande	49189	Mano	902	Room, Massive Walled Adobe	Classic, Civano Phase	Hedgpeth Hills

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Pueblo Grande	49406	Mano	2056	Pithouse	Classic, Soho Phase	Hedgpeth Hills
Upper Santan	3267.01	Mano	28	Midden	Classic, Soho phase	Santan Mtn
Upper Santan	3267.02	Mano	28	Midden	Classic, Soho phase	Santan Mtn
Upper Santan	3325.01	Metate	22	Trash Mound	Classic, Soho phase	Santan Mtn
Upper Santan	3325.02	Metate	22	Trash Mound	Classic, Soho phase	Unknown
Upper Santan	3504.01	Mano	21	Midden	Classic, undefined	Santan Mtn
Upper Santan	3521.01	Mano	21	Midden	Classic, undefined	Santan Mtn
Upper Santan	3616.01	Mano	25	Trash Mound	Classic, undefined	Santan Mtn
Upper Santan	3681.01	Ind.	373	Midden	Classic, Civano Phase	Santan Mtn
Upper Santan	4243.01	Ind.	801	Pithouse	Colonial	Santan Mtn
Upper Santan	4244.01	Metate	833	Pit, undefined	Colonial	Santan Mtn
Upper Santan	5707.02	Ind.	727	Pit Room	Classic, Soho phase	Santan Mtn
Upper Santan	5734.01	Ind.	727	Pit Room	Classic, Soho phase	Santan Mtn
Upper Santan	6001.01	Mano	763	Pit, undefined	Sedentary, Late Sacaton	Santan Mtn
Upper Santan	6001.02	Ind.	763	Pit, undefined	Sedentary, undefined	Santan Mtn
Upper Santan	6187.02	Ind.	794	Pit Room	Classic, Soho phase	Unknown
Upper Santan	6187.02	Metate	794	Pit Room	Classic, Soho phase	Santan Mtn
Upper Santan	6310.01	Ind.	268	Pithouse	Colonial	Santan Mtn
Upper Santan	6310.02	Mano	268	Pithouse	Colonial	Santan Mtn
Upper Santan	6478.02	Metate	801	Pithouse	Colonial	Santan Mtn
Upper Santan	6754.01	Ind.	833	Pit, undefined	Colonial	Santan Mtn
Upper Santan	6754.02	Ind.	833	Pit, undefined	Colonial	Santan Mtn
Upper Santan	6754.03	Ind.	833	Pit, undefined	Colonial	Santan Mtn

(cont.)

Table A.2. Artifact Attribute and Geographic Provenance Data

Site Name	Spec No.	Artifact Type	Feature No.	Feature Type	Temporal Classification	Provenance Classification
Upper Santan	6754.04	Ind.	833	Pit, undefined	Colonial	Santan Mtn
Upper Santan	6754.05	Ind.	833	Pit, undefined	Colonial	Santan Mtn
Upper Santan	6754.06	Ind.	833	Pit, undefined	Colonial	Santan Mtn
Upper Santan	6754.07	Mano	833	Pit, undefined	Colonial	Unknown
Upper Santan	6770.01	Metate	833	Pit, undefined	Colonial	Santan Mtn
Upper Santan	7147.01	Ind.	829	Pit, undefined	Colonial	Santan Mtn
Upper Santan	7147.02	Ind.	829	Pit, undefined	Colonial	Robbins Butte
Upper Santan	7147.03	Ind.	829	Pit, undefined	Colonial	Unknown
Upper Santan	7147.04	Metate	829	Pit, undefined	Colonial	Santan Mtn
Upper Santan	7289.01	Mano	873	Pit Room	Classic, Soho phase	Santan Mtn
Upper Santan	7334.01	Ind.	873	Pit Room	Classic, Soho phase	Santan Mtn
Upper Santan	7334.02	Ind.	873	Pit Room	Classic, Soho phase	Unknown
Upper Santan	7351.01	Ind.	890	Midden	Colonial	Santan Mtn
Upper Santan	7351.02	Ind.	890	Midden	Colonial	Santan Mtn
Upper Santan	7377.01	Mano	890	Midden	Colonial	Santan Mtn
Upper Santan	7868.01	Metate	876	Pithouse	Colonial	Santan Mtn
Upper Santan	7974.01	Ind.	877	Pit, Thermal	Sedentary, undefined	Santan Mtn
Upper Santan	7974.02	Ind.	877	Pit, Thermal	Sedentary, undefined	Santan Mtn
Upper Santan	8285.01	Ind.	931	Pit, undefined	Sedentary	Santan Mtn
Upper Santan	8285.02	Metate	931	Pit, undefined	Sedentary, undefined	Unknown
Upper Santan	8285.03	Metate	931	Pit, undefined	Sedentary, undefined	Santan Mtn
Upper Santan	10482.01	Ind.	1096	Pithouse	Colonial	Santan Mtn
Upper Santan	10482.02	Ind.	1096	Pithouse	Colonial	Santan Mtn