JOURNAL OF
ARIZONA
ARCHAEOLOGY

VOLUME 2 NUMBER 1 SPRING 2012

IN THIS ISSUE:

ISSN 2159-2837

Mission Statement

The Journal of Arizona Archaeology is a peer-reviewed journal that focuses on the presentation of emerging ideas, new methods, and current research in Arizona archaeology. It endeavors to be a forum for the scholarly, yet simple communication of research and management related to Arizona's archaeological record. The journal is published twice a year by the Arizona Archaeological Council (AAC). At least one issue per year is devoted to the theme of the AAC annual fall conference. The conference issue (or issues) is overseen by a guest editor. The remaining issues of the journal are intended for open submissions. The frequency of general submission issues is dependent on the number of appropriate manuscripts received throughout the year and the workload of the editorial staff.

The journal is one benefit of membership in the AAC. Individual membership rates in the AAC are $30 per year. To apply for AAC membership, report a lost/damaged journal, or to learn more about the mission of the AAC, please visit the AAC website: http://arizonaarchaeologicalcouncil.org. Membership must be paid in full in order to receive regular copies of the Journal of Arizona Archaeology. Members and non-members can purchase additional copies of the journal for $15 per issue.

Instructions for Authors

The format of all submitted papers should correspond to the SAA style guide, which can be accessed at this web address: http://www.saa.org/Publications/StyleGuide/styframe.html. All manuscripts must be submitted as a MS Word document. All review (editorial and peer review) will be conducted electronically. Authors should be familiar with the "track changes" and "comments" functions of MS Word. Authors are encouraged to contact the editor with questions regarding the content or formatting of their manuscripts prior to submitting their papers.

Authors should anticipate two to three months for review of their manuscripts. The editor will review each paper prior to peer review to determine if the manuscript meets content and formatting guidelines. If the paper meets these preliminary guidelines, the editor will send the manuscript out for peer review. The editor makes the final decision to accept a manuscript on the basis of his review as well as those of the peer referees. If a manuscript is accepted for publication, authors must submit images in at least 300 dpi. All permissions for photographs and figures are the responsibility of the author and must be obtained prior to publication.

Editorial Contact Information

M. Scott Thompson
School of Human Evolution and Social Change, Arizona State University
PO Box 872402, Tempe, AZ 85287-2402
Mason.Thompson@asu.edu

THEMED ISSUE:

THE APPLICATION OF ARCHAEOLOGICAL SCIENCES IN ARIZONA

PREFACE

This issue of the Journal of Arizona Archaeology is largely dedicated to presentations given at the 2010 annual AAC Fall Conference, held in Tucson on October 29th and 30th at the University of Arizona. The theme for the conference was "The Application of Archaeological Sciences in Arizona." Archaeological sciences (a.k.a. archaeometry) describe approaches that apply scientific methodologies to understand material culture and test hypotheses about human behavior. Techniques largely focus on the application of the physical sciences to dating and sourcing, but can range from environmental approaches to mathematical modeling and from lithic analysis to bioarchaeology. This approach has become one of the central directions within the discipline and is providing the foundation for future advances in archaeology.

The 2010 conference was a huge success with 22 presentations from 35 participants covering a diversity of topics within the archaeological sciences. Of these presentations, eleven were submitted for publication and eight were accepted and are presented in the proceeding pages. This is also the first fully peer-reviewed issue of the Journal of Arizona Archaeology and provides a model for subsequent issues. Each submission was subjected to single-blind review by three referees. Those that were deemed appropriate for publication were invited to revise their manuscripts and publish with the journal.

The papers presented in this issue are important contributions to the archaeology of Arizona and demonstrate the breadth and flexibility encompassed under the umbrella of archaeological sciences. Abbott and colleagues present a manual and graphical guide for Hohokam decorated ceramics from the Middle Gila River Valley in hopes of systematizing and regularizing classification for researchers. Byrd and colleagues use the context and spatial distribution of mortuary features from a late Classic period site in the Tucson Basin to suggest that household inheritance was legitimized though placement of the dead. Conyers describes recent advances in the application of ground-penetrating radar in southern Arizona through several case studies to demonstrate its utility in identifying buried archaeological features. Doyel largely focuses on the results of X-ray fluorescence spectrometry (XRF) to characterize Pre-Classic procurement and exchange in and around the Phoenix Basin and identifies that, with a few exceptions, it was largely based in local economies—a pattern that changes with the Classic period. Dybowski also examines obsidian from Arizona using XRF but focuses on its inherent utility using different methods to identify that results are generally not comparable. Ownby and Miksa present an overview of petrofacies modeling for Arizona and their utility for understanding exchange networks in their socio-cultural contexts, specifically considering methods, processes, and results, and highlighting examples from two Classic period sites in the Tucson and Tonto basins, respectively. Lack and colleagues use petrofacies modeling to track the rise of Hohokam red-on-buff pottery production along Queen Creek from the Pre-Classic to the Classic Period. Steinbach uses historical documents, aerial imaging, and Geographic Information Systems (GIS) to relocate a platform mound at the Classic Period site of Las Canopas in South Phoenix. His analysis provides important context for the interpretation of spatial relationships with the site. All of these papers enhance our understanding of human behavior in the past by employing a range of methodologies and increasing our interpretive and explanatory power in the discipline.

James T. Watson

PRE-CLASSIC PROCUREMENT AND EXCHANGE IN AND AROUND THE PHOENIX BASIN, ARIZONA

David E. Doyel

ABSTRACT

Hohokam society was characterized by complex exchange systems wherein materials were procured from specific source locales and then distributed across a wide geographic region. Material science analyses can further elucidate Hohokam exchange systems by providing detailed data to assist archaeologists to track the movement of ancient materials and artifacts across the landscape. Fifteen years ago I initiated sourcing studies to look at multiple product circulation in Hohokam exchange, including pottery and obsidian, in the Pre-Classic period (ca. A.D. 800-1100). One lesson from this project is that science applications will include successes and failures, and this paper describes an example of each. X-ray fluorescence spectrometry (ED-XRF) analysis of obsidian revealed successfully that proximity to source was a primary factor in obsidian procurement during the Pre-Classic period. Obsidian from the Vulture Mountains was the most evenly distributed obsidian at heartland settlements whereas obsidian from the Superior source was the most abundant type. This pattern changed in the ensuing Classic period with the increased use of obsidian from non-local sources, a shift that reflected transformations in the procurement and exchange of obsidian across the Hohokam world. Another component of this project was the use of inductively coupled plasma acid-extraction (ICP-AE) to assess the composition of pottery sherds of a type known as Sacaton Red that, for reasons to be described, was a bust.

In 1995 I initiated a small-scale research project that I named the Pre-Classic Exchange Research Project (PERP) (Doyel 1995). At that time, studies of Hohokam trade and exchange focused on Classic period material culture. PERP's objectives included examining exchange by collecting provenance data on multiple materials dating to the Sacaton phase of the Pre-Classic period. These data would then be utilized to compare the circulation patterns of different products across space to evaluate whether these materials were part of the same or different exchange networks. Completion of this research was delayed for years, and a primary reason for the present contribution is to make unpublished data available.

One objective was to collect source data on obsidian artifacts using X-ray fluorescence spectrometry (ED-XRF). Since this study was conducted, new obsidian source data have been reported. Specifically, over 700 obsidian samples from Pre-Classic villages have been sourced. I compare my results to these other studies. A second objective was to collect source data on Sacaton Red, an understudied pottery type temporally restricted to the Sacaton phase and known to be present at multiple sites in the region. This study used inductively coupled plasma acid-extraction (ICP-AE) to assess the composition of pottery samples.

PERP DATA FOR LATE PRE-CLASSIC OBSIDIAN SOURCES

The first goal of the PERP obsidian analysis was to source artifacts recovered from large Sacaton phase sites in the Phoenix Basin; samples were selected from the Gatlin site, Frogtown, and Las Colinas. I had planned to source obsidian from Snaketown as well, but excluded these samples when I learned that Shackley (2005) was studying Snaketown obsidian. For comparison with the PERP obsidian samples, I also included some results of a sourcing analysis from the Globe Highlands (Figure 1; Table 1).[1] I briefly describe each set of samples and the results from each analysis in the following section.

Gatlin (Gila Bend) Site

This site is located along the Gila River on the southwestern frontier of the Hohokam region on the north edge of the Papagueria (Doyel 1998, 2008). Source analysis of obsidian projectile points, bifaces, flakes, cores, and nodules identified five distinct

David E. Doyel / Barry M. Goldwater Range, East Luke Air Force Base, Glendale AZ / ddoyel@cox.net

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 4-14

sources. Most (75 percent) were sourced to the Sauceda Mountains, less than 50 km to the south; nodules can also be found in north-draining arroyos closer to the Gila River (Doyel 1996; Shackley 1993). The remaining 15 percent of the sample was sourced to Los Sitios del Agua (LSA, formerly Unknown A) (7 percent);[2] Vulture (4 percent); Superior (3 percent); and Los Vidrios (1 percent). These sources are located 100-150 kilometers from the Gatlin site.

Frogtown

This site is located in the Queen Creek drainage north of the Gila River about 25 km from Snaketown (Bernard-Shaw 1984; Sires 1984). The samples included projectile points, a biface, flakes, cores, and nodules. Most of the samples were sourced to Superior (89 percent), with smaller frequencies of Vulture (6 percent) and Mule Creek (6 percent). The Superior source is 50 km to the east, Vulture is 100 km northwest, and Mule Creek is 225km to the east (Shackley 1998a). Thus, the dominant obsidian type among the Frogtown samples was derived from the closest source.

Las Colinas

Las Colinas is located in west Phoenix along Canal System 2 on the north side of the Salt River (Gregory et al. 1988). Artifacts sourced in this analysis were matched to nine different locales (Shackley 1998b). In contrast to the other site findings, the obsidian sample from Las Colinas was not predominantly derived from nearby sources. Northern Arizona sources (Government Mountain; RS Hill / Sitgreaves; Partridge Creek), located 200 km to the north, constitute 50 percent of the samples. Obsidian from the nearby (50 km) Vulture Mountain source represents 26 percent of the samples. The remaining samples were sourced to Sauceda, the Sand Tanks, Los Vidrios, and Los Sitios del Agua.

Pinal Creek, Globe Highlands

Obsidian was sourced from multiple sites along Pinal Creek in the Globe Highlands about 100 km east of Snaketown. The sample included projectile points, a biface, and nodules. Of the 96 samples analyzed, 84 percent were matched to the nearby (30 km) Superior (Picketpost Mountain) source (Shackley 2003). Of the 24 specimens from Pre-Classic contexts, 23 (96 per-

Table 1. Obsidian source data from selected Pre-Classic settlements.

	Artifact/Obsidian	Superior	Vulture	Mule Creek	Gov't Mtn	Sauceda	Los Vidrios	LSA	RS Hill/ Sitg.	Part. Creek	Sand Tanks	Row Total
Globe Highlands	Projectile points	3	-	1	-	-	-	-	-	-	-	4
	Biface/Drill	1	-	-	-	-	-	-	-	-	-	1
	Nodule	19	-	-	-	-	-	-	-	-	-	19
	Column Total	23	-	1	-	-	-	-	-	-	-	24
	Column Percent	96	-	4	-	-	-	-	-	-	-	100
Frogtown	Projectile points	12	-	2	-	-	-	-	-	-	-	14
	Biface	-	1	-	-	-	-	-	-	-	-	1
	Flake	13	1	-	-	-	-	-	-	-	-	14
	Core	3	-	-	-	-	-	-	-	-	-	3
	Nodule	3	-	-	-	-	-	-	-	-	-	3
	Column Total	31	2	2	-	-	-	-	-	-	-	35
	Column Percent	89	6	6	-	-	-	-	-	-	-	101
Gila Bend (Gatlin)	Projectile points	2	2	-	-	16	1	1	-	-	-	22
	Biface	-	-	-	-	4	-	2	-	-	-	6
	Debitage/flake	-	1	-	-	30	-	2	-	-	-	33
	Core	-	-	-	-	11	-	-	-	-	-	11
	Nodule	-	-	-	-	3	-	-	-	-	-	3
	Column Total	2	3	-	-	64	1	5	-	-	-	75
	Column Percent	3	4	-	-	85	1	7	-	-	-	100
Las Colinas	Projectile points	-	2	-	11	2	-	1	2	-	2	20
	Drill	-	-	-	1	-	-		-	-	-	1
	Debitage/flake	1	11	-	7	3	2	1	3	1	-	29
	Column Total	1	13	-	19	5	2	2	5	1	2	50
	Column Percent	2	26	-	38	10	4	4	10	2	4	100

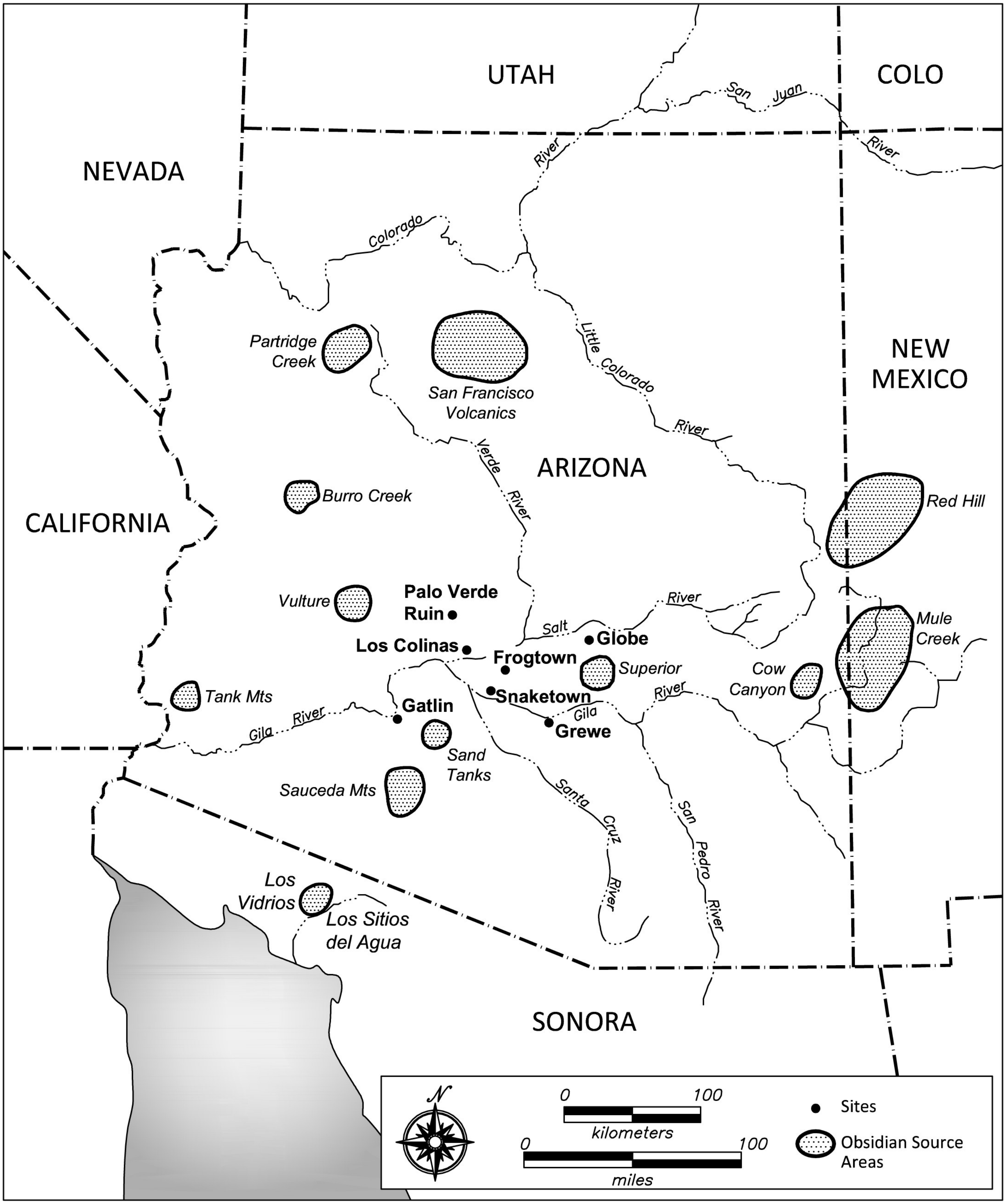


Figure 1. Selected obsidian source areas and archaeological sites in Arizona.

cent) were from the Superior source, and a single exception was from Mule Creek. Pre-Classic projectile points from the Globe Highlands sites are illustrated here (Figure 2), and examples of Phoenix Basin obsidian points are illustrated elsewhere (e.g., Doyel 1996; Shackley 2005).

OBSIDIAN PROCUREMENT PATTERNS IN THE PRE-CLASSIC PERIOD

A second objective of the PERP analysis was to identify the distribution and circulation patterns of obsidian in the Phoenix Basin. To increase the sample size, I compare these data to other obsidian sourcing data from sites in south and central Arizona (Table 2). The data presented in Table 2 represent most but not all of the available obsidian source data for the late Pre-Classic period (see Loendorf 2010; Peterson et al. 1997; Shackley 2005).

The combined obsidian source data indicate that prehistoric residents at several sites had access to a wide variety of obsidian types. At Las Colinas and Snaketown, the analyses have identified specimens from nine different source locales. At Grewe and Gatlin, analyses have distinguished seven and six different sources respectively. Five different source types were identified at Palo Verde. These results suggest that large settlements were likely located along major travel routes and were actively involved in resource procurement and in multi-product exchanges. This is not a

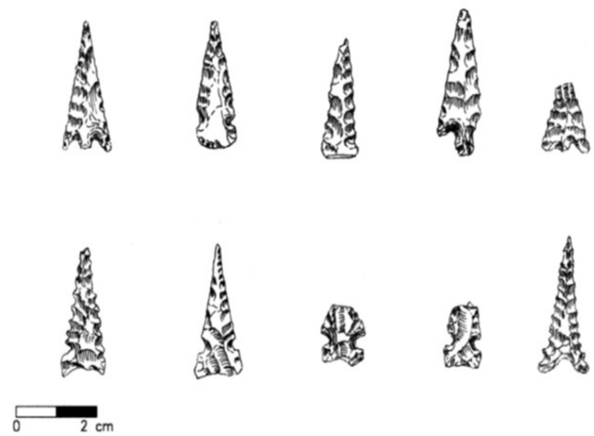


Figure 2. Examples of late Pre-Classic Hohokam obsidian projectile points from the Wheatfields sites in the Globe Highlands (Rapp and Oglesby 2003:250).

Table 2. Obsidian source data from late Pre-Classic settlements (in counts).

Source / Site/Citation	**Las Colinas** Shackley 1998b	**Palo Verde** Shackley 2007	**Gatlin (Gila Bend)** Doyel 1996	**Gillespie Dam** Shackley 2009	**Frogtown** Shackley 1998a	**Snaketown** Shackley 2005	**Grewe** Bayman and Shackley 1999	**Globe Sites** Shackley 2003	**Totals Counts**	**Per Cent**
Government Mtn.	19	39	-	-	-	5	1	-	**64**	**8.3**
RS Hill/Sitgreaves	5	13	-	3	-	7	-	-	**28**	**3.7**
Partridge Creek	1	2	-	-	-	-	-	-	**3**	**0.4**
Bull Creek	-	-	-	1	-	-	-	-	**1**	**0.1**
Superior	1	-	2	-	31	180	130	25	**369**	**48.0**
Sand Tanks	2	-	-	-	-	4	-	-	**6**	**0.8**
Vulture	13	67	3	17	2	16	1	-	**119**	**15.6**
Sauceda	5	-	64	-	-	65	1	-	**135**	**17.6**
Los Vidrios	2	-	1	-	-	-	-	-	**3**	**0.4**
Los Sitios del Agua	2	-	5	-	-	15	3	-	**25**	**3.7**
Cow Canyon	-	1	-	-	-	5	-	-	**6**	**0.8**
Mule Creek	-	-	-	-	2	2	1	1	**6**	**0.8**
Totals	**50**	**122**	**75**	**21**	**35**	**299**	**137**	**26**	**765**	**100.2**
No. Sources	9	5	6	3	3	9	7	2		

simple function of sample size, however, as nine sources were present in the 50 samples from Las Colinas but only seven were present in the 137 samples from Grewe.

Despite the variety of sources represented, the evenness and abundance of artifacts from particular sources reveals interesting patterns. I briefly review the data relevant to the evenness and abundance of obsidian sources at different sites in the sample.

Evenness

The combined source data indicate that Vulture Mountain is the most evenly distributed source at Pre-Classic Hohokam settlements. With the exception of the Globe Highlands sites, Vulture Mountain obsidian is present in all the site samples analyzed, although it occurs in low frequency (less than 4 percent in the middle Gila) in later time periods.

Abundance

Regarding source frequency, 94 percent of Pre-Classic obsidian samples were sourced to four areas: Superior, Sauceda, Vulture, and northern Arizona. Superior obsidian is the single-most abundant source, representing 48 percent of the samples. Sauceda, Vulture, and the northern Arizona obsidians constitute a significant portion of the samples (13 - 18 percent each). In addition to the four most abundant sources, obsidian from other sources appeared in minor amounts; for example, obsidian from Bull Creek, Sand Tanks, Los Vidrios, Los Sitios del Agua, Cow Canyon and Mule Creek represents only 6.3 percent of the total sample.

It is interesting to note that the most abundant source in the sample of Pre-Classic obsidian is not the most evenly distributed. Superior specimens occur in high frequencies along the middle Gila River valley but are nearly absent (less than one percent) at sites to the west along both the Salt and the lower Gila. Specimens from the southern source areas, including Sauceda, Los Vidrios, and Los Sitios del Agua, have uneven distributions across the region. These types are present at Las Colinas and Snaketown but are almost absent at Frogtown and Grewe. It remains puzzling why obsidian from the Sand Tank Mountains appears in such low frequencies while obsidian from the nearby Sauceda Mountains is among the most frequently used obsidian types in the Pre-Classic period (see Shackley and Tucker 2001 for discussion). Sand Tank obsidian has only been identified at Las Colinas and Snaketown where it represents less than 1 percent of the samples.

The distribution of obsidian from some sources appears to be particularly uneven. No eastern sources (Cow Canyon and Mule Creek) are represented at the western sites such as Las Colinas, and only a single piece of Cow Canyon is present at Palo Verde Ruin. Overall, these eastern sources are poorly represented in the total sample (1.6 percent) of Pre-Classic obsidian, but this small amount anticipates a larger presence of these sources in the Classic period (Clark et al. 2011). Sauceda has a relatively strong presence at Snaketown (22 percent), but, overall this source and the other westerly and southerly sources, including Los Vidrios and Los Sitios del Agua, have low presence values in the Phoenix Basin, whether in the Salt or Gila river valleys.

SUMMARY AND DISCUSSION

PERP and other Pre-Classic obsidian sourcing data indicates that the Vulture source, located northwest of Phoenix, is the most ubiquitous and that the Superior source northeast of the middle Gila area is the most abundant. In addition, these analyses reveal that geographic proximity plays an important role in the distribution of obsidian debitage and finished tools across central Arizona. In this section, I explore three intriguing results of the analysis that warrant further research. These topics include 1) exceptions to the distribution of obsidian on the basis of geographic proximity to source locales, 2) trade in finished obsidian tools versus raw material, and 3) differences in obsidian exchange patterns between the pre-Classic and Classic period.

Exceptions to Procurement from Proximate Sources

The Pre-Classic obsidian source data presented here suggest that obsidian was usually obtained from nearby sources (Figure 3), but there are exceptions. In this section, I discuss data that deviate from the general model of local obsidian procurement in the Pre-Classic period.

Las Colinas. Although Las Colinas is located in the Salt River valley, 48 percent of the Pre-Classic obsidian artifacts recovered from this site was sourced to the Flagstaff area located 200 km distant. The Las Colinas obsidian assemblage is distinguished by the variety of obsidian sources represented (n = 9). Points made of obsidian from six different sources are present, and the corresponding presence of debris in most cases from these sources suggests on-site knapping.

Palo Verde Ruin. The site is located in the New River drainage on the northern edge of the Phoenix Basin (Hackbarth and Craig 2007; Marshall 2007). The obsidian source data from this site are strikingly similar to Las Colinas and support the dominance of northern and western sources in these areas (Shackley 2007); no southern sources, such as Sauceda, are present in

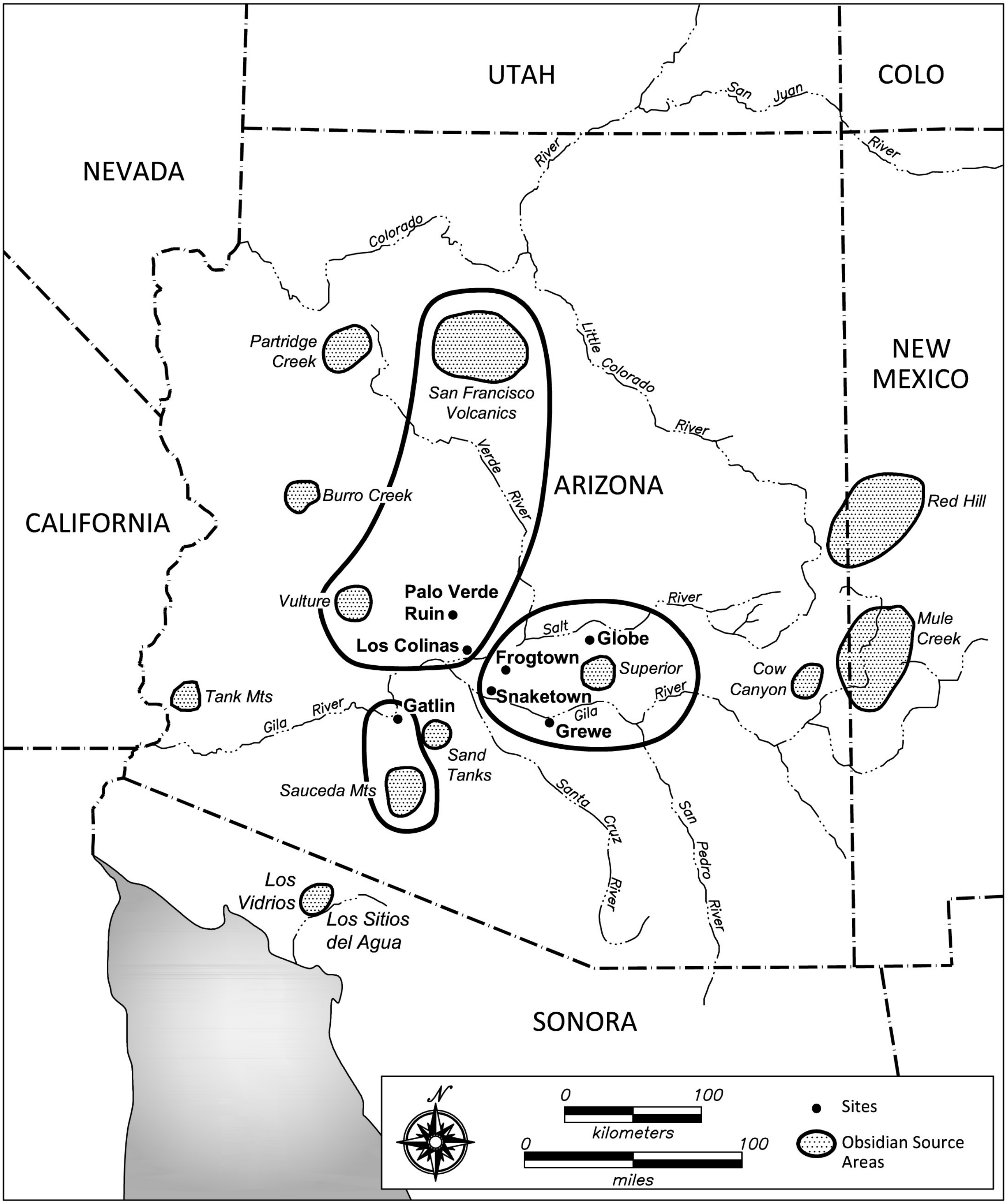


Figure 3. Pre-Classic period obsidian procurement areas.

the obsidian assemblage. Overall, Palo Verde Ruin lacks the low level frequencies from the wide variety of sources present at Las Colinas.

Palo Verde Ruin developed into a ballcourt center in the middle Sacaton phase that was likely tied into the regional Hohokam ballcourt network (Hackbarth and Craig 2007). Trade with groups to the north would account for the relatively homogeneous obsidian collection when compared to Las Colinas. The high number of Flagstaff area obsidians at these two sites could be due to a number of factors: the presence of Hohokam populations located to the north (in the Verde Valley and adjoining areas); the presence of active north-south exchange systems; the possible presence of people (e.g., visitors, trading partners) from the north at sites like Las Colinas; and/or the high quality of the obsidian from Flagstaff sources (Shackley 2005:34).

Gillespie Dam Site. Sourcing data from a small sample of obsidian (n=21) from the Gillespie Dam site, located 32 km north of Gila Bend, revealed that most of the artifacts were from the Vulture Mountains (81 percent) and northern Arizona (19 percent) (Henderson 2009; Ryan 2009; Shackley 2009). Recent fieldwork for a pipeline project elsewhere on the Gillespie Dam site (Rice et al. 2009) also sourced one non-mortuary obsidian artifact to the Vulture source (Rapp and Rowe 2009; Erik Steinbach, personal communication, April 5, 2011). No Sauceda obsidian was identified in the Gillespie Dam sample even though this source was close by and the site occupation overlaps with the occupation at the Gatlin site, where Sauceda was dominant. The Vulture Mountain obsidian at Gillespie Dam defies the expectation that people procured and used obsidian from the closest available source.[3] This analysis provides an excellent example of why samples should be processed based on science instead of simply assuming the predicted results; i.e., that the dominant source would be Sauceda based on proximity.

Trade in Finished Items, Not Raw Material

The 22 projectile points sourced from Gatlin were derived from five different sources. Sauceda obsidian dominated the sample. Small amounts of debitage from Vulture Mountain and Los Sitios del Agua were also present. However, no debitage from Superior and Los Vidrios was recovered from the site. Similarly, points made of Mule Creek obsidian are present at Frogtown and at the Globe Highlands sites without any corresponding debris from these sources. The movement of finished tools suggests trade in arrows or arrow points instead of the exchange of raw materials (Doyel 1996). An alternative theory is that these artifacts were associated with warfare among people from different regions. The movement of finished tools could represent points removed from wounds, or possibly collected as war trophies.

Classic Period Obsidian Exchange and Procurement

In general, the use of Superior obsidian diminishes from the Pre-Classic to the Classic period in the Phoenix Basin, and use of other, more distant sources (Cow Canyon and Mule Creek), including the heretofore little-used eastern sources, become common (Bayman 1995; Clark et al. 2011; Loendorf 2010; Shackley 2005). Shackley (2005) noted that the Superior source declined in the Phoenix Basin after the late Pre-Classic, but that the source continued to be common in the Classic period in the Tucson Basin. This pattern suggests some type of barrier to access to Superior obsidian that led to significant increases in the use of Sauceda obsidian. Loendorf (2010) suggests that the presence of foraging groups like the Apache may have cut off access to the Superior source. However, if this is the case, why is Superior obsidian still common in the Tucson Basin? Additionally, the Gila Bend area appears to have witnessed reduced population at the beginning of the Classic period that may have led to more open access to the Sauceda sources (Doyel 2008). Clark et al. (2011) suggest that small groups of ancestral Puebloan immigrants situated east of the Phoenix Basin in the Safford and San Pedro river valleys disrupted traditional routes of commerce and travel and facilitated the circulation of obsidian from other non-local sources including Mule Creek, where related populations may have controlled or at least had open access to the source.

However, 11 percent of the obsidian from Classic period contexts at Pueblo Grande in the Salt River valley was from Superior (20 of 179) (Peterson et al. 1997:240), whereas only a trace was present in the Pre-Classic period. It is also important to note that the four main sources present at Pueblo Grande (Sauceda, Vulture, Northern Arizona, and Superior) are the same sources relied on in the Pre-Classic. The Superior source is the closest source but is fourth in frequency, which is a departure from the Pre-Classic pattern.

Significant changes, including alterations in obsidian procurement, appear to have occurred in the organization of exchange in the Classic period. In some cases, perhaps like Pueblo Grande, it may have been a matter of relative frequencies rather than access to a particular source being completely cut off. In Pinal Creek in the Globe Highlands, specimens from more distant sources were recovered from Classic period contexts. Samples were sourced to Cow Canyon and Mule Creek to the east and to Government Mountain and RS Hill/Sitgreaves to the northwest. Continued research should track changes in the distribution of obsidian from different sources across the Pre-Classic, early Classic, and late Classic periods.

POTTERY COMPOSITION

By design, the Pre-Classic Exchange Research Project (PERP) was to include several material products commonly utilized by the Hohokam, including obsidian and pottery. Sacaton Red was chosen for the pottery component because it was understudied and seemed to be temporally restricted to the Sacaton phase (Doyel 2010). The plan was to obtain source data for these two products - pottery and obsidian - and then compare their distributions across space.

I analyzed several hundred sherds from Frogtown, Gatlin, Las Colinas, Snaketown, and from sites in the Globe Highlands for production style and technology. Macroscopic analysis indicated homogeneity in production technology and temper sources. A sand tempered variety was produced at Las Colinas in the Salt River Valley that is easily distinguishable from the middle Gila-produced materials also present at that site; Abbott (1988) noted this variation, and my analysis supports his observations. Petrographic analysis by Nora Gladwin suggested that this pottery was produced at Snaketown (Gladwin et al. 1937:204). Although local copies may have been produced, like that at Los Colinas, Sacaton Red was likely produced along the middle Gila area near Snaketown where the buff and plain wares were also produced, and widespread exchange from this source is predicted (Doyel 2010). Sacaton Red has an uneven distribution in the Phoenix Basin; it is present at the four study villages but almost absent at both Pueblo Grande in the Salt River Valley (Abbott 1994:322) and the Grewe site in the Gila River Valley (Abbott and Henderson 2001:300). Sherds and a whole vessel recovered from sites in the Globe Highlands likely derive from middle Gila sources (Doyel and Ferguson 2003). The sherds were then sent to James Burton at the University of Wisconsin, Madison for compositional analysis by Inductively Coupled Plasma Acid-Extraction (ICP-AE) (Burton and Simon 1993). Historically ICP-AE analysis has not been without controversy (Neff et al. 1996; Burton and Simon 1996). Years later when I returned to this study, Burton informed me that:

> I no longer feel the results [of compositional work on low-fired ceramics] can provide reliable archaeological inferences. I'm convinced that archaeologists shouldn't be generating or using elemental data from ancient pots… If we had just been using the microscope instead [for petrography], I think we'd have about a half- century of progress instead of retardation" ([James Burton, emails, September 15-21, 2009]).

Research commonly requires experimentation and there will be false starts and dead ends along the way, such as the now discredited yet extensive work conducted by Burton and Simon (1993) on Southwestern pottery using ICP-AE. This method still has applications but in current studies of pottery the preferred compositional techniques include optical emission spectrometry (OES) or atomic emission spectrometry (AES) (see Ownby 2010 for discussion). As analytical studies continue to expand, it would be instructive to include Sacaton Red, as this type has an interesting history and was present during a period of significant technological, stylistic, and organizational change in Hohokam society.

DISCUSSION

EDXRF analysis of late Pre-Classic period obsidian indicates that geographic proximity largely explains the distribution of obsidian materials in and around the Phoenix Basin. The obsidian data point to reliance on local sources for this period, although four different sources were commonly used. The low frequency presence of distant sources should not be overlooked, as this variability may provide additional insights into exchange and cultural behavior.

The distribution of obsidian varieties contrasts markedly with the distributions of pottery. Obsidian source areas were located on Phoenix Basin's peripheries, from which obsidian was procured and circulated to sites in and around the Basin. In contrast, production source identification indicates that pottery was produced at a limited number of locales within the basin and then widely circulated from these sites (e.g. Abbott et al. 2007). Thousands of pottery vessels including plain, buff, and red wares were manufactured in, and near, Snaketown and distributed across a vast area from the Papagueria to the Globe Highlands. Pre-Classic exchange of materials, both raw and manufactured, was likely facilitated by gatherings at ballcourt villages and by other social, economic, and ideological factors (Abbott 2009; Abbott et al. 2007; Doyel 1979, 1991, 2006). How specific products were circulated through the ballcourt/marketplace network remains to be determined.

The presence of non-Hohokam trade pottery (e.g., Anasazi, Mogollon) at sites in the Phoenix Basin suggests that the Hohokam participated in multiple interaction spheres and that the region was not monolithic in character (Doyel 1993). The distribution of obsidian in the Pre-Classic period seems to support this interpretation. Social networks may also have played a role in the movement of raw and finished artifacts including obsidian from their source locales to the sites where they were deposited. It is possible that network analysis could be useful in assessing the distributions of these materials and products.

ARCHAEOLOGICAL SCIENCES AND HOHOKAM PROCUREMENT AND EXCHANGE

Hohokam society was highly social, highly interactive, and highly interdependent. Science applications are providing opportunities to evaluate this view of Hohokam society, in part by providing archaeologists tools to help track the movement of ancient materials and products across space. Hohokam procurement, production, and exchange were active and extensive, and likely involved many hard and soft fabric materials. Identifying the sources, frequency of exchange, and the quantity of goods moved across the landscape is integral to understanding the Hohokam economy. Rigorous use of science based approaches has resulted in substantial dividends in the work on Hohokam pottery by Abbott and his colleagues (Abbott 2009; Abbott and others 2007), and new approaches are being investigated (Kelly 2012).

Pottery, obsidian, marine shell, and ground stone are common hard fabric products known to have been produced and exchanged in great quantities. Although headway has been made, these materials represent the low hanging fruit for demonstrating Hohokam exchange. Specialized production and exchange were integral to the regional economy throughout the Hohokam sequence (Doyel 1991). Trade was also of great importance to historic populations in the region (Russell 1975; Underhill 1969:103), and this knowledge combined with the archaeological data provides rich sources of ideas to investigate economic and social systems. More creativity would be useful in the pursuit of science-based applications to learn more about the organization of Hohokam society.

More broadly, science based applications have helped to identify the presence of chocolate (cacao) at Chaco Canyon dating to A.D. 1000-1125 (Crown and Hurst 2009), 2000 km north of its source area. Investigations currently underway to determine if this exotic product was also present in the Hohokam region are yielding positive results (Patricia Crown, personal communication 2011). I have been searching for chili pepper in southern Arizona ever since Emil Haury suggested it to me in the early 1970s but I have yet to find any. The first meager evidence of chili pepper was recently identified in northern Chihuahua (Minnis and Whalen 2010). The point here is that some things take time and that persistence is often rewarded! In the years ahead I predict multiple revelations for the Hohokam derived at least in part from science-based applications in archaeology.

Notes

1. For additional information on x-ray fluorescence analysis in archaeology, the reader is referred to publications by Shackley (1995, 2005, 2011).

2. The obsidian source known for years as Unknown A is now identified as "Los Sitios del Agua" (LSA) located in extreme northern Sonora near the Los Vidrios source (Martynec et al. 2011; Shackley 1995:544). This new source "is distinctive chemically and morphologically, and is often green when viewed in transmitted light" (Steven Shackley, email, December 9, 2011). Sauceda samples also tend to exhibit a green hue (Doyel 1996), suggesting a shared attribute that might cause confusion if samples are identified based solely on color.

3. Two projectile points were associated with the Hohokam and Patayan burials at the Gillespie Dam Site. These artifacts were not sourced because of proscriptions to keep artifacts from a burial together. In the future, a portable XRF device could be used in the field to collect data while allowing all the artifacts from a mortuary feature to remain together.

Acknowledgements. Thanks to Steve Shackley for his pioneering research on those "little black rocks" and to Jim Burton for his pioneering research on chemical analysis of material culture. I am grateful to Mike Jacobs of the Arizona State Museum and to Marcie Donaldson of the Bureau of Reclamation for their assistance with collections, and to Jean Baker for producing the figures. A grant from the Arizona Archaeological and Historical Society provided partial funding for sourcing the Las Colinas and Frogtown obsidian. Sourcing of the Gatlin site obsidian was funded by the Town of Gila Bend Gatlin Site Fund. Finally, thanks to the three reviewers whose thoughtful comments improved the final version of this paper.

REFERENCES CITED

Abbott, David R.

1988 Form, Function, Technology, and Style in Hohokam Ceramics. In *The 1982-1984 Excavations at Las Colinas, Material Culture*, edited by David R. Abbott, Kim E. Beckwith, Patricia L. Crown, R. Thomas Euler, David A. Gregory, J. Ronald London, Marilyn B. Saul, Larry A. Schwalbe, Mary Bernard-Shaw, Christine R. Szuter, and Arthur W. Vokes, pp. 73-197. Archaeological Series No. 162(4). Arizona State Museum, University of Arizona, Tucson.

1994 Detailed Analysis of Sherds. In *The Pueblo Grande Project: Ceramics and the Production and Exchange of Pottery in the Central Phoenix Basin*, edited by David R. Abbott, pp., 261-368. Publications in Archaeology No. 20(3). Phoenix: Soil Systems, Inc.

2000 *Ceramics and Community Organization among the Hohokam.* University of Arizona Press, Tucson.

2009 Extensive and Long-Term Specialization: Hohokam Ceramic Production in the Phoenix Basin, Arizona. *American Antiquity* 74:531-557.

Abbott, David R. and T. Kathleen Henderson

2001 Ceramic Rough Sort Counts. In *The Grewe Archaeological Research Project: Volume 2 Material Culture,* edited by David R. Abbott, pp. 273-306. Anthropological Papers No. 99-1. Tempe: Northland Research Inc.

Abbott, David R., Alexa Smith and Emiliano Gallaga

2007 Ballcourts and Ceramics: The Case for Hohokam Marketplaces in the Arizona Desert. *American Antiquity* 72:461-484.

Bayman, James M.

1995 Rethinking "Redistribution" in the Archaeological Record: Obsidian Exchange at the Marana Platform Mound. *Journal of Anthropological Research* 51(1):37-63.

Bayman, James M., and S.M. Shackley

1999 Dynamics of Hohokam Obsidian Circulation in the North American Southwest. *Antiquity* 73:836-845.

Bernard-Shaw, Mary

1984 Artifacts. In *Hohokam Archaeology along the Salt-Gila Aqueduct, Central Arizona Project,* edited by Lynn S. Teague and Patricia L. Crown, 447-481. Archaeological Series No. 150 (4, Part 3). Arizona State Museum, Tucson.

Burton, James H. and Arleyn W. Simon

1993 Acid Extraction as a Simple and Inexpensive Method for Compositional Characterization of Archaeological Ceramics. *American Antiquity* 58:45-59.

Burton, James H., and Arleyn W. Simon

1996 A Pot is not a Rock: A Reply to Neff, Glascock, Bishop, and Blackman. *American Antiquity* 61:405-413.

Clark, Jeffery, Steven Shackley, Robert Jones, and Stacy Ryan

2011 Through Volcanic Glass: Measuring the Impact of Ancestral Puebloan Immigration on the Hohokam World. Paper presented at the 76th Annual Meeting of the Society for American Archaeology, Sacramento.

Crown, Patricia and W. Jeffrey Hurst

2009 Evidence of Cacao Use in the Prehispanic American Southwest. *Proceedings of the National Academy of Sciences* 106(7): 2110-2113.

Doyel David E.

1979 The Prehistoric Hohokam of the Arizona Desert. *American Scientist* 67:544-554.

1991 Hohokam Exchange and Interaction. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by Patricia Crown and W. James Judge, pp. 226-252. School of American Research, Santa Fe.

1993 On Rivers and Boundaries in the Phoenix Basin, Arizona. *Kiva* 8:455-474.

1995 Research Grant Proposal: Hohokam Obsidian Sourcing, Estrella Cultural Research, Arizona Archaeological and Historical Society. Tucson.

1996 Resource Mobilization and Hohokam Society: Analysis of Obsidian Artifacts from the Gatlin Site. *Kiva* 62:45-60.

1998 Vacant Ceremonial Centers Revisited. *Kiva* 64:225-244

2006 Irrigation, Production and Power in Phoenix Basin Hohokam Society. In *The Hohokam Millennium*, edited by Suzanne Fish and Paul Fish, pp. 82-89. School for Advanced Research Press, Santa Fe.

2008 Edge Work: The Late Prehistory of the Gila Bend Frontier. In *Fragile Patterns: Perspectives on Western Paguería Archaeology*, edited by J. Altschul and A. Rankin, pp.233-252. SRI Press, Tucson.

2010 Sacaton Red and the Norton Allen Collection. *Journal of the Southwest* 52 (2-3): 277-298.

Doyel David E. and Deborah Ferguson

2003 Undecorated Ceramics and Clay Artifacts from the SR88-Wheatfileds Sites. In *Settlement History along Pinal Creek in the Globe Highlands, Arizona*, edited by David E. Doyel and T. Hoffman, Volume 3, pp. 41-94. Archaeological Consulting Services Cultural Resources Report No. 112, Tempe.

Gladwin, Harold S., Emil W. Haury, E. B. Sayles, and Nora Gladwin

1937 *Excavations at Snaketown: Material Culture*. Medallion Papers No. 25. Globe, Arizona: Gila Pueblo Foundation.

Gregory, David A. W. L. Deaver, S. K. Fish, R. Gardiner, R. W. Layhe, F. L. Nials, and L. S. Teague

1988 *The 1982-1984 Excavations at Las Colinas: The Site and Its Features.* Archaeological Series No. 162(2). Arizona State Museum, University of Arizona, Tucson.

Hackbarth, Mark and Douglas Craig, editors

2007 *Archaeological Investigations at the Palo Verde Ruin AZ:T:8:68(ASM): The Terra Mar Project.* Anthropological Papers No. 02-02, Tempe and Flagstaff, Arizona.

Henderson, T. Kathleen, editor

2009 *Archaeology at the Gillespie Dam Site: Data Recovery Investigations for the Palo Verde to Pinal West 500 kV Transmission Line, Maricopa County*. Technical Report No. 2009-06, Desert Archaeology, Inc.

Kelly, Sophia E.

2012 A Refined Methodology to Source Hohokam Schist-Tempered Pottery. Paper presented at 77th Annual SAA Meeting, Memphis, TN.

Loendorf, Chris R.

2010 Regional and Temporal Variation in Obsidian Use within the Hohokam region. *Journal of Arizona Archaeology* 1(1): 47-59.

Marshall, John T.

2007 Flaked Stone Artifacts. In *Archaeological Investigations at the Palo Verde RuinAZ:T:8:68(ASM): The Terra Mar Project*, edited by Mark Hackbarth and Douglas Craig, pp. 115-140. Anthropological Papers No. 02-02, Tempe and Flagstaff, Arizona.

Martynec, Richard J., Rich Davis, and M. Steven Shackley

2011 The Los Sitios del Agua Obsidian Source (Formerly AZ Unknown A) and Recent Archaeological Investigations Along the Rio Sonoyta, Northern Sonora. *Kiva* 76:413-430.

Minnis, Paul E. and Michael E. Whalen

2010 The First Prehispanic Chile (Capsicum) from the U.S. Southwest/ Northwest Mexico and Its Changing Use. *American Antiquity* 75:245-258.

Neff, Hector, Michael D. Glascock, Ronald L. Bishop, and M. James Blackman

1996 An Assessment of the Acid-Extraction Approach to Compositional Characterization of Archaeological Ceramics. *American Antiquity* 61:389-404.

Ownby, Mary F.

2010 Canaanite Jars from Memphis as Evidence for Trade and Political Relationships in the Middle Bronze Age. Doctoral Dissertation, University of Cambridge.

Peterson, Jane D., D. Mitchell, and S. Shackley

1997 The Social and Economic Contexts of Lithic Procurement: Obsidian from a Classic Period Hohokam Site. *American Antiquity* 62:231-259.

Rapp, John M. and Fred Oglesby

2003 Analysis of Chipped Stone Artifacts from the SR88 Wheatfields Sites. In *Settlement History along Pinal Creek in the Globe Highlands, Arizona*, edited by David E. Doyel and Teresa Hoffman, Volume 3, pp. 183-262. Archaeological Consulting Services Cultural Resources Report No. 112. Tempe.

Rapp, John M. and Robert A. Rowe

2009 Lithic Analysis. In *The Transwestern Phoenix Expansion Project, Analytical Studies and Synthesis Yavapai, Maricopa, and Pinal Counties, Arizona, Volume 5, Part A*, edited by Kenneth L. Brown and Susan Crespin. TRC Report No. 48936-C-125, Albuquerque.

Rice, Glen E., John L. Czarzasty, Christopher N. Watkins, Erica L. O'Neil , Karen Adams, David Bustoz, Richard Holloway, Gary Huckleberry, Thomas C. O'Laughlin, Manuel R. Palacios-Fest, Lydia Pyne, John Rapp, Erik Steinbach, Arthur W. Vokes

2009 AZ T:13:18 (ASM), the Gillespie Dam Site. In *The Transwestern Phoenix Expansion Project, Bureau of Reclamation (Central Arizona Project), Arizona State, and Private Lands, Maricopa and Pinal Counties, Arizona: Sites in the Sonoran Desert, Pipeline Mile Posts (MP) 110.8 to 138.8. Volume 4 Part B*, edited by Kenneth L. Brown and Susan Crespin. TRC Report No. 48936-C-123, Albuquerque.

Russell, Frank

1975 *The Pima Indians.* The University of Arizona Press, Tucson.

Ryan, Stacy L.

2009 Flaked Stone Artifacts from the Gillespie Dam Site, AZ T:13:18 (ASM). In *Archaeology at the Gillespie Dam Site: Data Recovery Investigations for the Palo Verde to Pinal West 500 kV Transmission Line, Maricopa County, Arizona*, edited by T. Kathleen Henderson, pp. 97-108. Technical Report No. 2009-06, Desert Archaeology, Inc.

Shackley, Steven M.

1993 *Sources of Obsidian from the Gatlin Site (AZ Z:2:1 ASM): An Energy Dispersive X-Ray Fluorescence (EDXRF) Analysis.* Phoebe Hearst Museum of Anthropology, Berkeley.

1995 Sources of Obsidian in the Greater American Southwest: An Update and Quantitative Analysis. *American Antiquity* 60:531-551.

1998a *An Energy Dispersive X-Ray Fluorescence (EDXRF) Analysis of Obsidian Artifacts from Pre-Classic Contexts at Frogtown (AZU:15:61 ASM).* Phoebe Hearst Museum of Anthropology, Berkeley.

1998b *X-Ray Fluorescence (EDXRF) Analysis of Obsidian Artifacts from Las Colinas (AZ:T:12:10 ASM).* Phoebe Hearst Museum of Anthropology, Berkeley

2003 Source Provenance of Obsidian Artifacts from Late Formative through Classic Context on the Arizona State Route 88 Project, Gila County, Arizona. In *Settlement History along Pinal Creek in the Globe Highlands, Arizona,* edited by David E. Doyel and T. Hoffman. Archaeological Consulting Services Cultural Resources Report No. 112. Tempe.

2005 *Obsidian: Geology and Archaeology in the North American Southwest.* University of Arizona Press, Tucson.

2007 Obsidian Projectile Point Sourcing Study. In *Archaeological Investigations at the Palo Verde Ruin-AZ:T:8:68(ASM): The Terra Mar Project,* edited by Mark Hackbarth and Douglas Craig, pp. 501-508. Anthropological Papers No. 02-02, Tempe and Flagstaff, Arizona.

2009 Source Provenience of Obsidian Artifacts from the Gillespie Dam site, AZ T:13:18 (ASM), Central Arizona. In *Archaeology at the Gillespie Dam Site: Data Recovery Investigations for the Palo Verde to Pinal West 500 kV Transmission Line, Maricopa County, Arizona*, edited by T. Kathleen Henderson, pp. 221-226. Technical Report No. 2009-06, Desert Archaeology, Inc., Tucson.

2011 An Introduction to X-ray Fluorescence (XRF) Analysis in Archaeology. In *X-Ray Fluorescence Spectrometry (XRF) In Geoarchaeology*, edited by M.S. Shackley pp. 7-44. Springer, New York.

Shackley, Steven M. and D. B. Tucker

2001 Limited Prehistoric Procurement of Sand Tank Obsidian, Southwestern Arizona. *Kiva* 66:345-374.

Sires, Earl, Jr.

1984 Excavations at Frogtown. In *Hohokam Archaeology along the Salt�Gila Aqueduct, Central Arizona Project,* edited by Lynn S. Teague and Patricia L. Crown, pp. 357-443. Archaeological Series No. 150 (4, Part 3). Arizona State Museum, Tucson.

Underhill, Ruth

1969 *Social Organization of the Papago Indians.* AMS Press, New York.

PXRF/WDXRFS INTER-UNIT DATA COMPARISON OF ARIZONA OBSIDIAN SAMPLES

Daniel G. Dybowski

ABSTRACT

This paper focuses on two separate x-ray fluorescence methods to determine whether or not element readings between them are comparable. Four stable elements from seven varieties of Arizona obsidians are used in this comparison study. The first pXRF method is a non-destructive fluorescence method using the NITON XL3t handheld analyzer, housed in the archaeology laboratory (ARL) at the University of Wisconsin, Milwaukee (UW-M). The second method is the wavelength dispersive x-ray fluorescence spectrometry (WDXRFS), a destructive powder method. The NITON (pXRF) XL3t is a mobile handheld device that can be used in the field, and the other a fixed stationary WDXRFS model. PXRF technology provides an opportunity for scientists to obtain rapid feedback of elemental compositions for raw materials in the field, and the primary importance is that it is non-destructive. However, obsidian researchers are continuously adamant about honing in on which instruments they should use for consistency and reliability; this paper highlights this issue.

Recently, researchers have expressed interest in understanding the variation in results returned by different x-ray fluorescence instruments. More importantly, the research community has become concerned with the ability to compare results generated by different instruments and to reproduce these results precisely (Shackley 2010). Craig et al. (2007:2016) demonstrated that although the elemental concentration readings produced by both a stationary EDXRF and a portable XRF instrument were able to determine that 66 out of 68 obsidian artifacts could be identified to one particular source, they did not render exactly the same cluster data, which could "be resolved through instrument cross-calibration" (Craig et al. 2007:2012). Drake et al. (2009) and Nazaroff et al. (2010) also showed that there is considerable variation between EDXRF and pXRF instruments.

This study directly addresses the problems inherent to comparing x-ray fluorescence unit data generated by different types of instruments. I compare elemental concentration measurements that were produced by two different XRF instruments for seven types of obsidian from Arizona (see also Hampel 1984). The first instrument that I use to measure elemental concentrations in the obsidian samples is the pXRF Niton XL3t handheld analyzer. The second XRF instrument I use to analyze the same samples is the Bruker S4 pioneer wavelength dispersive x-ray fluorescence spectrometer (WDXRFS). I test the hypothesis that both the non-destructive pXRF and the destructive WDXRFS methods render very similar patterns of data for each of the obsidian samples.

If analysis results validate the hypothesis, then obsidian researchers may have some confidence in their use of data tables that were generated with different x-ray fluorescent instruments. In addition, researchers may view data produced by pXRF instruments as somewhat reliable in comparison to the consistent results often created by WDXRFS instruments. Validating the reliability of pXRF instruments would be advantageous, as researchers could then trust them to render relatively accurate trace element readings in the field. It would be very beneficial and convenient to examine artifacts or raw materials in the field without collecting objects for lab analysis. Moreover, since pXRF instruments do not require the sample specimen to be crushed into a powder, it would be possible to perform an XRF analysis without destroying archaeological materials. Overall, the expediency of a pXRF device would increase the potential of geochemical artifact analysis.

Daniel G. Dybowski / Department of Anthropology, University of Wisconsin-Milwaukee / dybowski@uwm.edu

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 15-22

APPLICATIONS FOR OBSIDIAN SOURCING

Obsidian is a homogenous, volcanic glass. It is an ideal lithic material for sourcing analyses because the geochemical characteristics of obsidian sources often vary. Therefore, it is often possible to match the geologic signature of an obsidian sample to the signature of its source. In addition, obsidian was a valued lithic resource that was used throughout the prehistoric Southwest. Obsidian has excellent conchoidal fracture properties that are amenable to shaping, and it maintains a very sharp edge for cutting. Thus, people wanted it and traveled great lengths to obtain it (Doyel 2012, Loendorf 2010).

Since obsidians can have different geochemical signatures, archaeologists use various XRF methods to pursue trade and exchange and mobility practices. Because researchers are able to use material science techniques to identify obsidian artifacts to their sources, they are able to address research questions about the movement of people using these items and about the exchange of the items themselves. Archaeologists can examine questions about mobility and about the trade patterns and/or routes that moved obsidian across the landscape. These studies may also involve investigations of human land and resource use, resource procurement strategies, and even large-scale economic strategies (e.g., exchange of raw materials, craft production, exchange of finished crafts, etc.)

Obsidian is an ideal material for sourcing studies (Shackley 1988, 1995, 1998, 2005), because researchers have published a great deal of data on individual obsidian samples and sources in the Southwest. Shackley has published[1] EDXRF data from northern Arizona obsidians that are a useful referent for comparing trace element readings between all kinds of x-ray fluorescence instruments.

I compare the results of geochemical data that are generated by two different x-ray fluorescence instruments: 1) a pXRF Niton XL3t handheld analyzer and 2) a Bruker S4 pioneer wavelength dispersive x-ray fluorescence spectrometer (WDXRFS). In particular, I test a hypothesis that the results produced by these two instruments produce similar and thus comparable data patterns. To test this hypothesis, I analyze seven obsidian samples, each from a different source, with the two different instruments. First, the pXRF instrument recorded three readings per specimen from a freshly fractured surface that was free of patina. Then, the WDXRFS instrument measured readings from the samples after they were turned into powder with a tungsten-carbide shatter box and prepared for analysis. Once these data were collected, the two data sets were compared with the geochemical program Igpet and graphed as bi-plots to see if the data were superimposed over one another (i.e. to see if the data were similar). Such an exercise will draw attention to whether specific part-per-million data rendered using one instrument is either similar or dissimilar to another. This will test the question of whether or not it is reliable to use part-per-million data from data tables generated by one instrument, and assume that it will be the same for another instrument.

GEOLOGICAL SAMPLES

The first group of obsidian samples contains specimens from the Mount Floyd (Round Mountain) volcanic field near Ash Fork, Arizona, on the Colorado Plateau. This volcanic field is Upper Cenozoic (60-15 my) in age. Mark Bush (1986) has provided a summary of the geochemical complexity of the Mount Floyd (Round Mountain) volcanic field. I collected samples of three different types of fine-grained volcanics (FGVs) that occur in separate areas of the Mount Floyd fields and that have different geologic and chemical characteristics. I gathered specimens of Round Mountain obsidian (FGV 1), glassy gray rhyolite (FGV6), and black rhyolite (FGV7) for geochemical analysis.

The second sample set is a specimen from the Government Mountain area (FGV 2), near Flagstaff, Arizona. This geographic feature is part of the San Francisco volcanic field. The third sample set is a specimen from Vulture Mountain (FGV 3), which is near the Transition Zone between the Colorado Plateau and the Basin and Range Province of mid-west Arizona. A fourth set of samples are specimens from the Basin and Range Province, which contains older rocks but geologic features that are younger (15-0 my) than the Colorado Plateau. I collected a specimen of Sauceda obsidian (FGV 4), which comes from a mountain range located on the Barry M. Goldwater Air Force Range near Gila Bend, Arizona. Both Sauceda and Sand Tank obsidian, two geochemically distinct obsidians, are derived from sources in this area; however, I have only included Sauceda obsidian in this study. The final sample set is a specimen of obsidian from Picketpost Mountain (FGV 5), which is near Superior, Arizona. This source is currently mined for its rich perlite (Reynolds et al. 1986).

METHODS

To examine any differences in the measurements returned by different x-ray fluorescence instruments, I subjected the seven obsidian samples to xrf analysis with two different devices. The samples served as experimental controls in the study. The geochemical composition of each of the seven samples was measured first with a Niton pXRF instrument, and then with a WDXRFS one. Each specimen's compositional readings from the Niton pXRF and the WDXRFS were then compared using the program Igpet.

The seven obsidian samples were analyzed both with a Niton XL3t pXRF analyzer and a Bruker S4 pioneer wavelength dispersive x-ray fluorescence spectrometer (WDXRFS). The Niton pXRF is intended for use in the metal alloy industry, but the instrument has a soil function that can be used specifically for obsidian studies. It is equipped with a Rhodium (Rh) anode target. The Niton bombards the specimen with high-energy photons dispersed from a 50 keV 40 µA maximum miniature x-ray vacuum tube with multiple primary filters (Thermo Scientific NITON 2007). This causes the sample to fluoresce and to produce characteristic x-rays for each of the elements present. The x-ray detector then receives the secondary x-rays from the sample specimen and determines its unique geochemical composition. The WDXRFS instrument,[2] a Bruker S4 pioneer wavelength dispersive x-ray fluorescence spectrometer, has analyzer crystals and collimators for higher quality elemental resolution. It is a stationary device that requires the samples to be prepared into flat glass beads (circular discs) using a Claisse M4 fusion system.

Sample Preparation

Trace element studies that address regional patterns of obsidian procurement rely on extensive sampling of raw and archaeological materials (sensu Shackley 2005). This scope of this study, however, is methodological; it determines whether the two instrumental methods render similar results. Therefore, the analysis focuses on a small number of obsidian samples.

The preparation of samples for pXRF analysis and the actual pXRF analysis itself are relatively simple. An obsidian sample is laid over the instrument's aperture within a lead-lined containment box. Then the trigger, controlled by an attached computer, is depressed for 180 seconds. Preparation of samples for a WDXRFS analysis and the subsequent analysis (which used a 10 to 1 dilution glass bead fusion method) are much more complex than for the pXRF analysis. After each sample specimen was powdered in a tungsten-carbide (WC) shatter box for four minutes, the powdered sample was dehydrated overnight in a 105° C oven. Then, 1.0000±0.0003 g of the powdered sample was combined with 10.0000±0.0003 g of Claisse 50:50 LiT:TiM flux with an integrated LiBr non-wetting agent and mixed with 1 g of ammonium nitrate-oxidizer. The mixture was then heated in a platinum crucible to a maximum temperature near 1050° C, and fused into a glass bead with a Claisse M4 fluxer. The x-ray beam was centered on either a fresh fracture plane of an obsidian specimen, or a fresh surface of a flake of a specimen.

Data Collection and Processing

The data that I have collected represent three readings of each specimen from the pXRF analysis, and one reading from the WDXRFS analysis. I took three readings of each sample with the Niton pXRF in order to test and ultimately improve the accuracy of measurements from this instrument. In general, the data returned by the Niton pXRF instrument were more inconsistent than the data returned by the WDXRFS instrument. Elemental concentrations for the Niton pXRF and the WDXRFS raw data were calculated with a calibration curve based on 11 USGS rock standards (Table 1) in the program F-Quant. After calculation (calibration) of elemental concentrations, only four trace elements were chosen from the XRF analysis of obsidian samples using the Niton pXRF instrument. The four elements that were chosen were based on a consistently rendered amount of the elements shared between both instruments to facilitate data comparison.

The WDXRFS produced nine major elements and 24 trace elements. In total, the calibrated elemental concentration data sets from both the Niton pXRF and the WDXRFS analyses included only four specific elements that were rendered consistently by both instruments: major elements CaO, TiO_2, and Fe_2O_3, and trace

Table 1. Weight percent oxides (major elements) and trace element data.

Three Weight Percent Oxides and One Trace Element				
USGS rock standards	CaO(%)	TiO2(%)	Fe2O3(%)	Sr(%)
RGM-1	1.15	0.267	1.86	0.011
STM-1	1.09	0.135	5.22	0.07
AGV-1	4.94	1.05	6.77	0.066
BCR-2	7.12	2.26	13.8	0.035
BHVO-2	11.4	2.73	12.3	0.039
BIR-1	13.24	0.96	11.26	0.011
DNC-1	11.27	0.48	9.93	0.015
DTS-2B	0.12	0	7.76	0
GSP-2	2.1	0.66	4.9	0.024
SGR-1	8.38	0.264	3.03	0.042
G-2	1.96	0.48	2.66	0.048
mean	5.706364	0.844182	7.226364	0.032818
std dev	4.797719	0.88324	4.119756	0.022947

Table 2. Elemental data after using the multipliers. The multipliers to obtain this data table include Ca=0.7143, Ti=0.5995, and Fe=0.6994.

Percents after Multipliers			
USGS rock standards	Ca%	Ti%	Fe%
RGM-1	0.82	0.16	1.30
STM-1	0.78	0.08	3.65
AGV-1	3.53	0.63	4.73
BCR-2	5.09	1.35	9.65
BHVO-2	8.14	1.64	8.60
BIR-1	9.46	0.58	7.88
DNC-1	8.05	0.29	6.95
DTS-2B	0.09	0	5.43
GSP-2	1.50	0.40	3.43
SGR-1	5.99	0.16	2.12
G-2	1.40	0.29	1.86

element Sr. Many of the other elements that were recorded by the two instruments were rendered inconsistently, and were not useful for comparing the results produced by the two different instruments. Thus, I was limited to the elements Ca, Ti, Fe, and Sr for the data comparison between both instruments.

Typically, in obsidian studies, researchers use specific "transition metals" (Rb, Sr, Y, Zr, and Nb) to compare two or more obsidian data sets. The relative concentration of these metals reflects the geochemical variation among different obsidian sources. However, in this study, I am not comparing two different obsidian data sets. Rather, I am comparing two versions of the same samples: one version that contains readings from a Niton pXRF instrument, and a second version that contains readings from a WDXRFS instrument. In this case, it is not imperative to follow the protocol of comparing "transition metals." Researchers, including Shackley, often include Ti, Fe, and Sr elements in their analytical work to identify obsidian from different sources. On this basis, I use the elements of Ti, Fe, and Sr as well as the element Ca in my comparative analysis of the instruments.

In order to compare the instrument data, I had to convert the weight percent oxides that were obtained using the WDXRFS to make the data from both instruments comparable in parts per million. I chose the three major elements (CaO, TiO_2, and Fe_2O_3) rendered from the WDXRFS, which were converted (Table 2) to percents using the following multipliers (Ca=0.7143, Ti=0.5995, Fe=0.6994) in order to compare the data to the pXRF results in parts per million (ppm). Once the new data table was generated after using the multipliers, each of the numbers were then multiplied by 10,000, because the conversion from weight percent oxides to ppm involves multiplication by 104 (Tables 3 and 4).

When the three elements plus the trace element Sr were chosen for correlation to the United States Geologic Survey (USGS) rock standard samples, a calibration curve showed that all four elements had high correlation coefficients (R2= 0.99). Therefore, only four biplots of these four elements were necessary to compare both the Niton and the WDXRFS instruments. Once the weight percent oxides (CaO, TiO_2, and Fe_2O_3) were converted to trace elements in ppm, the combination of the four total elements (Fe, Ti, Ca, and Sr) could be easily compared between the Niton and the WDXRFS instruments.

RESULTS

The geochemical data that the pXRF and the WDXRFS instruments returned for each of the samples is presented in Table 5. To compare the similarity of these two data sets, I created two scatter plots with Igpet, a software package developed by Dr. Michael Carr at Rutgers University for analyzing lithic geochemical data (Figures 1 and 2). Each of the scatter plots displays the amount (in parts per million [ppm]) of one element in an obsidian sample against the amount of a second element in that sample. One scatter graph plots the amount (in ppm) of Fe against the amount of Ti in the analyzed obsidian samples, while the second plots the amount of Ca versus the amount of Sr. Since only four elements were isolated, there was no particular reason for producing bi-plots of these particular elements. For each of the seven samples in the study, I plot both the WDXRFS measurements and the pXRF measurements. Thus, I plot two placements on the graph for each sample. I can then visually compare the measurements that were recorded by each instrument by inspecting the placement of the two sample runs on the scatter plot.

Although the four elements in this analysis were chosen as a result of the high coefficient of determination of comparability using 11 USGS rock standards, each of the seven obsidians measured by both instruments in the graphs should hypothetically be centered over one another. However, they are not. A scatterplot of Fe concentrations against Ti concentrations in the obsidian samples reveals that the results generated by the pXRF and the WDXRFS are not identical for many of the samples (see Figure 1). Contrary to expectations, none of the pairs of measurements for the same samples measured by each instrument matched. The difference in the Fe measurements between the two

Table 3. Calcium and titanium percents converted to ppm data. The multiplier here is 10^4.

Percent Conversions to ppm					
Ca(%)			Ti(%)		
USGS rock standards	Ca ppm standards	Ca ppm Niton	USGS rock standards	Ti ppm standards	Ti ppm Niton
RGM-1	8214.45	1299.11	RGM-1	1600.665	493.79
STM-1	7785.87	1205.62	STM-1	809.325	0
AGV-1	35286.42	9751.95	AGV-1	6294.75	2109.15
BCR-2	50858.16	14583.65	BCR-2	13548.7	4759.87
BHVO-2	81430.2	24397.87	BHVO-2	16366.35	5477.26
BIR-1	94573.32	28786.13	BIR-1	5755.2	1858.77
DNC-1	80501.61	24223.08	DNC-1	2877.6	864.73
DTS-2B	857.16	0	DTS-2B	0	0
GSP-2	15000.3	3128.61	GSP-2	3956.7	1220.18
SGR-1	59858.34	19212.33	SGR-1	1582.68	498.36
G-2	14000.28	2968.48	G-2	2877.6	980.66

Table 4. Iron and strontium percents converted to ppm data. The multiplier here is 10^4.

Percent Conversions to ppm					
Fe(%)			Sr(%)		
USGS rock standards	Fe ppm Niton	Fe ppm standards	USGS rock standards	Sr ppm Niton	Sr ppm standards
RGM-1	817.34	13008.84	RGM-1	4.58	110
STM-1	2533.15	36508.68	STM-1	53.4	700
AGV-1	3349.9	47349.38	AGV-1	52.9	660
BCR-2	7310.32	96517.2	BCR-2	23.67	350
BHVO-2	6363.49	86026.2	BHVO-2	30.16	390
BIR-1	5738.5	78752.44	BIR-1	4.85	110
DNC-1	5068.09	69450.42	DNC-1	7.7	150
DTS-2B	3993.28	54273.44	DTS-2B	1	0.00
GSP-2	2364.61	34270.6	GSP-2	17.45	240
SGR-1	1545.63	21191.82	SGR-1	27.95	420
G-2	1244.63	18604.04	G-2	34.7	480

Table 5. The WDXRFS data used in this analysis is on top, while the pXRF Niton data used in this analysis is on the bottom. Be advised that a "1" had to be used for strontium, because the Niton did not register the element. This was done in order to include the Sr symbol in the biplot in the program Igpet.

WDXRFS Data	Ca (ppm)	Ti (ppm)	Fe (ppm)	Sr (ppm)
FGV1a	3000.06	239.8	7384.35	0.03
FGV2a	5928.69	659.45	7695.27	78.15
FGV3a	3214.35	719.4	6218.4	56.74
FGV4a	3357.21	599.5	11737.23	16.18
FGV5a	5071.53	839.3	9560.79	109.22
FGV6a	11285.94	1618.65	15779.19	182.39
FGV7a	11357.37	1618.65	15701.46	181.54
pXRF Data Case#				
FGV1b 1	1974.64	262.86	5592.97	1
2	1920.76	230.61	5625.22	1
3	2054.68	209.48	5257.3	1
FGV2b 1	5939.82	636.31	4440.63	71.22
2	5854.56	705.08	4248.68	67.45
3	6027.62	631.52	4536.38	66.86
FGV3b 1	2562.5	702.19	4056.9	43.28
2	2355.37	642.72	4013.46	40.13
3	2552.26	601.34	4154.47	35.66
FGV4b 1	2754.99	426.18	7174.22	6.02
2	2871.39	492.27	7263.7	6.05
3	3108.35	515.43	7309.97	7.43
FGV5b 1	2779.24	600.38	3264.29	15.8
2	2841.4	627.54	3453.71	17.03
3	2950.16	618.37	3362.1	14.37
FGV6b 1	8784.99	1449.11	10328.32	185.57
2	8410.18	1428.28	10158.12	188.56
3	8679.13	1371.91	10315.47	186.54
FGV7b 1	17826.91	2984.26	16336.06	240.04
2	17750.33	3209.44	16842.02	231.33
3	18103.71	3102.37	16717.45	233.45

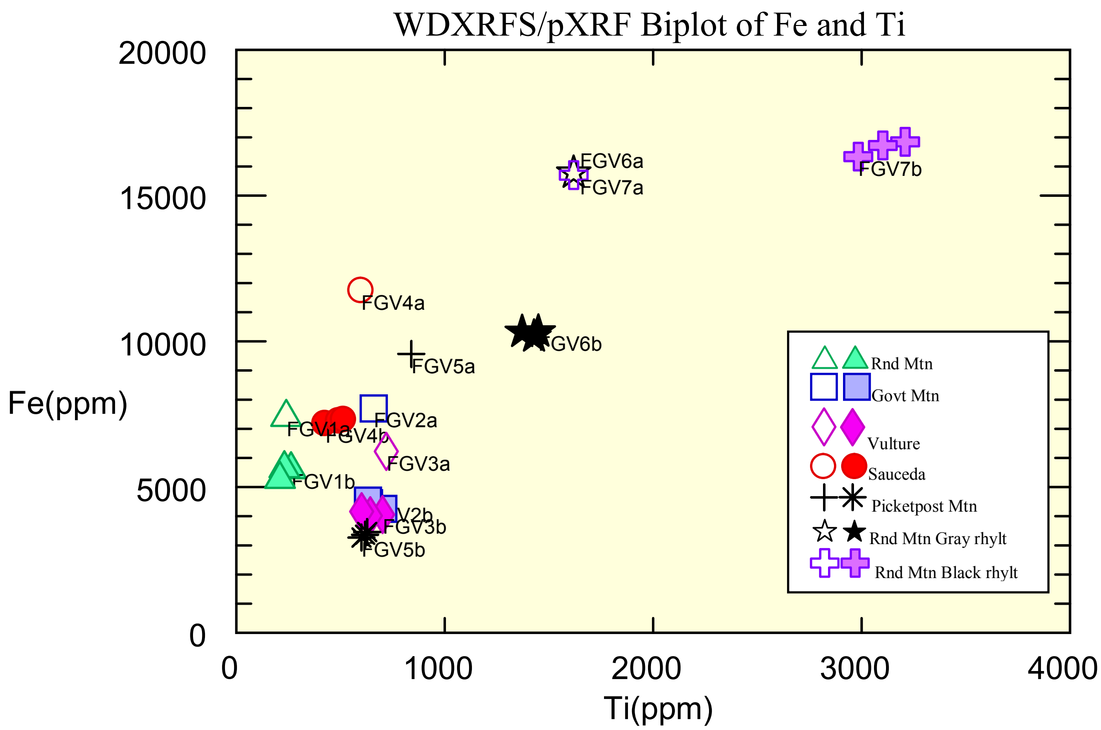


Figure 1. Biplot comparison of Fe and Ti readings from the WDXRFS analysis (FGV 'a') and the Niton (pXRF) analysis (FGV 'b') of seven obsidian sources. Empty symbols = WDXRFS data; solid symbols = pXRF data.

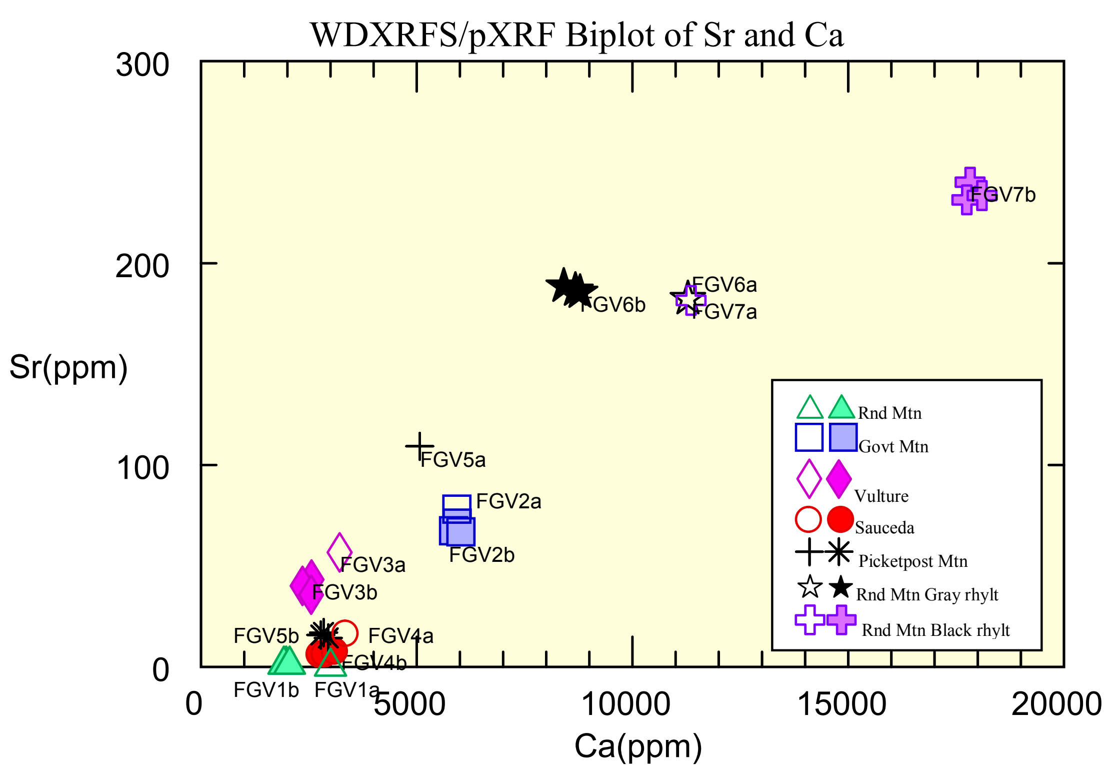


Figure 2. Biplot comparison of Sr and Ca readings from the WDXRFS analysis (FGV 'a') and the Niton (pXRF) analysis (FGV 'b') of seven obsidian sources. Empty symbols = WDXRFS data; solid symbols = pXRF data.

sample runs ranges from 0-5000 ppm, while the difference in Ti measurements ranges between 0-1000 ppm. However, the WDXRFS Round Mountain gray rhyolite was similar to Round Mountain black rhyolite, while the pXRF readings for the same samples were off by more than 1000 ppms in this plot. This discrepancy among the sample measurements produces a fundamental question: how much of a difference among instrument readings (in ppms) is acceptable in XRF studies?

A scatterplot of Ca concentrations against Sr concentrations in the obsidian samples reveals a similar result to the previous plot. The measurements taken by the pXRF are not identical to those recorded by the WDXRFS (see Figure 2). The difference in the Ca measurements between the two sample runs ranges from 0 -7000 ppm, while the difference in Ti measurements ranges from 0-100 ppm. The two samples whose pXRF and WDXRFS readings deviated the most widely are the Picketpost Mountain and black Round Mountain rhyolite specimens.

DISCUSSION

This paper follows a suite of recent publications that highlight instrument commensurability. As a result, it highlights some benefits of comparing two different XRF techniques, which becomes especially relevant when a newer technique is less well known, such as the pXRF (Niton). Until now, there have been few studies that compare portable-EDXRF (pXRF) techniques with other more reliable, peer-tested and reviewed XRF techniques like the WDXRFS. The results of this analysis suggest that the readings from a Niton pXRF instrument are not directly comparable to the results produced by a WDXRFS instrument when using the same samples.

However, in any comparative analysis of measurements generated by different XRF instruments, we must establish that systematic differences are not due to differences or errors in sample preparation and data collection. A variety of errors can be introduced into XRF analysis results from the following sources: specimen contamination, equipment contamination, background effects, "the statistical nature of the emission and detection of x-rays" (Willis 2006: Section 10), matrix effects, apparatus stability. There are also some other kinds of problems that every scientist must take into consideration in XRF studies: reproducibility, reliability, random errors, systematic errors, and the variability between inter-observer error and the interpretation of data. I tested whether a certain piece of technical equipment would render comparable results, and in this analysis, I made every effort to eliminate these sources of error. I completed these experiments under the close supervision of Dr. Lindsay McHenry in the controlled laboratories of the Geosciences Department, and the Anthropology Department at the University of Wisconsin-Milwaukee.

After controlling for analytical differences between the instruments and most major sources of analytical error, I conclude that there is only one plausible explanation for the differences in the pXRF and the WDXRFS measurements, which is that errors exist within the Niton pXRF software. Thus, I am suspicious of the Niton and its continued use in XRF studies for archaeological applications. I recommend that researchers conduct additional comparative tests, like the one conducted in this paper, to identify appropriate instruments for archaeologically related analyses. These studies should focus on issues of measurement consistency, accuracy, and replicability. In addition, researchers should also discuss the issue of instrument standardization to ensure that published data are comparable.

Finally, as material scientists continue to evaluate different x-ray instruments, it is important to consider the benefits of non-destructive methods over destructive ones. It is of course desirable to preserve all archaeological materials in an analysis. It is also convenient to collect data in the field with such a portable XRF instrument, and (if possible) leave specimens in situ. At present, though, the reliability and consistency of the Niton (pXRF) data remains to be demonstrated.

CONCLUSIONS

This analysis indicates that elemental concentration data generated by a Niton pXRF instrument are not comparable to elemental data produced by a WDXRFS instrument, even after calibration with curves of 11 USGS rock standards. Until more studies can ameliorate the deficiencies between inter-instrumental x-ray fluorescence methods, I suggest that researchers use considerable caution when aggregating ppm data from different studies that may have used different x-ray fluorescence instruments. Future investigations should focus on detailed comparison of results produced by different instruments. More specifically, these investigations should concentrate on evaluating each of the sources of error that I have discussed in order to identify the source of incomparable measurements.

Notes

1. See Shackley's websites here:
http://www.swxrflab.net/swobsrcs.htm,
http://www.sourcecatalog.com/index.html

2. See booklet:
http://www.bruker-axs.com/uploads/tx_linkselector
forpdfpool/01954_BR_S4_Pioneer_E_Internet.pdf

Acknowledgements. I want to thank Dr. Lindsay McHenry for her supervision, critical commentary, and use of the WDXRFS, shatter box, and glass bead fusion equipment. This project would not have been possible without her help. I want to thank Drs. John Richards, Jane Peterson, Jerry Howard, Steven Shackley, Craig Skinner, Richard Hughes, Doug Craig, David Killick, and Ted Roberts for their input and advice. Thank you all for helping understand which XRF instruments we should use for obsidian studies.

REFERENCES CITED

Bush, Mark M.
1986 The Geology of Round Mountain: A Bimodal Volcanic Field in Northwest Arizona. Unpublished Master's thesis, Department of Geology, State University of New York, Buffalo.

Craig, Nathan, Robert J. Speakman, Rachel S. Popelka-Filcoff, Michael D. Glascock, J. David Robertson, M. Steven Shackley, and Mark S. Aldenderfer
2007 Comparison of XRF and PXRF for analysis of archaeological obsidian from southern Peru. *Journal of Archaeological Science* 34:2012-2024.

Doyel, David E.
2012 Preclassic Exchange in the Phoenix Basin, Arizona. *Journal of Arizona Archaeology 2(2):* 4-14.

Drake, Brandon L., Adam J. Nazaroff, and Keith M. Prufer
2009 Error Assessment of Portable X-ray Fluorescence Spectrometry in Geochemical Sourcing. *Society for Archaeological Sciences Bulletin* 32(3): 14-17.

Hampel, Joachim H.
1984 Technical Considerations in X-ray Fluorescence Analysis of Obsidian. In *Obsidian Studies in the Great Basin*, edited by R. E. Hughes, pp. 21-25. Contributions of the University of California Archaeological Research Facility No. 45. Archaeological Research Facility, University of California, Berkeley.

Loendorf, Chris
2010 Regional and Temporal Variation in Obsidian Use within the Hohokam Region. *Journal of Arizona Archaeology* 1(1):47-59.

Nazaroff, Adam J., Keith M. Prufer, and Brandon L. Drake
2010 Assessing the Applicability of Portable X-ray Fluorescence Spectrometry for Obsidian Provenance Research in the Maya Lowlands. *Journal of Archaeological Science* 37:885-895.

Reynolds, Stephen J., John W. Welty and Jon E. Spencer
1986 Volcanic History of Arizona. *Arizona Bureau of Geology and Mineral Technology Fieldnotes* 16(2):1-5.

Shackley, M. Steven
1988 Sources of Archaeological Obsidian in the Southwest: An Archaeological, Petrological, and Geochemical Study. *American Antiquity* 53(4):752-772.
1995 Sources of Archaeological Obsidian in the Greater American Southwest: An Update and Quantitative Analysis. *American Antiquity* 60(3):531-551.
1998 Gamma rays, X-rays, and stone tools: some recent advances in archaeological geochemistry. *Journal of Archaeological Science* 25(3):259-270.
2005 *Obsidian: Geology and Archaeology in the American Southwest.* University of Tucson Press, Tucson.
2010 Is there Reliability and Validity in Portable X-Ray Fluorescence Spectrometry (PXRF)? *The SAA Archaeological Record* 10(5):17-20.

Thermo Scientific NITON
2007 Radiation Safety Training Course Materials. Thermo Fischer Scientific, Thermo Scientific NITON Analyzers, 900 Middlesex Turnpike, Bldg. #8, Billerica, MA 01821. Website: http://www.thermo.com/eThermo/CMA/PDFs/Product/productPDF_1690.pdf

Willis, James P.
2006 Short Course on Modern X-Ray Fluorescence Spectrometry. Unpublished lecture materials on file at the University of Western Ontario, Department of Earth Sciences and Department of Geological Sciences, University of Capetown.

OVERVIEW OF PETROFACIES MODELING WITH EXAMPLES FROM CLASSIC PERIOD HOHOKAM SITES

Mary F. Ownby
Elizabeth J. Miksa

ABSTRACT

Petrofacies models aid in the reconstruction of past ceramic exchange patterns by identifying the provenance of sand temper within ancient ceramics. This paper presents an overview of petrofacies modeling in Arizona. It addresses the principles behind the method, how the sand resources are collected, processed, and analyzed, and how the resulting data are used to create a statistical discriminant model. It also considers the utility and challenges of petrofacies modeling in two case studies that are derived from Classic period Hohokam sites. First, new results from recent analyses of Tanque Verde Red-on-brown have clarified production and exchange in the Tucson Basin. The difficulty in locating the sources of sand temper in Classic period ceramics is discussed and a new hypothesis proposed. The specialized production of Gila Polychrome vessels in the Tonto Basin provides a second case study in support of petrofacies modeling. Such modeling is always a work in progress; with more samples, greater refinement is achieved and our understanding of exchange networks in their socio-cultural context is increased.

Petrofacies models are developed by defining zones of distinct sand composition (i.e. petrofacies) within a geographically restricted area. Over the last 25 years, developing petrofacies models has moved forward at a steady pace. Since the first petrofacies model was created for the Tucson basin in 1986, petrographers based at Desert Archaeology Inc. (DAI) have devoted considerable effort to collecting a robust network of sand samples. This has allowed one of the most common resources employed by Hohokam potters to be mapped at a scale that captures the principal resource use patterns of prehistoric ceramic specialists in Arizona (see Miksa 2009 for a thorough discussion of the history of petrofacies modeling in Arizona). As of 2010, we have developed 11 petrofacies models, which cover a wide swath of central and southern Arizona.

This paper will provide a synopsis of our method for building a petrofacies model: the fundamental principles that underlie the method, the standard practices for applying a model, and the types of results that can be expected (for a more detailed discussion see Miksa and Heidke 1995, 2001). This discussion will be followed by an overview of the current status of DAI petrofacies models in Arizona. In particular, we describe the petrofacies models available throughout the state, the statistical robustness of these models, and current research issues affecting petrofacies modeling. The limitations and appropriate applications of petrofacies models are addressed.

The goal of this work is foremost to connect the sand temper in pottery to geographic areas where that resource is available. Because of the unique geology and geomorphology of Arizona, sands with specific compositions can be sourced to limited areas. Assuming that in most cases vessels were made in the general area of the sand sources (see below), exchange networks can be reconstructed by comparing the temper sources to the locations where the ceramics were found. The methodology provides a more complete understanding of changes in ceramic production and distribution both chronologically and spatially. This information can then be interpreted in light of the possible social and economic mechanisms that were in place to facilitate the exchange of pottery.

To illustrate the utility of petrofacies models, two case studies from the Hohokam Classic period (ca. A.D. 1150-1450) will be presented. Petrographic analysis of Tanque Verde Red-on-brown ceramics from two sites in the northern Tucson Basin reveals several production locations. However, changes in technology were also noted, involving the utilization of fine sands that were probably available locally. Application of the petrofacies model to Gila Polychrome sherds from the

Mary F. Ownby / Desert Archaeology Inc., Tucson, AZ / mary@desert.com
Elizabeth J. Miksa / Southwest Petrographic Specialists, Inc., Tucson, AZ / miksa@cox.net

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 23-36

Tonto Basin also identified several production locales. Both of these examples highlight aspects of Classic period ceramic specialization where pottery production exceeds that of local community demand.

PETROFACIES MODELING

Methodological Overview

Petrofacies modeling relies on the use of sand to temper ceramics in the production process. The fundamental assumption for these models is that the geological source of a sand temper also represents the general production location of a pottery vessel containing that sand temper. This postulate is supported by ethnographic research demonstrating that potters typically travel one kilometer or less, and in most cases less than three kilometers, to collect sand resources for temper (Arnold 2006; Heidke 2009: Table 4.10). Further, sand is very common in Arizona and would be readily available to most potters without needing to travel long distances. Thus, the ethnographic data and the distinctiveness and ubiquity of sand in Arizona suggest that identifying the location of a specific sand temper can indicate where the vessel was made.

Discrete sand compositions are present within limited areas because of the high geological diversity of Arizona, especially along the Mogollon Rim and south (Reynolds 1988). Other areas of the Southwest have fewer unique geologic units and less diversity, which reduces the potential to create successful petrofacies models (Figure 1). Also beneficial in Arizona is the presence of mountains separating basin areas and dividing the land into geologically mappable units that tend to coincide with where populations lived. By collecting a large number of sand samples in each basin under study, a map is developed of the actual sand composition zones, or petrofacies, available for pottery manufacture. When the sample collection grid is fine enough to capture the human scale of resource use, then the petrofacies are equivalent to temper resource procurement zones. Thus, sand temper in an analyzed sherd is compared to a wide range of known sand resources and the source of the material identified, which in turn specifies where the vessel was produced.

Petrofacies Model Development

Six major steps are taken to develop a petrofacies model (Figure 2). Briefly, the first is to examine the geology of the study area and utilize this information to establish predicted sand petrofacies. Next, sand collection, point counting and statistical analyses are used to confirm the petrofacies. Once these are determined, descriptions of the sands in each petrofacies are made and a flow chart for identifying particular sands developed. These are used to characterize the sand temper in sherds, from which a sample will be taken for petrographic analysis and point counting. Statistical analysis is used to confirm the petrofacies identification of the sand temper, and along with qualitative data, assign a provenance to the sampled sherds. Finally, the production and exchange of the examined sherds can be clarified.

The first step in the construction of a model is to delimit a study region, generally a basin with defined geographic boundaries within which a group of potters lived, worked, and traded. The boundaries of this geographically circumscribed area should easily encompass the potential resource areas that the study population would have used. The next step is to create a map of probable petrofacies by examining the bedrock geology, geomorphology, and sedimentology of the defined area. The map guides collection of sand samples that are usually in active channels which represent the geological variability in the petrofacies. It is important to remember that although bedrock geology determines the gross composition and texture of rocks available for breakdown into sand, factors such as stream flow, transport distance and direction, alluvial fan morphology, soil formation, climate, and depositional time all affect the final composition of sand at any given location. The goal is to have at least 10 samples of sand for each petrofacies in order to create a statistically robust model (see Miksa and Heidke 2001 for a discussion of the full randomization process). These methods are designed to sample as much as possible all available sand compositions in an area and to create a model that covers sand variability. This increases greatly the likelihood that the sand temper will be identified to its source.

Analysts clean the collected sand samples in the laboratory prior to macroscopic and petrographic (thin section) analysis. Thin sections of the sand samples are point-counted using a modified Gazzi-Dickinson technique in order to reduce the effects of sand maturity on the petrographic data (Dickinson 1970; Lombard 1987a; Miksa and Heidke 2001). Sands collected close to the parent rock contain large rock fragments, while sands located further from the source consist of loose minerals that have broken from the rock fragments. Thus, the Gazzi-Dickinson method places both monocrystalline mineral grains and mineral grains in coarse-grained rocks in the same category. Our modified method classifies fine-grained rock fragments according to their fabric, internal texture, and mineral composition. This categorization technique allows the sand in the sherd to be compared to the sand sample, even if the precise location of the sand is not the same as that chosen by the ancient potter. Fifty point count parameters have been defined for classifying the mineral and rock types counted to prevent the data from becoming overly fragmented. Using this method, 400

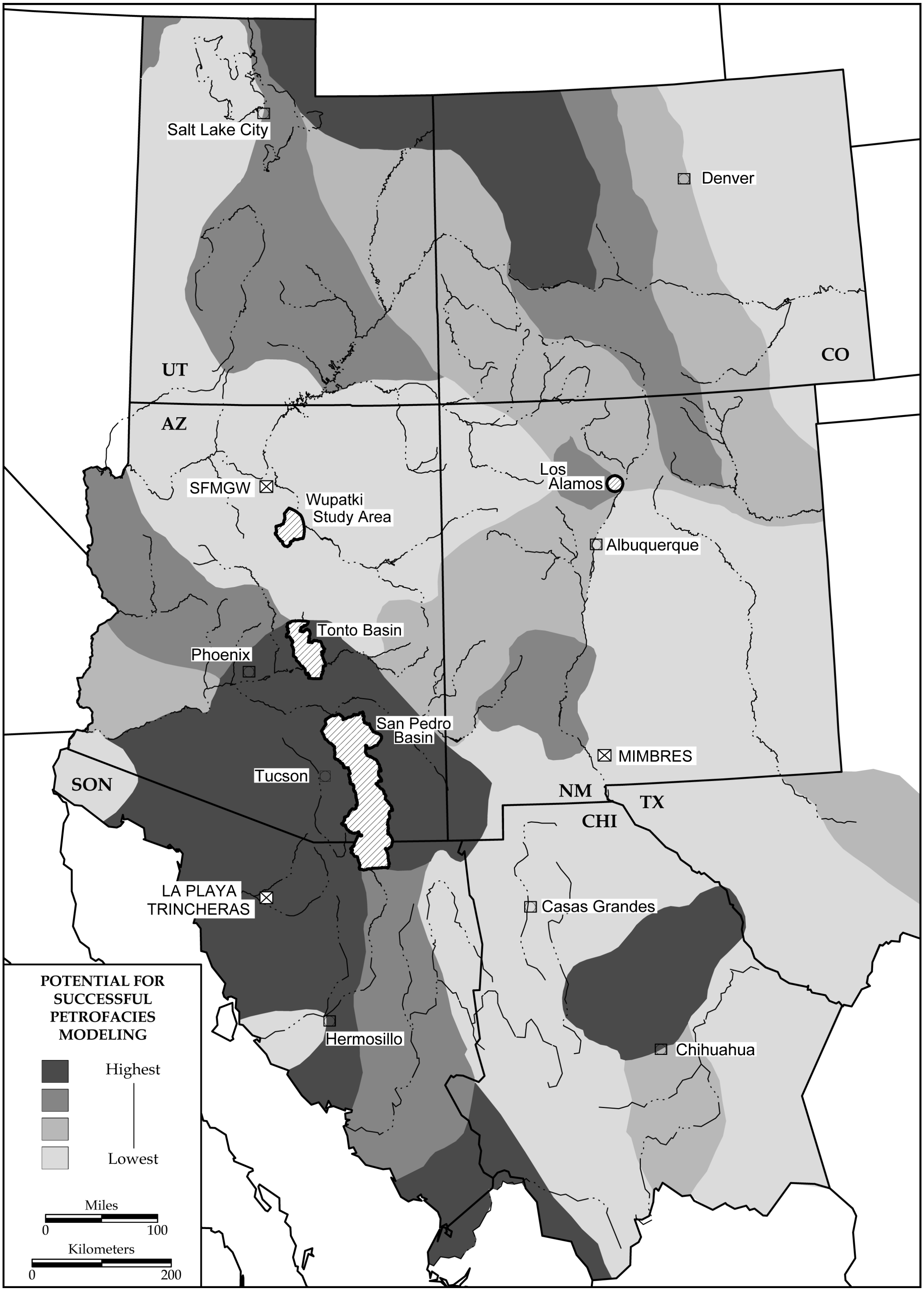
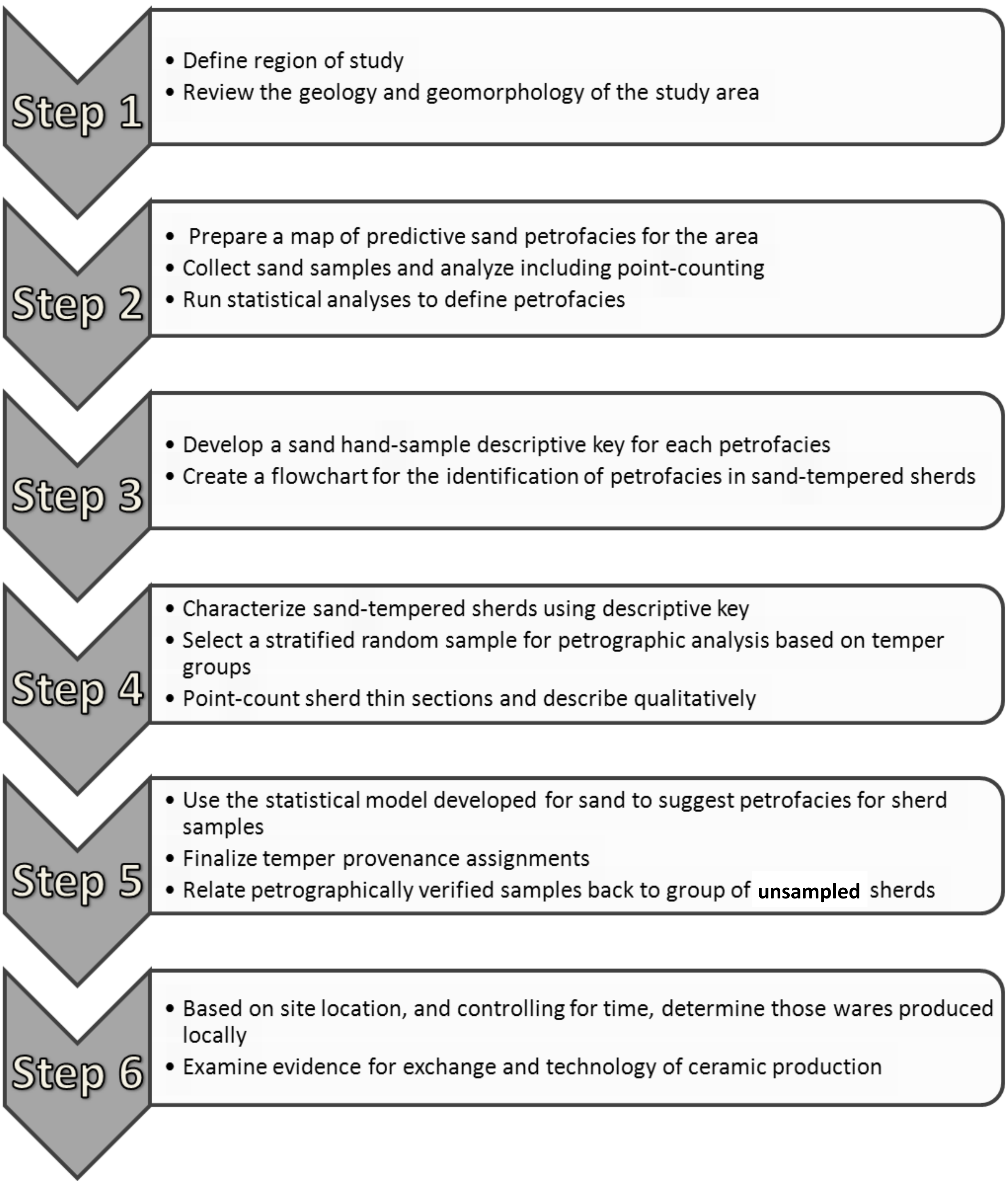


Figure 1. Map of major geological provinces with petrofacies potential.

Figure 2. Steps in the development of a petrofacies model and its application to ceramics.



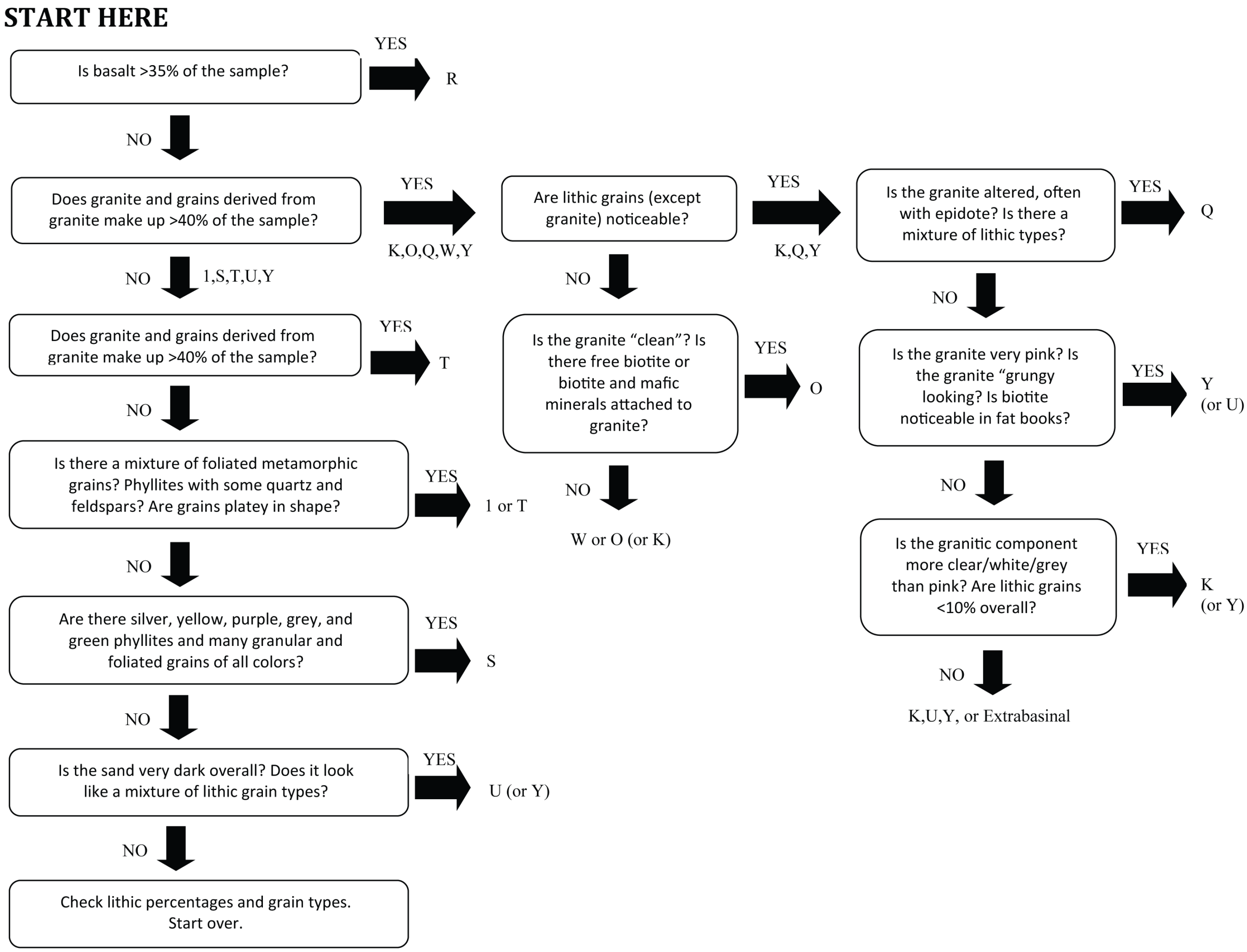


Figure 3. Flowchart for Sycamore Creek temper identification presented as an example.

sand-sized grains per thin section are point-counted at an average magnification of 200x.

Correspondence analysis (CA), a statistical exploratory data procedure, is used to examine the point count data. This method allows simultaneous exploration of both the objects (sand samples) and variables (point count parameters) (Greenacre 1984). The analysis identifies point count parameters that are most likely to facilitate separation of the different petrofacies (Heidke and Miksa 2000a). Because the point count data are a closed compositional set, a logratio transform is used to break the constant sum prior to submitting the data for discriminant analysis (Aitchison 1984). Discriminant analysis is employed to create a petrofacies model with maximum separation between the sand composition groups. In most basins, a nested discriminant approach is most effective in creating clear partitions in the sand compositional data. Nested discriminant models first place sands into two generic groups, such as mineralic sands versus lithic-rich sands, before dividing each of those groups into individual petrofacies by subsequent discriminant analysis runs. A final statistical model is used to define clearly the petrofacies in the basin under study.

Once a functioning statistical model of the petrofacies is developed, a finalized description of composition, colors, grain sizes, and texture is prepared for each defined petrofacies. Descriptive keys and grain boxes are generated so the sand can be identified macroscopically in sherds. In addition, a flow chart is developed for the basin that guides the analyst to the correct petrofacies based on sand temper components and their frequency. An analyst can take a single unknown sand sample or sand temper in a sherd and identify the likely petrofacies of origin of that sand. The petrofacies identification flow chart from Sycamore Creek is presented in Figure 3 as an example.

Using the descriptive keys and flow chart, ceramicists can classify the sand in a large number of sand-tempered sherds through binocular analysis. In order to check petrofacies assignments made with a low-powered microscope, analysts select a random stratified sample of 5 percent of the classified sherds for petrographic analysis. The analysts then thin section and point count the sherds using methods identical to those used in the petrographic analysis of the sand samples. Next, the analyst transforms the sherd point count data with the logratio procedure and uses the sand petrofacies discriminant model to classify these "unknowns." The discriminant model assigns a petrofacies to the sand temper based on compositional similarities to the collected sand.

With this method, strict control is maintained over the location and identification of the known resource—the sand—and its use to classify the unknown resource—the sand temper. Once the ceramicist's temper classification is petrographically verified, analysts assign a provenance to unsampled sherds that were previously grouped with thin sectioned sherds. In this way, the number of verified, provenance-characterized sherds is expanded to hundreds or thousands per project without requiring the petrographic examination of all collected sherds.

Current Status of Petrofacies Models in Arizona

Since these models are important for establishing ceramic provenance and examining exchange, it is critical to review their extent and spatial resolution. As of 2010, archaeological research has developed 11 petrofacies models in Arizona. These models provide continuous coverage of river basin areas from Payson to the southern border of Arizona, and from the Sierra Estrella on the west to Safford on the east. Petrofacies models exist for basins in the Payson area (in progress), Tonto Basin (Miksa and Heidke 2000), Pinal Creek (Montague-Judd et al. 2003), the lower Verde Valley (Heidke et al. 1997), Sycamore Creek (Miksa et al. 2003), the Phoenix Basin and the middle Gila River Valley (Miksa, Castro-Reino, and Lavayen 2004), the Tucson Basin and Avra Valley (Miksa 2009), the entire San Pedro Valley including Aravaipa Creek (Miksa, Lavayen, and Castro-Reino 2004), and the Safford Valley (Neuzil 2005). In addition, there is a petrofacies model for the Flagstaff-Sunset Crater area (Miksa et al. 2007). This model is the only one of the 11 that is not contiguous with the other models (Figure 4).

The models vary in the areas that they cover; ranging from 600 km^2 to 1,100 km^2 in extent. In addition, there is substantial variation in the number of petrofacies in each of the models. The Pinal Creek area model has the fewest number of petrofacies (seven) of any model, while the San Pedro Valley model has the largest number (36 petrofacies). The individual petrofacies in the models vary greatly in the areas that they cover. The Jaynes (H) Petrofacies in the Tucson Basin is the smallest, with an area of 3 km^2, while the Ma Petrofacies in the San Pedro Valley is the largest, with an area of 1,063 km^2.

At this time, Miksa and other analysts have collected a total of 1,800 sand samples from regions throughout Arizona. Of these samples, 1,650 have been fully processed, point counted, described, and included in the petrofacies models. The number of samples per petrofacies range from 2 to 39. However, a better sense of the precision of the models is based on the density of samples in a petrofacies, which covers sand variability; sample density is arrived at by dividing the kilometers covered by the petrofacies by the number of samples. This ranges from a sand sample for every 0.3 km^2 for well defined petrofacies to a sample for every 125 km^2 for petrofacies whose sand variability is less clear. The average for a petrofacies is 21 km^2. Currently, almost 2,000 sherds from these 11 basins have been submitted for thin section analysis. These sherds originated from almost 70 projects. To date, analysts have matched tens of thousands of sherds to specific temper groups based on the petrographic analysis.

In sum, sand petrofacies models in Arizona now cover an extensive geographic area and a diverse range of geological profiles. Continued work on petrofacies modeling is bolstered by new projects that involve additional sample collection in areas that are already covered by current petrofacies models and sampling in new areas where models have yet to be developed. Thus, further research is refining some petrofacies, and also characterizing others for the first time. The following section will illustrate how these petrofacies models have been used to address archaeological questions related to the production and exchange of prehistoric pottery. These cases demonstrate that petrofacies models are flexible techniques that can be applied in a variety of situations.

APPLICATION OF PETROFACIES MODELS

The petrofacies models developed for Arizona have allowed a multitude of ceramics to have their provenance postulated. These data, in turn, have provided valuable information on exchange networks in a wide range of areas and over a significant time period. However, recent research on Hohokam Classic period pottery has recognized unique sand compositions that are not easily sourced. Nevertheless, even in these instances the in-depth knowledge provided by petrofacies modeling has identified potential locations of origin. This is particularly important because the impact of socio-cultural changes that took place in the Classic period on pottery exchange and economic networks is still unclear. Two case studies illustrate that petrofacies models are flexible enough to clarify the production and consumption of Classic period decorated wares.

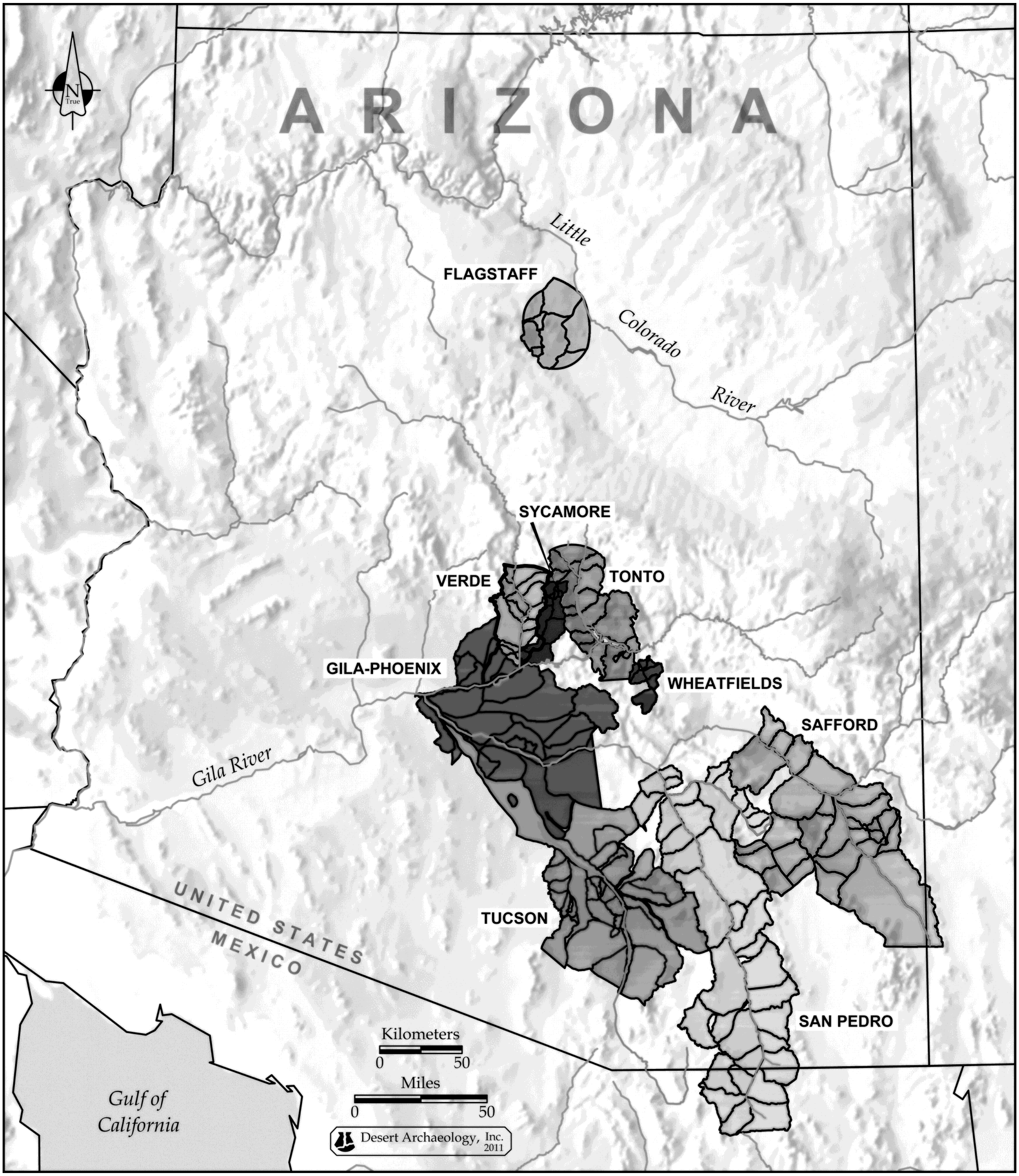


Figure 4. Map of Arizona with petrofacies models.

Classic Period Tucson Basin Pottery Production

Continued work to source Tanque Verde Red-on-brown vessels in the Tucson Basin illustrates how researchers can adapt petrofacies models to accommodate less-than-ideal sand compositional data. Tanque Verde Red-on-brown pottery features red painted designs on an orange-to-buff background, which are typically located on the exteriors of deep bowls and jars. It is found in abundance at Classic period sites throughout the Tucson Basin. Many examples of Tanque Verde Red-on-brown pottery have been found at sites such as Marana Platform Mound (AZ AA:12:251 [ASM]), Los Robles (AZ AA:12:118 [ASM]), Yuma Wash (AZ AA:12:311 [ASM]), Rillito Fan (AZ AA:12:788[ASM]) and Rabid Ruin (AZ AA:12:46 [ASM]) in the northern basin, Martinez Hill (AZ BB:13:3 [ASM]) and Zanardelli (AZ BB:13:1 [ASM]) in the southern basin, and University Indian Ruin (AZ BB:9:33 [ASM]) in the eastern basin (Harry 1997).

Ceramic researchers have attempted to source Tanque Red-on-brown pottery with Neutron Activation Analysis (NAA) data derived primarily from sherds found at the Marana Platform Mound and the Los Robles communities (Fish et al. 1992; Harry 1997). These studies suggested that specialists manufactured Tanque Verde Red-on-brown vessels, and that distribution of their products was controlled by larger settlements who participated in a centralized exchange network. Smaller sites appear to have been excluded from the distribution network for these decorated vessels (Fish et al. 1992; Harry 1997).

Although NAA produced intriguing data on Tanque Verde Red-on-brown production, researchers still struggled to pin-point specific production locales for these vessels. Petrographic analysis, which has had success in sourcing Pre-Classic wares in the Tucson Basin, has thus far encountered problems in identifying locations of production for Tanque Verde Red-on-brown (Heidke and Wiley 1997). The primary reason for this is that changes in materials and/or production methods of some Classic period pottery resulted in the use of fine-grained temper that is not easily matched to local sand samples. The standard point count method counts sand temper grains that range between 0.0625 mm and 2 mm in size. Because some Classic period pottery was made with fine-grained materials, there are few sand-sized grains to count in the sherds. In fact, some standard counts were too low for quantitative statistics. To increase the number of counts, analysts sometimes include the upper silt fraction (grains between 0.03 mm and 0.0625 mm) in the count. This fraction is often abundant in Tanque Verde Red-on-brown sherds.

Another issue complicating the sourcing of Classic period vessels in the Tucson Basin was that the first fully integrated discriminant model was not finalized until 2003 (Miksa 2009). Work completed before that time relied on various non-quantitative methods, such as ternary diagrams, simple cross-tabulation, and relative abundance methods. Thus, advantage was not taken of discriminant models based on sand point count data that are more reliable in identifying the origins of sand temper in pottery. Even after the discriminant models were developed, issues remained due to the previously mentioned problem of counting sand-sized grains only for the model that are uncommon in Tanque Verde Red-on-brown. Models run utilizing the silt-sized temper grain counts met with limited success as the known population is based on sand sized grains.

Qualitative examination of the sand temper suggested that the change in sand resources relates to changes in site location. Examination of a map of geomorphic surfaces in the Tucson Basin (McKittrick 1988) shows that Classic period Hohokam sites are often located on alluvial fans within active terraces closer to rivers and washes (Huckleberry 2005). In contrast, earlier sites are typically located on stable Pleistocene terraces. The active terraces would have had locally unique, fine-grained sediments available that could have been used to produce Tanque Verde Red-on-brown. Our previous sand-sampling strategy has focused on drainages crossing the stable Pleistocene terraces, so we have few to no samples representing the resources available to Classic period potters in these new site locations.

Once these issues were identified, which have hindered sourcing of fine-grained temper in Tanque Verde Red-on-brown, the approach to these sherds was adjusted and focused on new petrographic data on ceramics from the Zanardelli and Yuma Wash sites (Heidke and Miksa 2009; Ownby et al. 2011). The results suggest that some vessels were actually produced with sand derived from the Tucson Mountains, something that was not identified in the previous NAA study. The sand temper indicated likely production in the Wasson (J3) Petrofacies, where the Yuma Wash site is located, and the Twin Hills (J2) Petrofacies, where the Rabid Ruin site is located (Figure 5, Table 1). Petrographic analysis of Tanque Verde Red-on-brown from Zanardelli also suggested the presence of pottery production locales in the nearby Black Mountain (K) Petrofacies. Previous petrographic examination of Tanque Verde Red-on-brown sherds from the San Xavier Bridge site (AZ BB:13:14 [ASM]) supports this conclusion; results indicated that almost half of the samples contained sands from the Black Mountain Petrofacies (Lombard 1987b).

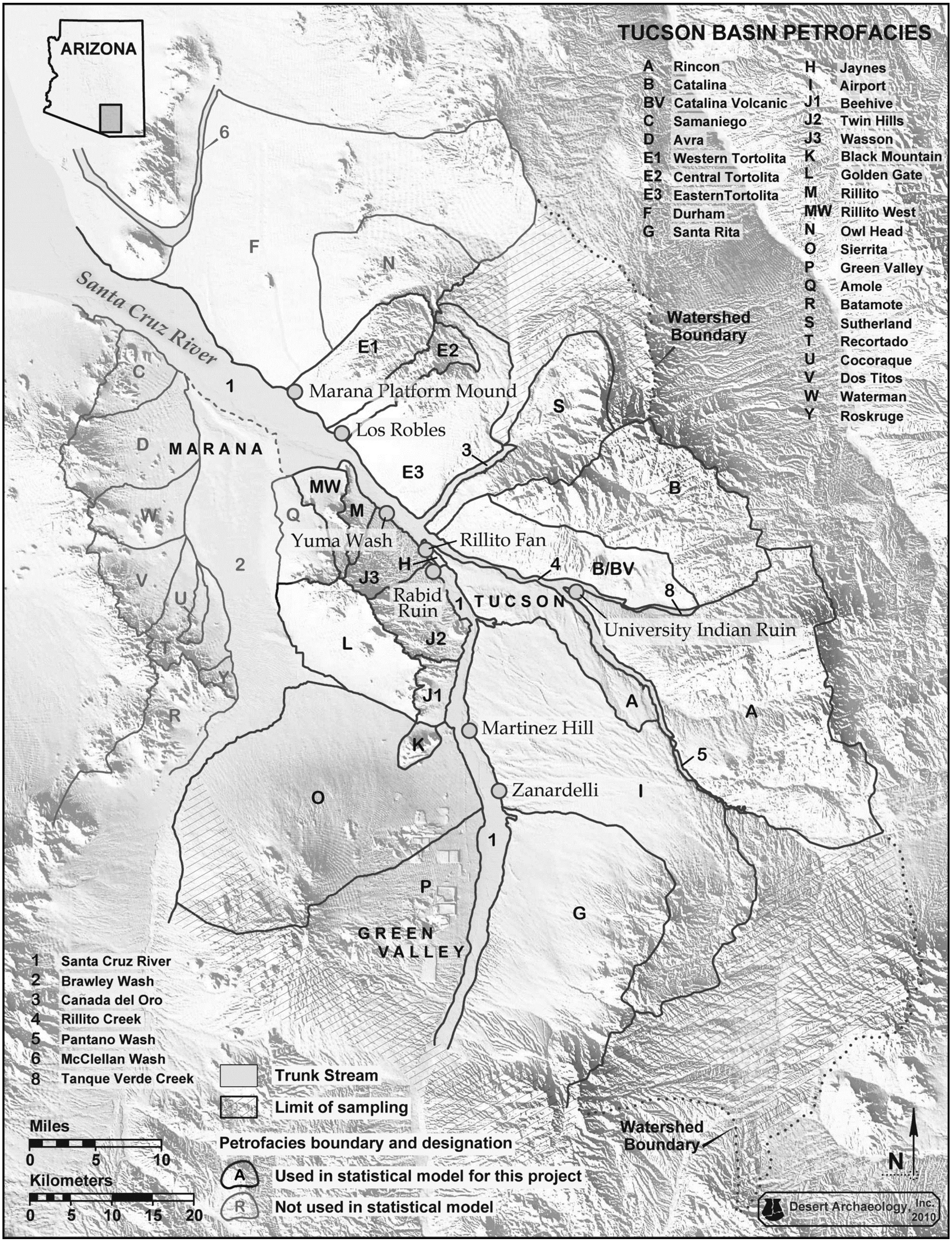


Figure 5. Map of Tucson Basin petrofacies with Classic period sites.

Table 1. Petrofacies assignments for Tucson Basin Tanque Verde Red-on-brown samples.

Site	Petrofacies	Number of Samples	Percent of Total
Zanardelli (Airport Petrofacies)	Black Mountain (K)	12	48
	Beehive (J1)	4	16
	Sierrita (O)	2	8
	Catalina (B)	1	4
	Airport (I)	1	4
	Indeterminate	5	20
Total		25	
Yuma Wash (Wasson Petrofacies)	Wasson (J3), mix	29	43
	Wasson (J3)	3	4
	Twin Hills (J2)	10	15
	Beehive (J1)	1	1
	Northern Tucson Mtns.	10	15
	Black Mountain (K)	8	12
	Western Tortolita (E1)	4	6
	Volcanic Indeter.	3	4
Total		68	

These petrographic results indicate that potters at several sites in the northern Tucson Basin were producing and distributing Tanque Verde Red-on-brown. Residents of the Yuma Wash site appear to have been both producers and consumers, while occupants of the Zanardelli site were probably only consumers. Prehistoric residents of the San Xavier Bridge site, or one nearby, may have been producers, because sand temper consistent with Black Mountain Petrofacies sand is available within 3 km of the site. These results suggest that production of Tanque Verde Red-on-brown may have occurred locally at a number of sites rather than being restricted to only a few specialized production locales. Moreover, it is likely that people at these sites and others in the Tucson Basin were involved in pottery exchange networks.

This study was also significant for the identification of the use of unique sand temper that is likely to be locally available on active alluvial terraces. This is based on the sand temper that the Yuma Wash sites potters appear to have used for manufacturing Tanque Verde Red-on-brown. The sand is a unique combination of northern Tucson Mountain volcanic grains and Tortolita Mountain granite-gneiss grains. This temper appears to be a mixture of the volcanic components that washed down from the Tucson Mountains and some Tortolita Mountain material deposited by the Santa Cruz River (i.e. alluvial sheet wash mixed with flood deposits). Thus, the temper composition may represent one of the unsampled active terraces on which the Yuma Wash site is situated (called Wasson, mix in Table 1). As we have noted, many late Classic sites are located on newly developed alluvial fans near the Santa Cruz River and Rillito Creek. Potters at the Yuma Wash site, and perhaps potters at other late Classic period sites, may have shifted their temper selection, from coarse-grained sediments derived from Pleistocene terraces to fine-grained sediments obtained from these alluvial fans. Thus, local production may have continued from the Pre-Classic to the Classic period, but the fine-grained sediments that were locally available in the Classic period have created difficulties in identifying the provenance of these resources.

CLASSIC PERIOD TONTO BASIN POTTERY PRODUCTION

Recent research to source Gila Polychrome vessels to production locales in the Tonto Basin also demonstrates how analysts can adjust petrofacies models to include fine-grained temper particles in petrographic analysis. Gila Polychrome pottery is a type of Salado polychrome (Crown 1994). The bowl exteriors are red with black painted designs, while bowl interiors are covered in a white slip overlain by designs in black paint. Jar exteriors are covered in red slip with panels of black-on-white designs. Gila Polychrome has been found at several sites in the Tonto Basin occupied during the Classic period: School House Mesa (AZ U:8:24 [ASM]), Tonto Cliff Dwellings (AZ U:8:48 [ASM]), Cline Terrace (AZ U:4:33 [ASM]), and the Griffin Wash site (AZ V:5:90 [ASM]).

Similar to Tanque Verde red-on-brown, Gila Polychrome vessels are tempered with fine-grained sand that is difficult to match to specific Tonto Basin petrofacies. In light of this, recent petrographic work on Gila Polychromes included examination of the sand temper and upper silt fraction in the paste. Analysis focused on Classic period Gila Polychrome vessels from the sites of School House Mesa, Cline Terrace, and the Tonto Cliff Dwellings. The results indicate that residents of these sites obtained the majority of Gila Polychromes from potters located in the Armer (C) Petrofacies (Figure 6, Table 2). Within this large petrofacies, manufacture may have been carried out at several sites. The sourcing data also suggest that potters producing Gila Polychrome were operating in other petrofacies on a smaller scale. Production of Gila Polychrome near Cline Terrace was proposed in a mineralogical study by Simon (1998). The results imply that, as in the Tucson Basin, pottery manufacture was not limited to a few sites.

This new sourcing data for Gila Polychromes enables, for the first time, a comparison between pottery manufacture and exchange during the Pre-Classic and

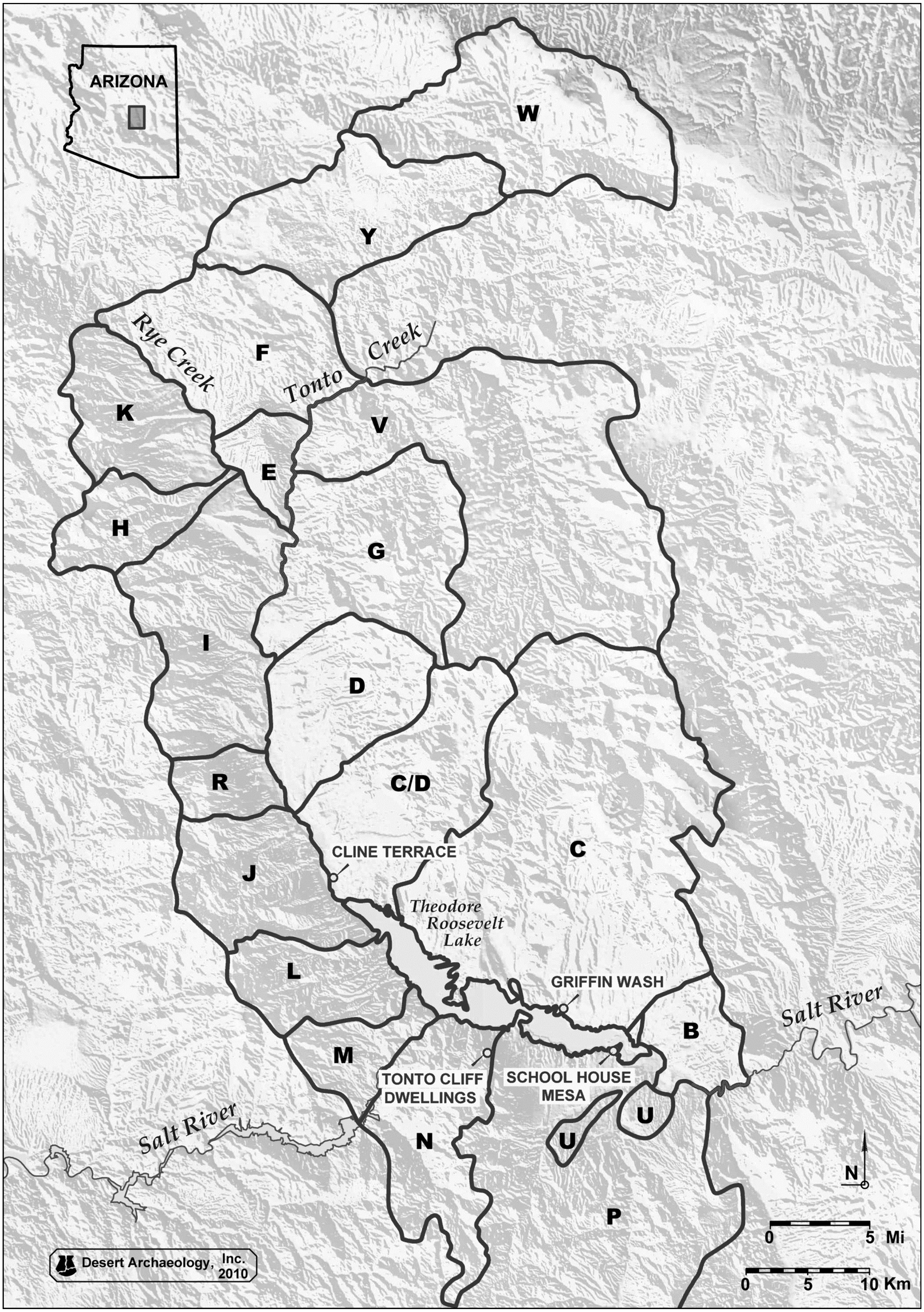


Figure 6. Map of Tonto Basin petrofacies with Classic period sites.

Table 2. Petrofacies assignments for Tonto Basin Gila Polychrome samples.

Site	Petrofacies	Number of Samples	Percent of Total
School House Mesa (Pinto Petrofacies)	Armer (C)	10	77
	Cline (C/D)	2	15
	Hackberry (D)	1	8
Total		13	
Cline Terrace (Cline Petrofacies)	Armer (C)	6	55
	Cline (C/D)	1	9
	Hackberry (D)	2	18
	Ash (J)	1	9
	Pinto (P)	1	9
Total		11	
Tonto Cliff Dwellings (Roosevelt Petrofacies)	Armer (C)	8	80
	Ash (J)	1	10
	Pinto (P)	1	10
Total		10	

Classic periods. During the Pre-Classic period, pottery in the Tonto Basin was often produced with sand from the Armer (C) and Cline (D) petrofacies, as well as the Ash (J) Petrofacies (Heidke and Miksa 2000b, 2000c). In the early Classic period, most plain and red wares were produced in the Ash Petrofacies, while most brown corrugated, Salado Red Corrugated, and Salado White-on-red were manufactured in the Armer Petrofacies. Clearly, in the Classic period the dominance of pottery production in the Armer Petrofacies continues, at least for Gila Polychromes. Manufacture of pottery in several petrofacies during the Pre-Classic and early Classic periods continues in these areas, though perhaps on a reduced scale. This suggests that the arrival of new ceramic types, and possible people, did not dramatically affect the use of traditional sand resources for pottery production.

CONCLUSIONS

Petrofacies modeling in Arizona has contributed in significant ways to our understanding of pottery production and the exchange networks that circulated ceramics in prehistoric economies. At a basic level, the method allows researchers to identify the source locale of pottery manufacture to a specific area on the landscape, and thus provides a means to track the movement of pottery. Successful petrofacies models have been developed in central and southern Arizona because the landscape is geologically diverse creating distinct sand compositional zones and prehistoric potters employed locally available sand temper into their wares. These two conditions enable researchers to match sand included in archaeological ceramics to defined petrofacies.

The two case studies presented in this paper demonstrate that, even when the sand temper is not directly comparable to collect sand samples, the knowledge of the existing sand compositions can lead to the identification of a likely provenance. For example, Tucson Basin Tanque Verde Red-on-brown and Tonto Basin Gila Polychrome, which were produced with fine sand temper, cannot be directly matched to collected sand samples. Petrographic analyses were still able to identify likely production locales with enough precision that detailed archaeological interpretation was possible. Results indicated that these vessels were manufactured at multiple locations and then widely distributed to sites throughout the Tucson and Tonto Basins respectively. These production and exchange patterns suggest the presence of a highly integrated economic system where sites both produced and consumed decorated wares.

Thus, petrofacies modeling through petrographic analysis is a flexible and robust technique that provides interpretable results. It clarifies production locales which enhance investigations of exchange networks or other economic systems. For these reasons, Desert Archaeology, Inc. remains committed to refining existing petrofacies models and expanding this research into new avenues.

Acknowledgements. This work was supported by William Doelle, Mark Elson, Deborah Swartz, and Jim Heidke, with much assistance by Carlos Lavayen, from Desert Archaeology, Inc. Patrick Lyons from the Arizona State Museum submitted material for analysis and provided valuable insight into polychrome production along with Jeff Clark of Archaeology Southwest. Figures were kindly put together by Catherine Gilman.

REFERENCES CITED

Arnold, Dean E.
2006 The Threshold Model for Ceramic Resources: A Refinement. In *Ceramic Studies: Papers on the Social and Cultural Significance of Ceramics in Europe and Eurasia from Prehistoric to Historic Times*, edited by Dragos Gheorghiu, pp. 3-9. BAR International Series 1553. Archeopress, Oxford.

Aitchison, John
1984 Reducing the Dimensionality of Compositional Data Sets. *Mathematical Geology* 16: 617-635.

Crown, Patricia L.
1994 *Ceramics and Ideology: Salado Polychrome Pottery*. University of New Mexico Press, Albuquerque.

Dickinson, William R.
1970 Interpreting Detrital Modes of Graywacke and Arkose. *Journal of Sedimentary Petrology* 40:695-707.

Fish, Suzanne K., Paul R. Fish, and John H. Madsen
1992 Evolution and Structure of the Classic Period Marana Community. In *The Marana Community in the Hohokam World*, edited by Suzanne K. Fish, Paul R. Fish, and John H. Madsen, pp. 20-40. Anthropological Papers No. 56. University of Arizona Press, Tucson.

Greenacre, Michael J.

1984 *Theory and Applications of Correspondence Analysis.* Academic Press, New York.

Harry, Karen G.
1997 Ceramic Production, Distribution, and Consumption in Two Classic Period Hohokam Communities. Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

Heidke, James M.
2011 Prehistoric Pottery Containers from the Julian Wash Site, AZ BB:13:17 (ASM). In *Craft Specialization in the Southern Tucson Basin: Archaeological Excavations at the Julian Wash Site, AZ BB:13:17 (ASM): Part 1. Introduction, Excavation Results, and Artifact Investigations*, edited by Henry D. Wallace, pp.263-294. Anthropological Papers No. 40. Center for Desert Archaeology, Tucson.

Heidke, James M., Diana C. Kamilli, and Elizabeth J. Miksa
1997 Petrographic and Qualitative Analyses of Sands and Sherds from the Lower Verde Valley. In *The Lower Verde Archaeological Project: Vol. 3. Material Culture and Physical Anthropology* (CD-ROM), edited by S. M. Whittlesey. Statistical Research, Inc., Tucson.

Heidke, James M., and Elizabeth J. Miksa
2000a Correspondence and Discriminant Analyses of Sand and Sand Temper Compositions, Tonto Basin, Arizona. *Archaeometry* 42:273-299.

Heidke, James M., and Elizabeth J. Miksa
2000b Ceramic Temper Provenance Studies. In *Tonto Creek Archaeological Project: Artifact and Environmental Analyses: Vol. 1. A Tonto Basin Perspective on Ceramic Economy*, edited by James M. Vint and James M. Heidke, pp. 95-146. Anthropological Papers No. 23. Center for Desert Archaeology, Tucson.

Heidke, James M., and Elizabeth J. Miksa
2000c Qualitative and Petrographic Analyses of Sherds. In *Archaeological Investigation of Rooms 15 and 16 at the Upper Cliff Dwelling (AZ U:8:48 [ASM], Tonto National Monument*, edited by Gregory L. Fox, pp. 83-96. Publications in Anthropology No. 73. Western Archeological and Conservation Center, Tucson.

Heidke, James M., and Elizabeth J. Miksa
2009 Sedentary and Late Classic Period Ceramic Production and Distribution in the Southern Tucson Basin: Evidence from the Punta de Agua Site Complex, AZ BB:13:16 (ASM), and the Zanardelli Site, AZ BB:13:1 (ASM). In *Archaeological Excavations at the Zanardelli Site, AZ BB:13:1 (ASM)*, edited by Ellen C. Ruble, pp. 133-159. Technical Report No. 2004-01. Desert Archaeology, Inc., Tucson.

Heidke, James M., and Michael K. Wiley
1997 Petrographic and Qualitative Analysis of Tanque Verde Red-on-brown Sherds from the Northern Tucson Basin and Avra Valley. In Ceramic Production, Distribution, and Consumption in Two Classic Period Hohokam Communities, edited by Karen G. Harry, pp. 302-362. Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

Huckleberry, Gary A.
2005 Geoarchaeological Assessment of Archaeological Sites and Water-Control Features at Yuma Wash and Vicinity, Marana, Arizona. Report submitted to Old Pueblo Archaeology, Tucson, AZ.

Lombard, James
1987a Provenance of Sand Temper in Hohokam Ceramics, Arizona. *Geoarchaeology* 2:91-119.
1987b Ceramic Petrography. In *The Archaeology of the San Xavier Bridge Site (AZ BB:13:14), Tucson Basin, Southern Arizona*, edited by John C. Ravesloot, pp. 335-368. Archaeological Series No. 171. Arizona State Museum, University of Arizona, Tucson.

McKittrick, Mary Anne
1988 Surficial Geologic Maps of the Tucson Metropolitan Area. Arizona Geological Survey Open-File Report 88-18. Arizona Geological Survey, Tucson.

Miksa, Elizabeth J.
2011 Half Million Points and Counting: Two Decades of Petrofacies Modeling in the Greater Tucson Basin and Avra Valley. In *Craft Specialization in the Southern Tucson Basin: Archaeological Excavations at the Julian Wash Site, AZ BB:13:17 (ASM). Part 2: Synthetic Studies*, edited by Henry D. Wallace, pp. 553-608. Anthropological Papers No. 40. Center for Desert Archaeology, Tucson.

Miksa, Elizabeth J., Sergio F. Castro-Reino, and Carlos Lavayen
2004 A Combined Petrofacies Model for the Middle Gila and Phoenix Basins, with Application to Pottery from the Dutch Canal Ruin. In *Hohokam Farming on the Salt River Floodplain: Refining Models and Analytical Methods*, edited by T. K. Henderson, pp. 7-44. Anthropological Papers No. 43. Center for Desert Archaeology, Tucson. Pueblo Grande Museum Anthropological Papers No. 10. City of Phoenix Parks and Recreation Department, Phoenix.

Miksa, Elizabeth J., and James M. Heidke
1995 Drawing a Line in the Sands: Models of Ceramic Temper Provenance. In *The Roosevelt Community Development Study, Volume 2: Ceramic Chronology, Technology, and Economics*, edited by James M. Heidke and Miriam T. Stark, pp. 133-205. Anthropological Papers No. 14. Center for Desert Archaeology, Tucson.
2000 Petrofacies Descriptions and Point Count Data. In *Tonto Creek Archaeological Project: Artifact and Environmental Analyses: Vol. 1. A Tonto Basin Perspective on Ceramic Economy*, edited by J. M. Vint and J. M. Heidke, pp. 375-388. Anthropological Papers No. 23. Center for Desert Archaeology, Tucson.
2001 It All Comes Out in the Wash: Actualistic Petrofacies Modeling of Temper Provenance, Tonto Basin, Arizona, USA. *Geoarchaeology* 16:177-222.

Miksa, Elizabeth J., Carlos Lavayen, and Sergio F. Castro-Reino
2004 The San Pedro Basin: Statistical Analyses and Petrofacies Model. <http://www.desert.com/petro web/petrology.php?proj=NSF1>, electronic document, accessed 23 December 2005.

Miksa, Elizabeth J., Danielle Montague-Judd, and James M. Heidke
2007 Petrographic Analysis of Tempering Materials. In *Sunset Crater Archaeology: The History of a Volcanic Landscape. Ceramic Technology, Distribution, and Use*, edited by S. Van Keuren, M. D. Elson, and S. A. Herr, pp.

89-144. Anthropological Papers No. 32. Center for Desert Archaeology, Tucson.

Miksa, Elizabeth J., Michael K. Wiley, and James M. Heidke
2003 Petrographic Analyses of Sands, Rocks, and Sherds from the Sycamore Creek Area. In *From the Desert to the Mountains: Archaeology of the Transition Zone: The State Route 87-Sycamore Creek Project: Vol. 2. Analyses of Prehistoric Remains*, edited by E. E. Klucas, R. Ciolek-Torrello, and R. Vanderpot, pp. 551-654. Technical Series No. 73. Statistical Research, Inc., Tucson.

Montague-Judd, Danielle, Elizabeth J. Miksa, and Michael K. Wiley
2003 Provenance Characterization of Sherds from SR 88-Wheatfields Sites. In *Settlement History Along Pinal Creek in the Globe Highlands, Arizona: Vol. 3. Material Culture and Special Analyses,* edited by T. L. Hoffman and D. E. Doyel, pp. 5-40. Cultural Resources Report No. 112. Archaeological Consulting Services, Ltd., Tempe, Arizona.

Neuzil, Anna Astrid
2005 In the Aftermath of Migration: Assessing the Social Consequences of Late 13th and 14th Century Population Movements into Southeastern Arizona. Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

Ownby, Mary F., Carlos P. Lavayen, and Elizabeth J. Miksa
2011 Binocular and Petrographic Analysis of Pottery from the Yuma Wash Site. In *Excavations at the Yuma Wash Site and Outlying Settlements*, edited by Deborah L. Swartz. Anthropological Papers No. 49. Center for Desert Archaeology, Tucson. In press.

Reynolds, Stephen J.
1988 Geologic Map of Arizona. Map No. 26. Arizona Geological Survey and U.S. Geological Survey, U.S. Department of the Interior, Washington, D.C.

Simon, Arleyn W., James H. Burton, and Jean-Christophe Komorowski
1998 Ceramic Production and Exchange in the Tonto Basin: the Mineralogical Evidence. In *Salado Ceramics and Social Organization: Prehistoric Interactions in Tonto Basin. The Roosevelt Archaeology Studies, 1989 to 1998*, by Arleyn W. Simon, pp. 93-125. Roosevelt Monograph Series No. 11, Anthropological Field Studies No. 40. Office of Cultural Resource Management, Department of Anthropology, Arizona State University, Tempe.

IDENTIFYING AND CHARTING THE RISE OF SPECIALIZED RED-ON-BUFF POTTERY PRODUCTION ALONG QUEEN CREEK, PHOENIX BASIN

Andrew D. Lack
Sophia E. Kelly
David R. Abbott
Joshua Watts
Pamela Cox

ABSTRACT

Recent studies have identified intensive Hohokam Red-on-buff pottery production along the middle Gila River in the southern Phoenix Basin. We present new evidence demonstrating that villages in the vicinity of Queen Creek were also important production locales. Utilizing ceramic petrography and low-powered optical techniques, we present data confirming that 1) production of buff ware did occur in the Queen Creek area, 2) production occurred over several centuries, and 3) production increased significantly in the late Sacaton/Soho phases, coinciding with the increased social fragmentation that accompanied the collapse of the Hohokam ballcourt system. These results allow us to explore the connection between the organization of pottery production and other socio-historical changes that occurred among the Hohokam.

Over the last few decades, a considerable amount of effort has been expended in understanding the organization of pottery production among the Pre-Classic and Classic period Hohokam in the Phoenix Basin. This effort has incorporated mineralogical (Abbott 1994, 1995, 2000; Abbott et al. 2007a; Lack and Watkins 2010; Miksa 2001; Schaller 1994) and chemical techniques (Abbott 2001; Beck and Neff 2007; Cogswell et al. 2005; Darling et al. 2007) to identify several plain ware and red ware production areas, and thereby generate increasingly refined models of production and consumption of this pottery over time. The greater utility of these models is their ability to inform the larger questions of Hohokam economic and social organization.

Despite the success of sourcing plain and red ware pottery, red-on-buff pottery production and distribution is not well understood. Our understanding of buff ware production and consumption has lagged behind that of plain and red ware for two main reasons. First, prior to the last decade, our knowledge of middle Gila River mineralogy was inadequate. Second, buff ware potters typically added crushed schist and caliche to the sand component of their pots, thus complicating the task of the analyst in making confident assessments of where the temper fraction originated on the geologic landscape.

More recently, the pioneering geological work by Elizabeth Miksa and colleagues (Miksa 2001; Miksa et al. 2004) has characterized and mapped mineralogical composition of sands across the Phoenix Basin, including the middle Gila River area. Miksa's research allows ceramicists to identify buff ware production locales by matching the sand temper in the pottery to sands from specific areas. One of the major conclusions that has been drawn from this work over the past decade is that the middle Gila River Valley, and in particular, the Snaketown area, was a major supplier of buff ware pottery to settlements in the lower Salt River Valley during the Sacaton phase (Abbott et al. 2007a).

We present new evidence demonstrating that the Queen Creek area was also an important buff ware production locale, though its relative importance seems to have varied considerably over time. While this area has been postulated as a possible source of buff ware vessels in the past (Lack et al. 2006), little supporting data have been presented.

The information we present in this paper is significant because it provides the data to assess the role of Queen Creek potters in the larger-scale Hohokam economy over time. Was buff ware produced in the Queen Creek area? If so, were buff wares exported out

Andrew D. Lack / / School of Human Evolution and Social Change, Arizona State University / Andrew.Lack@asu.edu
Sophia E. Kelly / School of Human Evolution and Social Change, Arizona State University / Sophia.Kelly@asu.edu
David R. Abbott / School of Human Evolution and Social Change, Arizona State University / David.Abbott@asu.edu
Joshua Watts / School of Human Evolution and Social Change, Arizona State University / Joshua.Watts@asu.edu
Pamela Cox / URS Corporation, Phoenix / Pamela_Cox@urscorp.com

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 37-50

of the Queen Creek area? If so, does their percentage in assemblages change over time locally or in other areas?

RESEARCH STRATEGY

Samples were selected from sites within the Queen Creek area in order to address the issue of local production, as well as from three areas outside of the Queen Creek vicinity to address questions concerning the distribution of Queen Creek-produced buff ware outside the local area (Figure 1). These questions were addressed through analyses of the sand fraction of buff ware temper to determine sherd provenance. Two strategies were employed to assess the sand fraction: 1) petrographic analysis of thin-sections, and 2) examination of sherd cross-sections with a low-powered binocular microscope. Petrographic analysis of thin-sections of a sample of sherds from Sonoqui Pueblo (AZ U:14:49[ASM]) (Rogge and Cox 2010; see also Peters et al. 2007; Wright 2004), near Queen Creek, provided a highly detailed description of their mineralogy, from which provenance could be confidently determined. This method allowed us to concretely address the question of whether or not buff ware production occurred in the Queen Creek area. The scope of the remaining questions, however, required a method which could determine the provenance of a much larger sherd sample. As described below, petrographic analyses have given us the ability to distinguish geographically distinct sand sources with a low-powered binocular microscope. A binocular microscope was utilized to examine the sand fraction of nearly 3,600 sherd cross-sections from multiple sites in different areas of the Phoenix Basin.

METHODS

Our analysis relied on the methods developed by Miksa and her colleagues for the identification of sand temper in Hohokam sherds (Miksa 2001; Miksa et al. 2004 *this issue*). They first collected and point-counted sand samples across the Phoenix Basin. The point count data from the raw sand samples were then subjected to a series of statistical analyses. Results demonstrated that there were distinct sand composition groups based on the lithic and mineral content of the samples. These groupings, called "petrofacies," are ideal for sourcing sand temper in pottery because they are both compositionally unique and geographically isolated. Miksa then developed detailed descriptions for each of the sand types that she identified. Using these descriptions, analysts can now identify sands

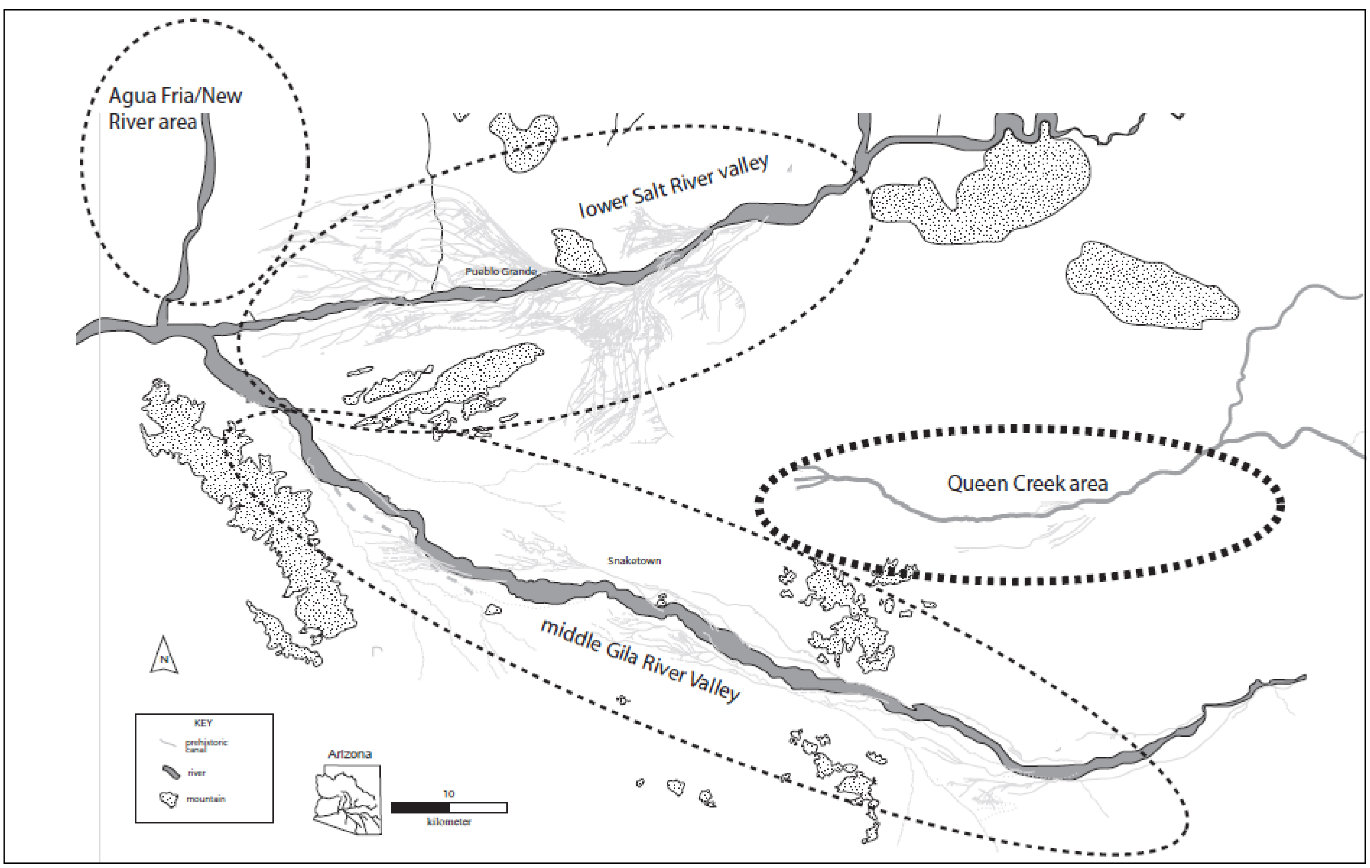


Figure 1. The Phoenix Basin, including the four areas mentioned in the text (based on Kelly 2010a).

from different areas using a low-powered binocular microscope.

One complicating factor in this procedure, however, is those buff ware sherds tempered exclusively with mica schist, which cannot be sourced to a geographic location with a binocular microscope. These sherds may represent one or multiple production areas, and at times account for nearly half of the buff ware assemblages. The analyses presented below are necessarily biased towards those buff ware sherds whose temper contained a sand component. Chemical analyses of the schist and clay of these sherds, as recently approached by Darling and colleagues (2007; see also Cogswell et al. 2005), is the most promising avenue for addressing this vexing problem.

Thin-section Analysis

The 12 buff ware sherds thin-sectioned from Sonoqui Pueblo, near Queen Creek, had been previously inspected with a low-powered binocular microscope by the authors to determine if they contained enough sand temper to match to a specific petrofacies. Sherds were thin-sectioned perpendicular to the vessel wall. Thin sections of several different areas of a sherd were then mounted on a single slide to increase the surface area available for identification. The sections were cut to a standard 30 µ thick and were partially stained with potassium cobaltinitrite to aid the identification of potassium feldspars.[1] The petrographic point-counting methods employed in the analysis were based on the sourcing methodologies outlined by Miksa and her colleagues (Miksa and Castro-Reino 2001; Miksa et al. 2004). All sherds were point-counted using the Gazzi-Dickinson technique by petrographer Sophie Kelly (2010b). In this technique, sand-size minerals are counted to their individual phase irrespective of whether or not they are attached to other minerals in a rock fragment. Minerals that are smaller than sand-sized, but appear in a sand-sized rock fragment are counted as that lithic type. This technique reduces the effects of erosion and transportation of mineral and lithic fragments from bedrock sources. Miksa (1999) has refined the Gazzi-Dickinson technique for analysis of coarse-foliated rocks such as schist. The parameters used for point counting are those published in the updated sand petrofacies model for the Salt and Gila basins (Miksa et al. 2004).

Binocular Microscope Examination

The temper in a fresh cross-section of each sherd was examined with a binocular microscope. To aid in the petrofacies identification, raw sand samples collected from wash beds in each petrofacies were repeatedly studied and referenced. In addition, each petrofacies had a corresponding small "grain box" that contained individually identified particles of rock and mineral types along with other comparative samples.[2] The estimated percentages for each rock and mineral type were then used to navigate through a detailed and comprehensive flow chart, used as a sand identification key (Miksa et al. 2004: Figure 2.12).

SAMPLING

The goal of the sampling procedure for this study was to analyze buff ware sherds from both within and outside the Queen Creek area in order to answer questions concerning both local production and non-local distribution (Table 1). Two sites were sampled from the Queen Creek area, in the Queen Creek petrofacies zone (Petrofacies D). Twelve sherds from Sonoqui Pueblo were analyzed under the binocular microscope and thin-sectioned, while 190 sherds from the Southwest Germann site (AZ U:10:2[ASM]) were examined with a binocular microscope alone (see Lack et al. 2006 for previous ceramic analysis at AZ U:10:2[ASM]). Sherds from Sonoqui Pueblo were thin sectioned because an existing contract with URS supplied funds for the analysis. Similar funds were not available for thin sectioning samples from the Southwest Germann site.

Local production at both sites was expected based on the criterion of abundance (Bishop et al. 1982; Rands and Bishop 1980). Sacaton and Soho phase contexts contained unusually high percentages of buff wares. Other researchers have suggested that high proportions of buff ware in the site ceramic assemblage may indicate local production (Bishop et al. 1982; Doyel 1981:58; Lack and Watkins 2010: Rafferty 1982:211; Rands and Bishop 1980; Walsh-Anduze 1993). Buff ware assemblages of Sacaton phase sites usually comprise approximately 20 percent of ceramic assemblages (Abbott 2009). In contrast, the percentage of buff ware from Sacaton phase contexts at the Southwest Germann Site averaged 57 percent (Watts 2007). Buff ware in Soho phase contexts is expected to total 5-10 percent (Doyel 1974:52, 71, 95, 139). At both Sonoqui Pueblo and the Southwest Germann Site, buff ware accounted for more than 20 percent of the pottery from Soho phase contexts (Watts 2007)

Red-on-buff samples were also selected from 16 sites outside of the Queen Creek area. These included three sites in the middle Gila River Valley, eight sites in the lower Salt River Valley, and five sites in the Agua Fria/New River areas (Figure 2). These sites ranged in age from the Snaketown to the Soho phase. In all cases, buff ware sherds were selected from contexts dated by the typological identification of buff ware sherds according to Wallace's refined seriation.

Table 1. The buff ware sample.

Area	Site	Preclassic	Snaketown	late Snaketown-late Gila Butte	early-late Gila Butte	early Gila Butte-middle Sacaton 2	early Gila Butte	late Gila Butte	Gila Butte-Santa Cruz	Santa Cruz	early-late Sacaton	early Sacaton	early Sacaton-Soho	early-middle Sacaton1	middle Sacaton 1	middle Sacaton1-2	middle Sacaton 2	middle Sacaton 2-late Sacaton	late Sacaton	late Sacaton-Soho	late Sacaton-Civano	Soho	Soho-Civano	Total
Queen Creek	Sonoqui Pueblo (AZ U:14:49[ASM])	4	-	-	-	1	-	-	-	-	1	-	-	-	-	1	-	-	-	2	-	3	-	12
	SW Germann Site (AZ U:10:2[ASM])	-	-	-	-	-	-	-	-	-	44	39	-	-	-	-	-	-	-	-	-	31	76	190
	subtotal	4	-	-	-	1	-	-	-	-	45	39	-	-	-	1	-	-	-	2	-	34	76	202
middle Gila River Valley	Grewe Site (AZ AA:2:2 [ASM])	-	-	-	-	-	-	47	-	-	-	145	-	-	-	-	-	-	-	-	-	-	-	192
	Lower Santan Site	-	-	-	-	-	-	-	-	-	-	-	-	144	64	40	-	-	55	98	38	-	20	459
	AA:1:124 (ASM)	-	-	-	-	-	-	-	-	-	73	-	-	-	-	-	-	-	-	-	-	-	-	73
	subtotal	-	-	-	-	-	-	47	-	-	73	145	-	144	64	40	-	-	55	98	38	-	20	724
lower Salt River Valley	La Ciudad (AZ T:12:1[ASM])	-	-	-	710	-	83	84	167	95	-	-	-	-	-	-	-	-	-	-	-	-	-	1139
	La Lomita (AZ U:9:67[ASM])	-	-	-	-	-	-	-	-	52	-	20	-	-	-	-	-	-	-	-	-	-	-	72
	La Villa (AZ T:12:148[ASM])	-	49	-	26	-	224	-	-	99	-	-	-	-	-	-	-	-	-	-	-	-	-	398
	Las Colinas (AZ T:12:10[ASM])	-	-	-	28	-	-	-	192	65	-	-	-	18	72	14	101	13	45	-	-	-	-	548
	Los Guanacos (AZ U:9:71[ASM])	-	-	-	-	-	-	-	-	-	-	-	-	-	87	-	-	-	-	-	-	-	-	87
	Los Hornos (AZ U:9:48[ASM])	-	-	-	-	-	34	-	2	29	-	-	-	-	-	64	-	-	-	-	-	-	-	129
	Pueblo Grande (AZ U:9:1[ASM])	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	53	18	-	32	-	103
	Pueblo del Rio (AZ T:12:116[ASM])	-	-	-	8	-	-	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40
	subtotal	-	49	-	772	-	341	116	361	340	-	20	-	18	159	78	101	13	98	18	-	32	-	2516
Agua Fria/ New River	AZ T:3:323 (ASM)	-	-	59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59
	N:16:175 (ASM)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	N:12:105 (ASM)	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	10
	T:3:19 (ASM)	-	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	11
	Palo Verde (AZ T:8:68[ASM])	-	-	-	-	-	-	-	-	-	-	-	-	32	46	-	-	-	-	-	-	-	-	78
	subtotal	1	-	59	-	-	-	-	-	-	-	-	21	32	46	-	-	-	-	-	-	-	-	159
	Total buff sample	5	49	59	772	1	341	163	361	340	118	204	21	194	269	119	101	13	153	118	38	66	96	3601

RESULTS

Thin-section Petrofacies Determination

The point count data summarized here is fully presented in Kelly's (2010b) analysis (Table 3). The sand sample descriptions published by Miksa (Miksa and Castro-Reino 2001; Miksa et al. 2004) were compared to the raw point-count data from the sand in the analyzed sherds. Petrofacies determinations were established based on a process of elimination that relied on proportions of mineral and lithic sand grains in the samples. Qualitative descriptions of the petrofacies were also used to make petrofacies determinations (Table 2). Three samples did not have enough sand particles visible in the thin section to assign them accurately to a petrofacies. The remaining nine samples, however, had a sufficient number of sand particles to link to a specific petrofacies. Three sherds with the largest sand component were point-counted according to Miksa's published parameters (2004). The remaining six sherds were point counted, but only the sand-sized grains were recorded. For instance, grains that were clearly part of an added metamorphic temper (i.e., schist) were not included (Miksa's SBiot, SChlor, SMusc, etc.).

Petrofacies determinations were made using a series of nested elimination procedures. In the first stage of analysis, the range of possible petrofacies options was narrowed by focusing on the presence or absence of volcanic grains. All of the analyzed samples contained volcanic sand grains. Therefore, all petrofacies categories were eliminated that did not have appreciable volcanic components (<2%) as possible sand compositions in the sampled sherds. The remaining petrofacies included 1, 9, B, D, E, F4, G, I, L, M, N, U, and Y. Petrofacies K (Casa Grande Mountains) was eliminated even though it is composed of 2-10 percent volcanics. Foremost, it is located well beyond the project area. Moreover, there is little to no evidence for ceramic production in the region, and very few prehistoric settlements are located in this area.

In the second stage of the analysis, the samples were divided by the presence or absence of granite. While granite was counted according to individual mineral phases with the Gazzi-Dickinson criteria, the presence of granite pieces in the sand temper was noted during a qualitative assessment of the thin sections. Samples that had a granite component included QCB 03, QCB 09, and QCB 11. Petrofacies that had a volcanic and a granitic component included 1, 9, B, I, M, N, and U. Samples that did not have a granite component included QCB 02, QCB 04, QCB 06, QCB 07, QCB 08, and QCB 10. Petrofacies that had a volcanic component, but only a minimal granitic component included D, E, F4, G, L, and Y.

In the granitic group, petrofacies that only had a trace amount of volcanics (U, M, and I) were eliminated because all samples had more than a trace amount of volcanic particles. Next, Petrofacies 1 and 9 were eliminated because the sands within the samples were not rounded river sediments. Petrofacies B was eliminated because granite is common to present and the sherd samples from Sonoqui Pueblo did not have this much granite. The final petrofacies designation for these sherds was N (Snaketown area). A check on the proportions of minerals within each sample established that they were within the expected range of Petrofacies N (Miksa and Castro-Reino 2001; Miksa et al. 2004).

In the non-granitic group, a different set of elimination procedures resulted in a final petrofacies determination: the Queen Creek area. First, petrofacies E was eliminated as a possibility because natural schist grains were not a significant part of any of these samples. Schist that occurred naturally in sand samples was distinguished from crushed schist on the basis of angularity, size, and textural variation. Next, F4 was eliminated because all the samples had more than 3 percent volcanic grains. Finally, petrofacies were eliminated that had a significantly higher proportion of feldspars than quartz (G, L, and Y). The final petrofacies remaining was D (Queen Creek). A check on the proportions of minerals within each sample established that they were within the expected range of Petrofa-

Table 2. Petrofacies determination of thin-sectioned sherds from Sonoqui Pueblo.

Sample #	Date	Petrofacies
QCB-01	Pre-Classic	indeterminate*
QCB-02	Pre-Classic	D
QCB-03	early-late Sacaton	N
QCB-04	late Sacaton-Soho	D
QCB-05	late Sacaton-Soho	indeterminate*
QCB-06	Soho	D
QCB-07	early Gila Butte-middle Sacaton II	D
QCB-08	Soho	D
QCB-09	Pre-Classic	N
QCB-10	Soho	D
QCB-11	Pre-Classic	N
QCB-12	middle Sacaton	indeterminate*

* lack of sufficient sand grains to make an accurate petrofacies designation

Table 3. Point count data for Sonoqui Pueblo thin section analysis.

	Sample	QCB-01	QCB-02	QCB-03	QCB-04	QCB-05	QCB-06	QCB-07	QCB-08	QCB-09	QCB-10	QCB-12
Sand Grains	Amph				2			2			3	1
	Biot	1	2		2	1		2			6	
	Chlor		1	1					1		1	
	Feld		12	4	4		3	2		2	6	1
	Kspar	5	1	6	2			5	3	2	4	
	LVF		3	5	19			4	6	11	15	1
	LVFB										9	
	LVI		3	1	3	1	5		4	6		2
	LVM		12	3	2	3		7	1	4	12	5
	Micr									1		
	Musc				2						1	
	Opaq	1			5			2			11	
	P			6	2			9	9	7	3	2
	Px		4	2	1	1		2		1	2	2
	Qtz	4	11	22	34	8	15	23	17	23	22	8
Metamorphic Grains	LMA				33			22			41	
	LMF				18			15			7	
	LMM							1			1	
	LMT				69			25			74	
	LMTP				1			1			9	
	Sbiot	23	n/a	n/a	3	n/a	n/a	3	n/a	n/a	9	n/a
	Schlor		n/a	n/a	2	n/a	n/a	1	n/a	n/a		n/a
	Sfeld		n/a	n/a	3	n/a	n/a	27	n/a	n/a	94	n/a
	Skspar	70	n/a	n/a		n/a	n/a	3	n/a	n/a	14	n/a
	Smusc	2	n/a	n/a	43	n/a	n/a	58	n/a	n/a	43	n/a
	Sopaq		n/a	n/a	6	n/a	n/a	1	n/a	n/a		n/a
	Splag	5	n/a	n/a		n/a	n/a	3	n/a	n/a	7	n/a
	SPx		n/a	n/a		n/a	n/a	1	n/a	n/a		n/a
	SQtz	91	n/a	n/a	86	n/a	n/a	102	n/a	n/a	221	n/a
Other	Void	36	n/a	n/a	93	n/a	n/a	82	n/a	n/a	117	n/a
	Paste	861	n/a	n/a	751	n/a	n/a	918	n/a	n/a	1797	n/a
	Clay Lump		n/a	n/a	17	n/a	n/a	39	n/a	n/a	25	n/a
	Total Sand	11	49	50	199	14	23	122	41	57	227	22
	Grand Total	1099	49	50	1203	14	23	1360	41	57	2554	22

KEY

(white)	Sand particles and added metamorphic components were point-counted
(grey) .	Sand particles only (no added metamorphic components) were point counted

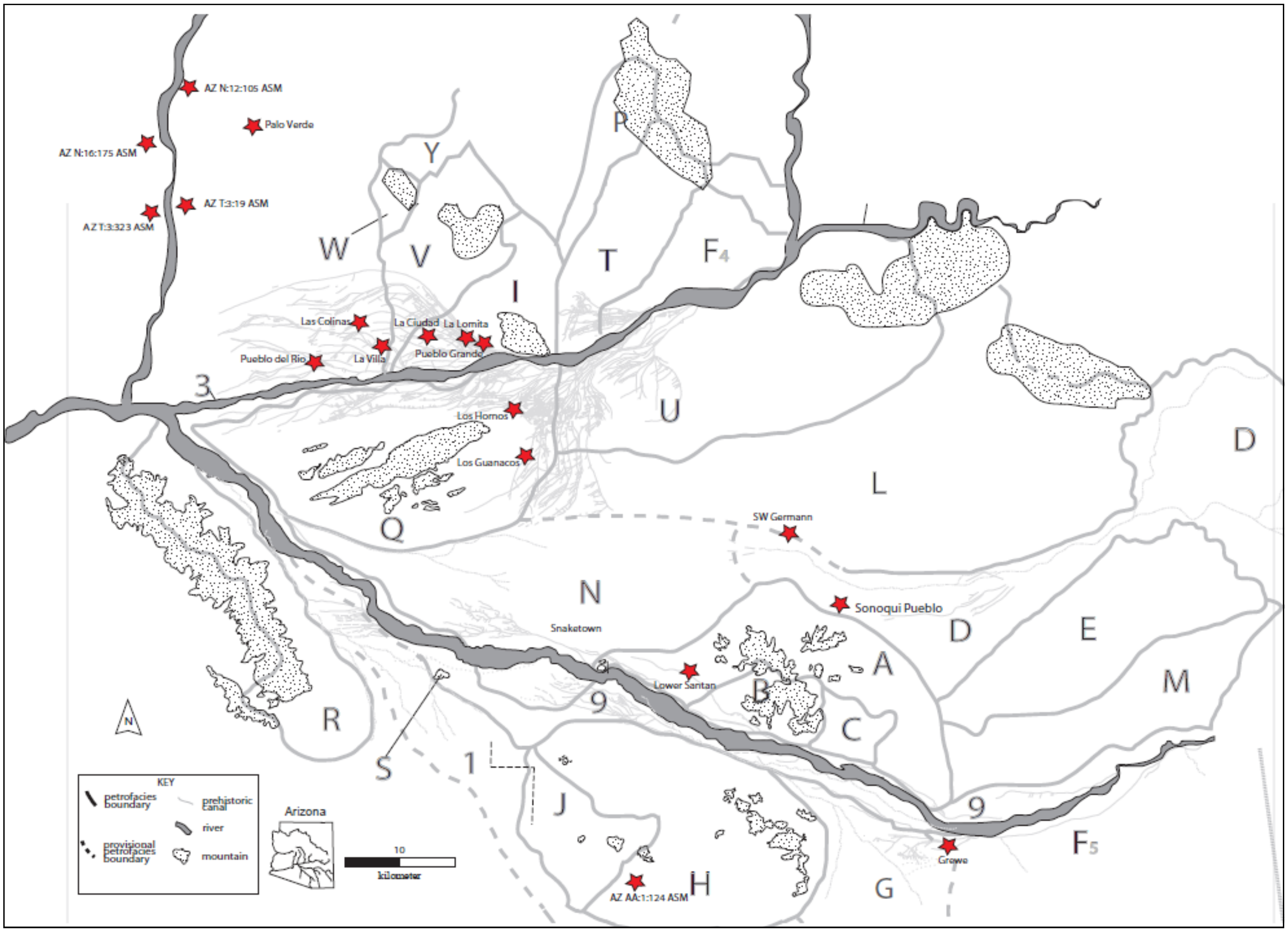


Figure 2. Phoenix Basin petrofacies and sites included in the analysis.

cies D (Miksa and Castro-Reino 2001; Miksa et al. 2004).

To summarize, petrographic analysis conducted on a sample of 12 sherds from Sonoqui Pueblo, located within the Queen Creek petrofacies, confirmed that sands from Petrofacies D (the Queen Creek petrofacies) were used to temper some buff ware vessels found at the site. Half of the sherds petrographically analyzed were tempered with sand from the Queen Creek petrofacies. Petrofacies assignments were not determined through discriminant model based on sand samples, but through comparison to point-count data on sand samples and sand sample descriptions provided by Miksa and her colleagues (Miksa and Castro-Reino 2001; Miksa et al. 2004).

Binocular microscopy

The results from the binocular microscope analysis were used to investigate the extent of both local production within the Queen Creek area and the distribution of locally-produced buff ware to sites outside the Queen Creek area. Of the 190 buff ware sherds from the Southwest Germann site analyzed with a low-powered binocular microscope, 31 (16%) were produced in the Queen Creek area– that is, with Petrofacies D sand. While these data do not necessarily confirm that these buff wares were produced at the Southwest Germann site, they do indicate that a measureable portion of the buff ware was produced within the vicinity of Queen Creek.

An examination of the temper of 3,399 sherds from sites outside the Queen Creek area revealed that, in addition to supplying themselves with red-on-buff pottery, potters from the Queen Creek area also supplied buff ware vessels to residents in the lower Salt River Valley, the middle Gila River Valley, and the Agua Fria/New River area. Of the 16 sites investigated outside of the Queen Creek area, 10 yielded buff ware produced in the Queen Creek area (Table 4). The pattern was a distance decay distribution, with the middle Gila River Valley receiving more Queen Creek buff ware (7.6%) than the lower Salt River Valley (4.0%), and the Agua Fria area receiving the least (1.9%).

The data were next examined diachronically. For this part of the study, those buff ware sherds that could be dated only to broad time periods were excluded from the analysis. This procedure left 3,167 buff ware sherds from 17 dated sites in the Queen Creek, middle Gila River Valley, Lower Salt River Valley, and Agua Fria/New River area to be considered. As a result, we were able to track changes in the percentages of Queen Creek-produced buff ware in different assemblages over time. All sherds and contexts were dated using Wallace's refined red-on-buff seriation (Wallace 2001, 2004).

First, the percentage of Petrofacies D-tempered buff ware was tracked over time locally, that is, within the Queen Creek area (Figure 3). Although our data are limited to the Southwest Germann site, and despite the fact that these samples were not as tightly dated as others used in this analysis, temporal trends were evident in the proportion of Queen Creek-produced buff ware. The most notable change was the spike that occurred sometime between the early and late Sacaton phases.

Second, in the lower Salt River Valley, there was a dramatic increase in the proportion of imported buff ware pottery from Queen Creek in the late Sacaton phase (Figure 4). Prior to this phase, Queen Creek products never accounted for more than 5 percent of the total buff ware assemblage. The percentage jumped to 25 percent in the late Sacaton, with a drop off to 10 percent in the subsequent Soho phase. It should be noted, however, that the increase during the late Sacaton phase is based on the ceramic information from one site, Pueblo Grande. The late Sacaton data from Las Colinas does not conform, which indicates that the rise in the Queen Creek pottery during the late Sacaton phase was not uniformly felt throughout the lower Salt River valley.

In the middle Gila River Valley, the proportion of buff ware pottery from Queen Creek also increased dramatically in the late Sacaton phase (Figure 5). The percentage then dropped off at some point during the Soho phase. There were not enough data from different time periods to make a similar examination of the trends in the Agua Fria/New River area.

Table 4. Frequency of Petrofacies D sand-tempered buff ware at sites outside the Queen Creek area for all time periods.

Area	Site	Petrofacies D	Total	% of Petrofacies D
Queen Creek	Southwest Germann Site	31	190	16.3
middle Gila River valley	Grewe Site	1	192	0.5
	Lower Santan Site	54	459	11.8
	AZ AA:1:124 ASM	0	73	--
	subtotal	55	724	7.6
lower Salt River valley	La Ciudad	32	1,139	2.8
	La Lomita	1	52	1.9
	La Villa	13	398	3.3
	Las Colinas	20	548	3.6
	Los Guanacos	2	87	2.3
	Los Hornos	5	129	3.9
	Pueblo Grande	27	103	26.2
	La Lomita	0	20	--
	Pueblo del Rio	0	40	--
	subtotal	100	2,516	4
Agua Fria/New River	AZ T:3:323 ASM	0	59	--
	AZ N:16:175 ASM	0	1	--
	AZ N:12:105 ASM	0	10	--
	AZ T:3:19 ASM	0	11	--
	Palo Verde	3	78	3.8
	subtotal	3	159	1.9
	Total	158	3,589	4.4

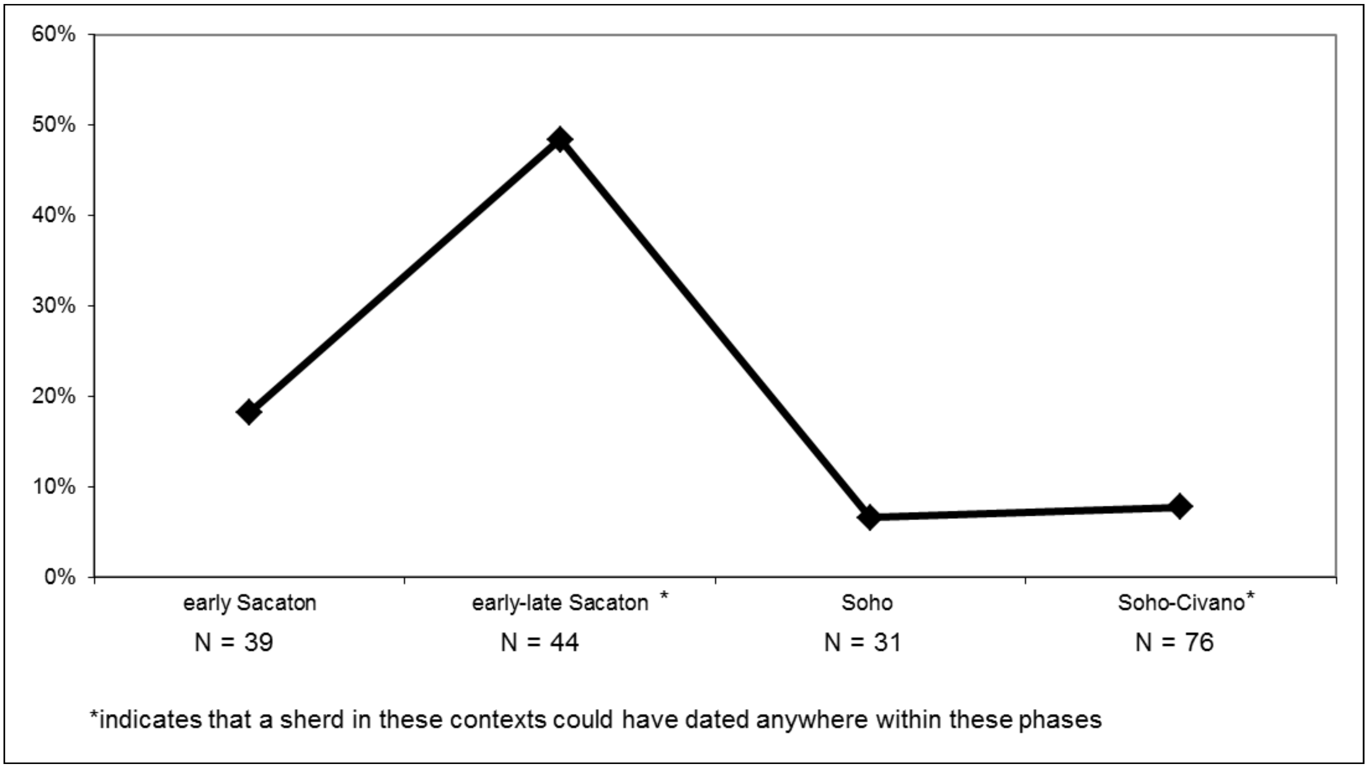


Figure 3. Percentage of Queen Creek-produced buff ware consumed locally (all sherds from Southwest Germann site).

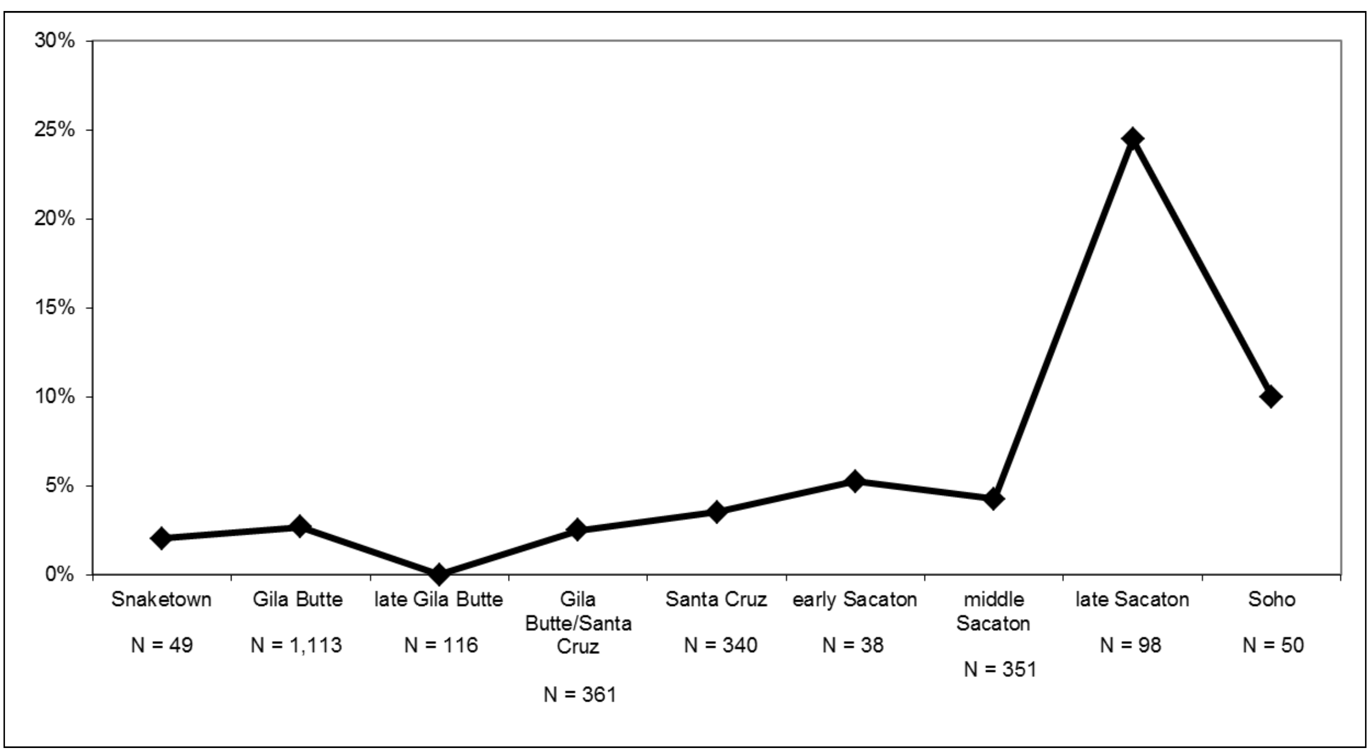


Figure 4. Percentage of Queen Creek-produced buff ware over time for the Salt River Valley.

DISCUSSION

The data from this study have demonstrated that Queen Creek potters produced buff ware pottery. This pottery was manufactured for local use, as well as for exchange. The relative importance of Queen Creek potters as buff ware suppliers also changed in significant ways over time.

One dominant pattern stood out from all of the results: the relatively small amount of buff ware pottery exported from the Queen Creek area between the Snaketown and the middle Sacaton phase compared to the amount that circulated during the late Sacaton and subsequent phases. These results become especially interesting when placed in the larger context of buff ware production over time.

In the lower Salt River Valley, data from nine sites from each of these broad time spans reveal that prior to the Sacaton phase, the dominant area from which buff wares were obtained was the Santan Mountains area (Petrofacies A, B, or C) (Figure 6). In the early through middle Sacaton phases, the Snaketown area (Petrofacies N) clearly became dominant. Finally, in the late Sacaton Phase, the Queen Creek area became the most important supplier to the lower Salt River Valley communities (though not overwhelmingly dominant).

The pattern was less dramatic in the middle Gila River Valley, with the Snaketown area accounting for a large portion of red-on-buff production throughout the Sacaton through Soho phases (Figure 7). As mentioned earlier, the relative proportion of Queen Creek-produced buff ware did increase in the late Sacaton phase here as well, but it did not achieve the level of importance it did for the lower Salt River Valley villages. Unfortunately, we do not yet have enough data to examine the early time periods.

It must be noted, however, that these graphs do oversimplify the picture. First, these data do not include the many buff ware sherds tempered exclusively with mica schist. The conclusions, therefore, may be significantly altered depending upon the production source or sources of the "schist-only" tempered buff ware.

The second factor complicating the picture was a lack of uniformity among sites during each time period. For example, prior to the late Sacaton phase, a relatively high degree of uniformity existed in the ratios of different buff ware suppliers to the lower Salt River Valley (Figures 8 and 9). Although some variability exists in the source locale for buffware pottery through time in each area through time, we do not consider this variability to be extreme. In contrast, the two assemblages from the lower Salt River Valley that dated to the late Sacaton and Soho phases were remarkably different from one another (Figure 10).

The data from this project conform well to current models of interaction networks in Hohokam society (Abbott 2009, 2010; Abbott et al. 2007a; Abbott et al. 2007b). These models suggest that Hohokam society was well integrated during the Pre-Classic era. Plain ware pottery was produced in a few concentrated locales and was widely distributed across the Phoenix Basin. The need for a reliable mechanism of exchange to facilitate such a system has led some to hypothesize that a marketplace economy existed during the middle Sacaton phase (Abbott 2010; Abbott et al. 2007b). These marketplaces, it is suggested, were associated with periodic ballgame events which would draw people from different villages. The ballcourts, therefore, served to integrate the Hohokam both socially and economically.

A dramatic economic reorganization, however, occurred in the late Sacaton phase. The ballcourts, and presumably the marketplaces, were abandoned. The organization of plain ware production and distribution became much more localized as a symptom of the overall social fragmentation that characterized the Phoenix Basin at that time. Our research into the organization of buff ware production and distribution followed the same trends. Although the details need to be more fully investigated, and more assemblages need to be sampled, it appears that the late Sacaton phase was a time of major changes for buff ware potters. Although changes in the social landscape during the late Sacaton phase seem to have restricted the exchange relationships of some potting communities, such as those in the Snaketown area, these same changes seem to have benefited Queen Creek potters in presenting them with the opportunity to build stronger relationships with exchange partners in the lower Salt and middle Gila River Valleys. Exactly how the potters of Queen Creek were able to expand such relationships, and why other potting communities may not have been as successful, are questions to be addressed through further research.

Notes

1. The ceramic thin sections used by Miksa in her petrographic analyses were cut horizontally to the vessel wall. The orientation of platy minerals and rock fragments such as mica and schist may differ in comparison between the thin sections used in this analysis and Miksa's thin sections.

2. All sands, grain boxes, and initial training were generously provided by Elizabeth Miksa.

Acknowledgments. We owe a great deal of thanks to many people for the production of this paper. Elizabeth Miksa provided the initial training on correlating sand samples with petrofacies through the use of a binocular microscope. Petrographic analysis for the

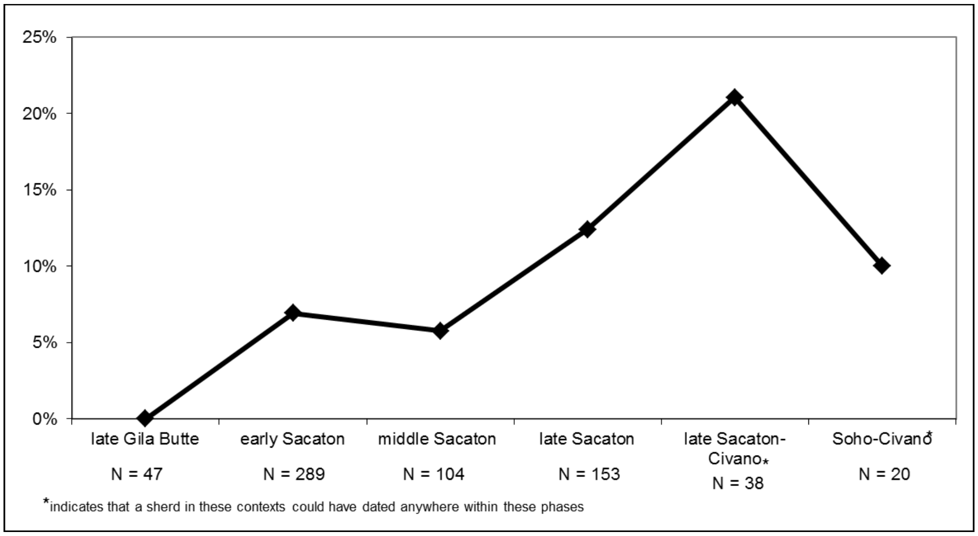


Figure 5. Percentage of Queen Creek-produced buff ware over time for the middle Gila River Valley.

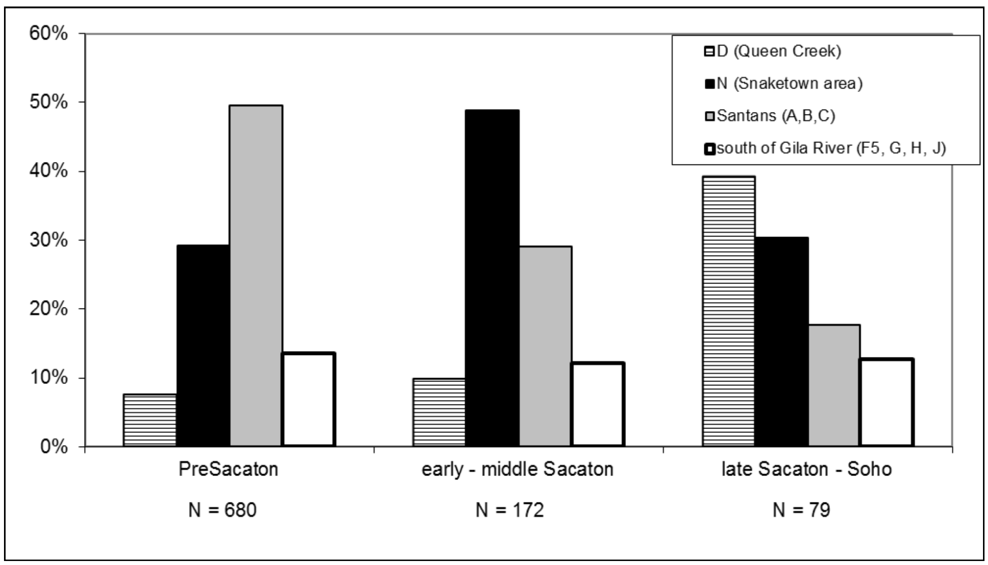


Figure 6. Lower Salt River Valley: Buff ware production group prevalence through time (excluding schist-only) and more generic sand groups.

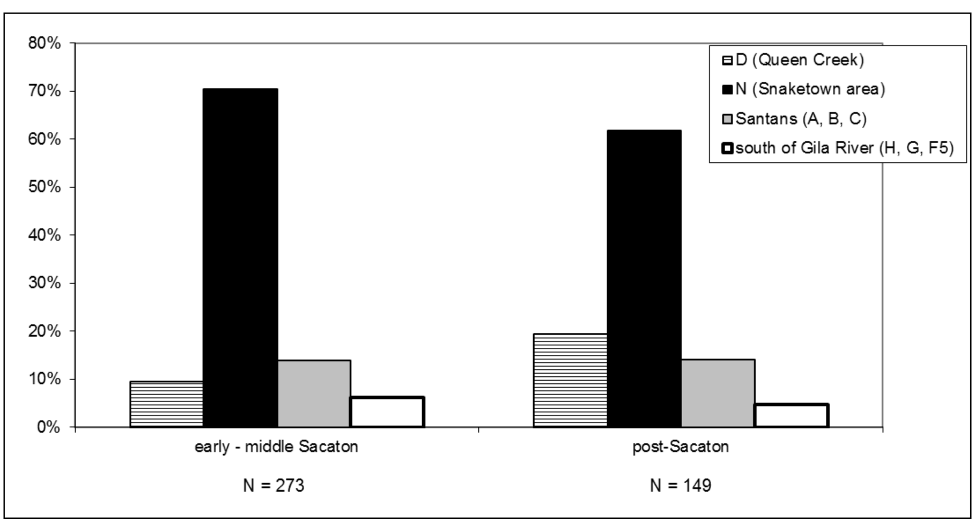


Figure 7. Middle Gila River Valley: Buff ware production group prevalence through time (excluding schist-only and more generic sand groups).

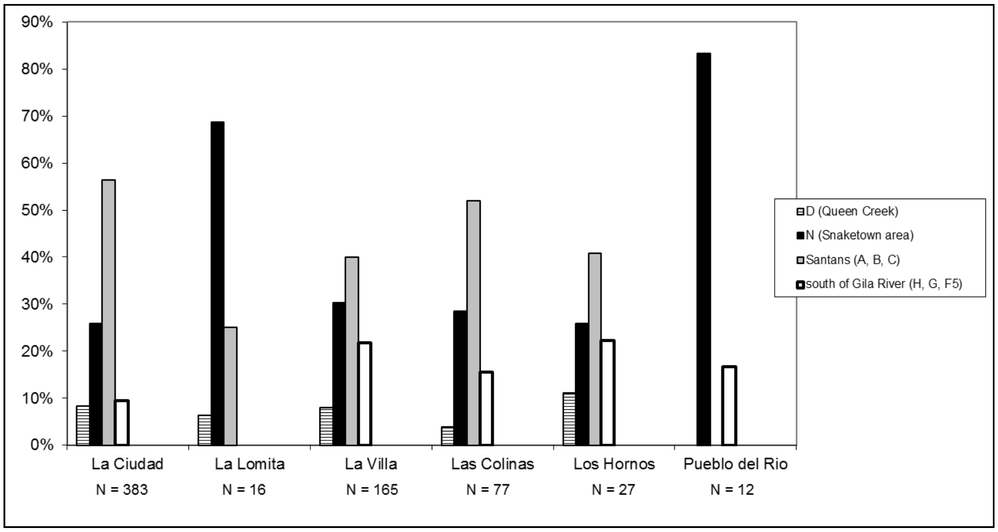
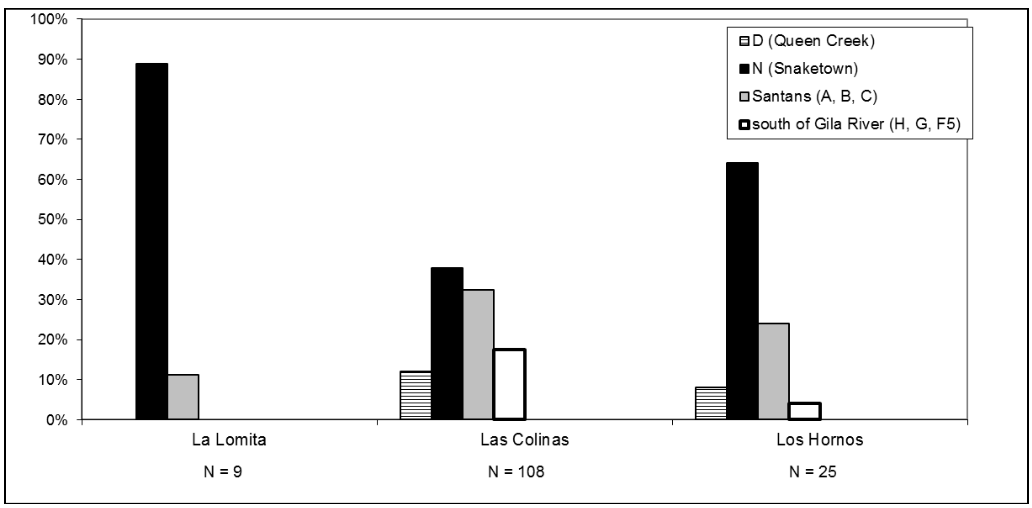


Figure 8. Distribution of buff ware sources among sites in the lower Salt River Valley, pre-Sacaton phase assemblages (excluding schist -only and more generic sand groups).

Figure 9. Distribution of buff ware sources among sites in the lower Salt River Valley, early-middle phase Sacaton assemblages (excluding schist-only and more generic sand groups).



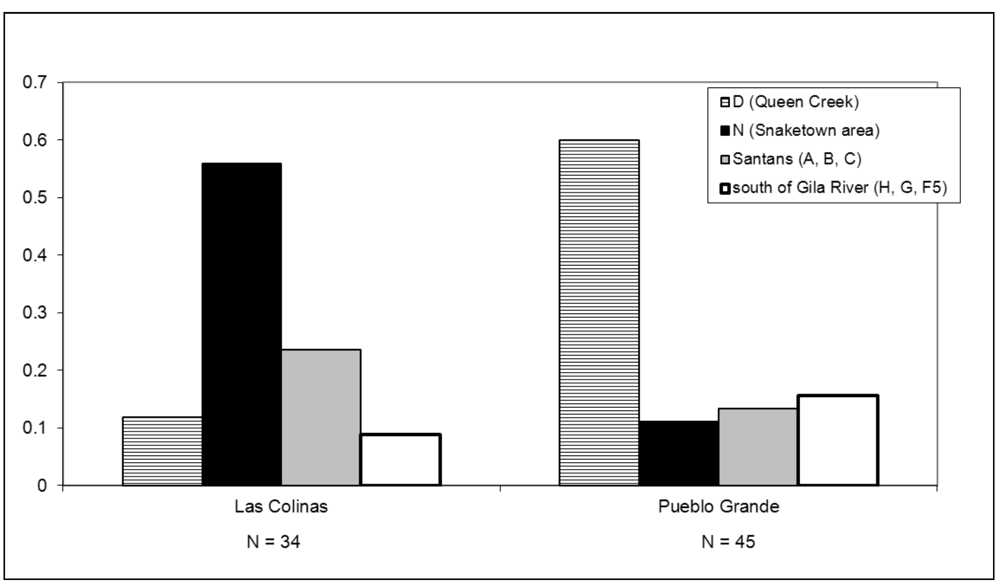


Figure 10. Distribution of buff ware sources among sites in the lower Salt River Valley, late Sacaton phase-Soho phase assemblages excluding schist-only and more generic sand groups).

Sonoqui Pueblo sherds was made possible by Gene Rogge of URS Corporation. All buff ware sherds from the Lower Santan site were analyzed as part of an ongoing research project with the Gila River Indian Community Cultural Resource Management Program. Thanks to Andrew Darling, Sunday Eiselt, and M. Kyle Woodson for organizing and directing this research, along with Linda Morgan, Lorie Sinclair, and Eloise Pedro for providing much needed help with the collections. Analysis of the buff ware assemblages from all sites in the Agua Fria/New River area (with the exception of Palo Verde), along with the assemblage from AZ AA:1:124 (ASM) was done with the helpful assistance and ideas from Glen Rice, Christopher Watkins, Erik Steinbach, and David Bustoz at Rio Salado Archaeology, LLC. Arleyn Simon, Dolma Roder, Nathan Wilson, and Steven Schmich of the School of Human Evolution and Social Change at Arizona State University allowed us access to curated materials. Arthur Vokes and Patrick Lyons generously provided access to curated collections at the Arizona State Museum. Material from Pueblo Grande Museum was accessed through the kind assistance of Holly Young.

REFERENCES CITED

Abbott, David R.

1994 Detailed Analysis of Sherds. In *The Pueblo Grande Project, Volume 3: Ceramics and the Production and Exchange of Pottery in the Central Phoenix Basin*, edited by David R. Abbott, pp. 261-370. Soil Systems Publications in Archaeology No. 20, Phoenix.

1995 Detailed Ceramic Analysis. In *Archaeology at the Head of the Scottsdale Canal System, Volume 2: Studies of Artifacts and Biological Remains*, edited by T. Kathleen Henderson and David R. Abbott, pp. 57-116. Anthropological Papers No. 95-1. Northland Research, Flagstaff.

2000 *Ceramics and Community Organization Among the Hohokam*. University of Arizona Press, Tucson.

2001 Electron Microprobe Analyses of the GARP Pottery and Raw Clays. In *The Grewe Archaeological Research Project, Volume 2, Part 1: Ceramic Studies*, edited by David R. Abbott, pp. 47-66. Anthropological Papers No. 99-1. Northland Research, Tempe, Arizona.

2009 Extensive and Long-Term Specialization: Hohokam Ceramic Production in the Phoenix Basin, Arizona. *American Antiquity* 74(3):531-557.

2010 The Rise and Demise of Marketplace Exchange among the Prehistoric Hohokam of Arizona. In *Archaeological Approaches to Market Exchange in Ancient Societies*, edited by Christopher P. Garraty and Barbara L. Stark, pp. 61-83. University Press of Colorado, Boulder.

Abbott, David R., Joshua Watts, and Andrew D. Lack.

2007a The Provenance and Concentrated Production of Hohokam Red-on-Buff Pottery from the Arizona Desert. *Journal of Anthropological Research* 63(3):331-357.

Abbott, David R., Alexa M. Smith, and Emiliano Gallaga

2007b Ballcourts and Ceramics: The Case for Hohokam Marketplaces in the Arizona Desert. *American Antiquity* 72:461-484.

Beck, Margaret E. and Hector Neff

2007 Hohokam and Patayan Interaction in Southwestern Arizona: Evidence from Ceramic Compositional Analyses. *Journal of Archaeological Science* 34:289-300.

Bishop, Ronald L., Robert L. Rands, and George R. Holley

1982 Ceramic Compositional Analysis in Archaeological Perspective. In *Advances in Archaeological Method and Theory*, Vol. 5, edited by Michael B. Schiffer, pp. 275-330. Academic Press, New York.

Cogswell, James W., David R. Abbott, Elizabeth J. Miksa, Hector Neff, Robert J. Speakman, and Michael D. Glascock

2005 Compositional Analysis of Hohokam Schist-tempered Pottery: Comparison of Methods. In *Laser Ablation ICP-MS in Archaeology*, edited by Robert J. Speakman and Hector Neff, pp. 104-116. University of New Mexico Press, Albuquerque.

Darling, Andrew J., Hector Neff, B. Sunday Eiselt, and Linda Newman

2007 Recent Advances in Provenance Research along the Middle Gila River Valley Using Time of Flight Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS). Poster Presented at the 72nd Annual Meeting of the Society for American Archaeology, Austin.

Doyel, David E.

1974 *Excavation in the Escalante Ruin Group, Southern Arizona*. Arizona State Museum Archaeological Series No. 37. Tucson.

1981 *Late Hohokam Prehistory in Southern Arizona*. Contributions to Archaeology No. 2. Gila Press, Scottsdale, Arizona.

Kelly, Sophia E.

2010a Updated Archaeological Map of the Lower Salt and Middle Gila River Valleys. Arizona State University, Tempe.

2010b Petrographic Analysis of Red-on-buff Pottery from Sonoqui Ruin [AZ U:14:49(ASM)]. In *Archaeological Data Recovery for the Ellsworth Road (Hunt Highway to Cloud Road) Widening Project, Queen Creek, Maricopa County, Arizona*, prepared by A.E. (Gene) Rogge and Pamela J. Cox, Appendix H. MCDOT Project TT178, Cultural Resource Report 2010-7(AZ). URS Corporation, Phoenix.

Lack, Andrew D., and Christopher N. Watkins

2010 Detailed Analysis of the Ceramic Assemblages. In *The Transwestern Phoenix Expansion Project, Analytical Studies and Synthesis Yavapai, Maricopa, and Pinal Counties, Arizona Volume 5, Part A*, assembled by Kenneth L. Brown and Susan Crespin, p. 91-146. TRC Report No. 48936-C-125, Albuquerque, NM.

Lack, Andrew D., Joshua Watts, and David R. Abbott

2006 Ceramic Artifacts. In *Archaeological Investigations along the Santan Expansion Project Pipeline Corridor from Gilbert to Coolidge, Maricopa and Pinal Counties, Arizona,* prepared by David R. Hart and Douglas B. Craig, pp. 143-216. Technical Report No. 05-48. Northland Research, Inc. Tempe, Arizona.

Miksa, Elizabeth J.

1999 *Provenance Characterization of Schist-Tempered Buff Ware Pottery*. Petrographic Report No. 99-6. Desert Archaeology, Inc., Tucson.

2001 Temper Provenance Studies. In *The Grewe Archaeological Research Project, Volume 2, Part 1: Ceramic Studies*, edited by David R. Abbott, pp. 7-46. Anthropological Papers No. 99-1. Northland Research, Tempe.

Miksa, Elizabeth J., and Sergio F. Castro-Reino

2001 *An Updated Sand Petrofacies Model for the Middle Gila River Basin*. Petrographic Report No. 2001-02. Desert Archaeology, Inc., Tucson.

Miksa, Elizabeth J., Sergio F. Castro-Reino, and Carlos Lavayen.

2004 A Combined Petrofacies Model for the Middle Gila and Phoenix Basins, With Application to Pottery From the Dutch Canal Ruin. In *Hohokam Farming on the Salt River Floodplain: Refining Models and Analytical Methods*, edited by T. Kathleen Henderson, pp. 7-44. Anthropological Papers No. 43. Center for Desert Archaeology, Tucson.

Peters, Matthew D., Kimberly R. Kennedy, Matthew Behrend, and Thomas E. Wright

2007 *Results of Phase I Archaeological Investigations in a Portion of the Sonoqui Ruin, AZ U:14:49(ASM), near Queen Creek, Maricopa County, Arizona.* Report 2005:036a. Archaeological Research Services, Tempe, Arizona.

Rafferty, Kevin

1982 Hohokam Micaceous Schist Mining and Ceramic Craft Specialization: An Example from Gila Butte, Arizona. *Anthropology* 6:199-222.

Rands, Robert L. and Ronald L. Bishop

1980 Resource Procurement Zones and Patterns of Ceramic Exchange in the Palenque Region, Mexico. In *Models and Methods in Regional Exchange*, edited by Robert E. Fry, pp. 19-46. Society for American Archaeology Papers No. 1, Society for American Archaeology, Washington, D. C.

Rogge, A.E. (Gene), and Pamela J. Cox

2010 *Archaeological Data Recovery for the Ellsworth Road (Hunt Highway to Cloud Road) Widening Project, Queen Creek, Maricopa County, Arizona*. MCDOT Project TT178, Cultural Resource Report 2010-7(AZ). URS Corporation, Phoenix.

Schaller, David M.

1994 Geographic Sources of Temper in Central Phoenix Basin Ceramics Based on Petrographic Analysis. In *The Pueblo Grande Project, Volume 3: Ceramics and the Production and Exchange of Pottery in the Central Phoenix Basin,* edited by David R. Abbott, pp. 17-90. Publications in Archaeology No. 20. Soil Systems, Phoenix.

Wallace, Henry D.

2001 Time Seriation and Typological Refinement of the Middle Gila Buffware Sequence: Snaketown Through Soho Phases. In The *Grewe Archaeological Research Project, Volume 2, Part 1. Ceramic Studies,* edited by David R. Abbott, pp. 177-262. Anthropological Papers No. 99-1. Northland Research, Tempe.

2004 Update to the Middle Gila Buff Ware Ceramic Sequence. In *Hohokam Farming on the Salt River Floodplain: Refining Models and Analytical Methods,* edited by T. Kathleen Henderson, p. 59-141. Anthropological Papers No. 43. Center for Desert Archaeology, Tucson.

Walsh-Anduze, Mary-Ellen

1993 An Evaluation of Ceramic Production at the Gila Butte Site. In *Archaeological Investigations at the Gila Butte Site: Hohokam Irrigation and Economic Systems along the Gila River, Arizona*, prepared by Thomas N. Motsinger, pp. 22-35. Archaeological Report No. 93-84. SWCA, Inc., Tucson.

Watts, Joshua

2007 *Power Ranch Chronological Assessment.* Report prepared for Soil Systems, Inc., Phoenix. Manuscript on file, SHESC, Arizona State University, Tempe.

Wright, Thomas E.

2004 *A Class III Cultural Resources Survey of 120 Acres of State Trust Land Located Northwest of the Corner of Crimson Road and Riggs Road, Maricopa County, Arizona.* Report 2004:109. Archaeological Research Services, Tempe, Arizona.

A MANUAL AND GRAPHICAL GUIDE FOR HOHOKAM DECORATED CERAMICS FROM THE MIDDLE GILA RIVER VALLEY: TOWARDS A SYSTEMATIC APPROACH TO HOHOKAM POTTERY CLASSIFICATION

David R. Abbott
Andrew D. Lack
Alexa M. Smith
Henry D. Wallace

ABSTRACT

We present a coding manual and graphical guide for typological analyses of Hohokam red-on-buff and red-on-gray pottery from the middle Gila River Valley. The manual and guide derive from Wallace's recent refinements to the Hohokam ceramic classification scheme. The routine application of the Wallace refinements, coding manual, and graphical guide will promote an objective, replicable, and systematic approach to Hohokam pottery classification.

Hohokam decorated ceramics, manufactured in the middle Gila River Valley and widely distributed across the Hohokam territory, have been classified into a temporal sequence of ceramic types since the early 1930s. Winifred and Harold Gladwin (1929, 1933) and Emil Haury (1932, 1937, 1945, 1976) developed the original chronological classification of the early red-on-gray and the later red-on-buff pottery. Their classification was based largely on stylistic attributes and vessel forms. The linear ordering of decorated types, the types' one-to-one correspondence with the temporal phases for the Estrella-to-Soho portion of the Hohokam chronology, and the unilineal model of slow and continuous stylistic change have been the foundations of chronometric control for Hohokam research.

The ceramic type/phase sequence has proven to be a highly effective chronological tool during many decades of archaeological investigations in the Arizona desert (e.g., Dean 1991). Over the years, Hohokam archaeologists have heatedly debated the absolute dating of the Hohokam occupation in south-central Arizona, but the relative sequence of phases and associated decorated ceramic types, first laid out 80 years ago, has remained widely accepted and unchanged.

Recently, however, Henry Wallace (2001a, 2004) made substantial and important refinements to the classification scheme. Surprisingly, despite the clear advantages offered by the Wallace refinements, they have not been widely adopted for archaeological practice. We suspect the hesitations to adopt Wallace's scheme correspond primarily to the daunting task of mastering the typology's many details about stylistic, vessel-form, and paste attributes, and, secondarily, to the time required for a detailed typological analysis. We also presume that some reluctance relates to uncertainty about how to implement the typological analysis.

We promote the application of Wallace's results and moving towards systematic procedures for an objective, precise, and replicable classification of Hohokam decorated pottery. To do so, we share a coding manual and a graphical guide of the refined ceramic classification scheme. They have proven effective for our pottery analyses in the Laboratory of Sonoran Ceramic Research at Arizona State University. The manual contains summaries and diagrammatic examples of the temporal diagnostics described in great detail by Wallace (2001a, 2004). The guide is a reformatted version of Wallace's (2004) Figure 3.22, and it is keyed to the coding manual.

WALLACE'S REFINEMENTS

Wallace's (2001a, 2004) typological studies of the middle Gila decorated pottery were prompted by two

David R. Abbott / School of Human Evolution and Social Change, Arizona State University / David.Abbott@asu.edu
Andrew D. Lack / / School of Human Evolution and Social Change, Arizona State University / Andrew.Lack@asu.edu
Alexa M. Smith / Tucson, AZ
Henry D. Wallace / Desert Archaeology, Inc., Tucson, AZ / henry@desert.com

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 51-79

constraints, which have plagued the accuracy and precision of the Hohokam ceramic chronological scheme. First, the Gladwins' (1929, 1933) and Haury's (1932, 1937, 1945, 1976) decorated types are based on stylistic variation that is perceived differently by different individual researchers. Ambiguities in the type descriptions have led analysts to emphasize attributes dissimilarly (Marmaduke 1993; Neitzel 1984; Wallace 1992:33-35, 1995:58-59), thereby creating subjectivity and typological inaccuracies. Second, the long temporal intervals associated with some of the ceramic types have hampered chronometric precision. For example, Sacaton Red-on-buff is a type that was made for approximately 150 years between ca. A.D. 950 and 1100. Such gross temporal divisions can obfuscate and confuse our understanding of short-term cultural patterns when they succeeded one another during one of the long temporal spans blocked out by the ceramic chronology.

Wallace (2001a, 2004) addressed the subjectivity problem by objectively weighting the stylistic, vessel form, and technological attributes used in the classification scheme. His typological refinements also improved the chronometric precision by subdividing some long-lived decorated types into subtypes, each associated with a relatively short temporal span.

Objective Attribute Weighting

Winifred and Harold Gladwin and especially Emil Haury published beautifully illustrated and richly described type descriptions of the middle Gila red-on-gray and red-on-buff ceramics with which generations of pottery analysts have been trained. For example, Haury (1976) thoroughly depicted the variation in the way by which particular design elements and motifs were rendered by Hohokam artisans and how those renderings evolved over time. But because Haury offered little guidance as to the relative importance of particular design attributes for classifying pottery specimens, some analysts inevitably and subjectively ranked some traits for ceramic classification in one way, while other analysts emphasized other attributes. Wallace's approach has overcome that subjectivity by using a numerical time seriation.

The time seriation used attribute data from ceramic assemblages excavated from undisturbed and rapidly filled contexts. The fine-scale seriation allowed Wallace to distinguish clusters of assemblages pertaining to subphase temporal intervals, which were checked using independent sequencing and dating techniques. The clusters of coeval assemblages then yielded attribute percentages for the various phase and subphase intervals. The association of individual stylistic, vessel-form, and paste attributes with particular temporal spans became the objective and explicit basis for the temporal classification of individual ceramic specimens. Some attributes were shown to be highly diagnostic, corresponding to only a single subphase segment of time. Many others corresponded to multiple phases and subphases and were less temporally sensitive traits.

Increased Precision

Wallace's refinements increase typological precision by subdividing several of the original red-on-buff types. The "subtypes" represent considerably narrower segments of time. For instance, based on Wallace's analysis, ceramic analysts can now distinguish among Early Sacaton, Middle Sacaton 1, Middle Sacaton 2, and Late Sacaton Red-on-buff.

The success and utility of Wallace's refinements have been demonstrated with several recent applications, which have yielded inferences about Hohokam prehistory that would not have been possible with less precise temporal control. These interpretive results include the founding and abandonment of the ballcourt village at Palo Verde Ruin during the middle Sacaton phase (Abbott 2002, 2007), the founding of Las Colinas during the early Sacaton/middle Sacaton transition (Abbott 2006), the abandonment of the Las Colinas ballcourt at the end of the middle Sacaton phase (Abbott 2006), and the reorganization of pottery production in the Phoenix Basin at various points in time (Abbott 2009).

PROMOTING REFINEMENT

Despite the utility of the typological refinements, practicing ceramic analysts have not whole-heartedly adopted them. Perhaps analysts have had difficulty mastering the many details about stylistic attributes and have experienced uncertainty about how to systematize the typological process. A solution, we suggest, includes the adoption and use of a coding manual to help the analyst recognize temporally sensitive attributes on sherds and whole pots. Also, we promote a simple, objective, and clearly defined procedure for assigning individual ceramic specimens to a temporal category. The procedure relies on a graphical guide that depicts the temporal span of each diagnostic trait. Armed with the guide, the analyst is led to a specimen's temporal classification via the temporal overlap of the specimen's diagnostic traits.

Proper implementation of Wallace's refinements requires typological procedures that conform to the manner by which pottery decorations and vessel forms changed over time. The data structure for Hohokam designs is one of overlapping attributes, each of whose popularity at a particular time was either rising or waning and whose lifespan was either short or long. Consequently, there are few natural breaks or discontinuities between temporal groups. Instead, as Haury

Table 1. Temporal Phase Abbreviations in Temporal Order.

Abbreviation	Phase
ES	Estrella
SW	Sweetwater
ESN	Early Snaketown
LSN	Late Snaketown
EGB	Early Gila Butte
LGB	Late Gila Butte
SC	Santa Cruz
ESAC	Early Sacaton
MSAC1	Middle Sacaton 1
MSAC2	Middle Sacaton 2
LSAC	Late Sacaton
SOHO	Soho

(1937) recognized early on, there was a continuum of stylistic variation over time.[1] In addition, each Hohokam decorated type includes members that share with other members a number of characteristics, but no one attribute is required for membership in the type. Moreover, because very few short-lived attributes occurred on pottery for only a single subphase, categorizing pottery specimens most often relies on a combination of traits. With that kind of data structure, the approach we take is well suited for systematizing the typological process.

The graphical guide presents the time ranges over which each attribute occurred (Appendix 1). The left column of the guide lists a code for each attribute. The code is a cross reference with the coding manual (Appendix 2). Each of the attributes is dated to a specific time segment, or to a range of time segments over which it occurred (Table 1). Thus, the ceramic analyst examines individual attributes and locates the attribute on the graphical scale.

To type any given sherd using this guide, all diagnostic attributes on a sherd are considered. The final type designation is the result of the temporal overlap among all the attributes on the sherds. Most sherds are not typed to a single time segment (e.g. Middle Sacaton 1), but to a range of time segments (e.g. Early Sacaton to Middle Sacaton 2) because most attributes were in use over the course of more than one time segment. The sherd can, therefore, belong to any one of those time segments in which the attribute, or combination of attributes, was in use.

For example, consider a typical red-on-buff bowl rim sherd with several different temporally diagnostic design attributes (Figure 1, Table 2). In this example, the potsherd displays a free-floating fringe pattern, a positive flying bird motif, and exterior trailing lines. According to Wallace (2004), free-floating fringe has a temporal span from the late Gila Butte phase to the late Sacaton phase (see the graphical guide). The positive flying bird motif dates from the early Gila Butte to the early Sacaton phase. When these two attributes are combined on the same sherd, the temporal range narrows to the late Gila Butte to the early Sacaton phase. The presence of exterior trailing lines that are closely spaced (<3cm) has a temporal range from the early Snaketown to the late Gila Butte phase. The only temporal phase in which all three of these attributes co-occurred was in the late Gila Butte phase. Therefore, a sherd with all three motifs can be typed as Late Gila Butte Red-on-buff.

This method of classification has proven to be more conservative, more accurate, and more objective

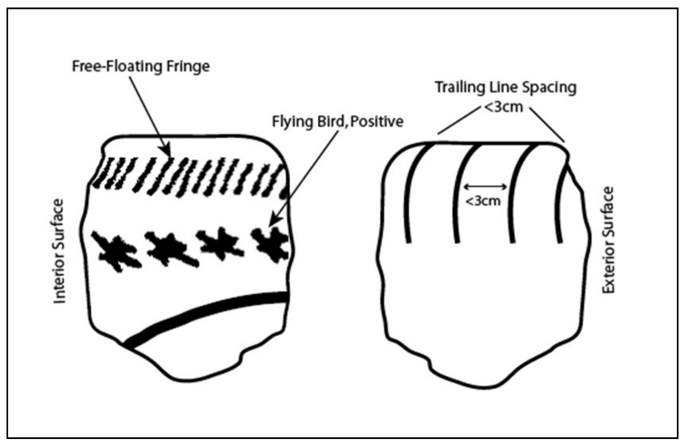
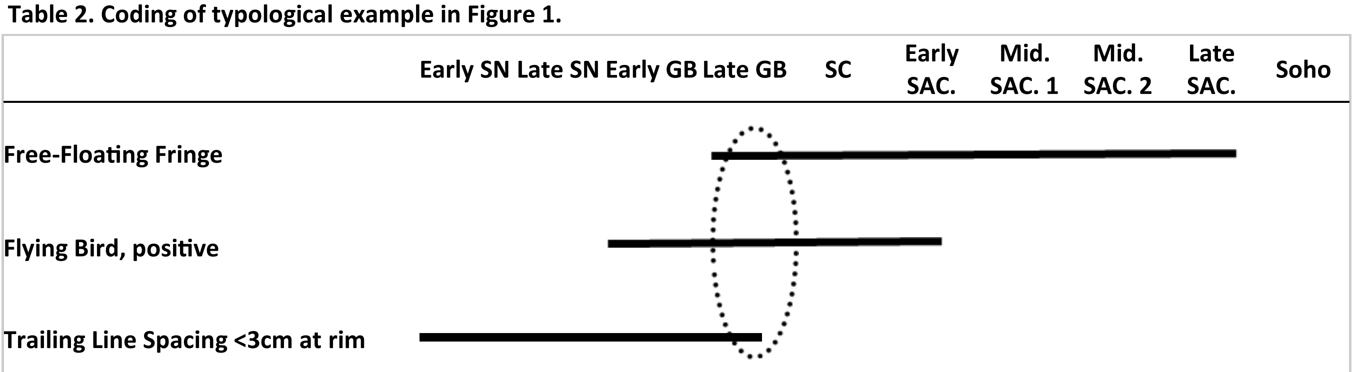


Figure 1. Typological example.

Table 2. Coding of typological example in Figure 1.



than previous buff ware temporal analyses. It is more conservative because it recognizes that many stylistic attributes were utilized over several phases. It is more objective because it identifies specific attributes and provides temporal ranges for each attribute, thus allowing different researchers to code individual sherds in the same way. It is more accurate because it identifies more attributes as temporally sensitive, and also uses multiple attributes on a single sherd to narrow the temporal range, sometimes to a single time segment.

Finally, we note that although the analyst's skill can affect the performance of the typological process, analysts are unlikely to confuse one attribute with another. Instead, the analyst's skill largely corresponds to his/her ability to recognize attributes on the ceramics; this skill impacts the precision of the temporal classification but not the accuracy. We hope that the analytical tools presented here will serve as a foundation from which analysts can develop their skills.

CONCLUSION

Hohokam archaeology has been well served for eight decades by the red-on-gray and red-on-buff ceramic chronology defined by Winifred and Harold Gladwin (1929, 1933) and Emil Haury (1932, 1937, 1945, 1976). Much more recently, that chronology has been made more precise and more accurate by Henry Wallace's (2001a, 2004) refinements. Unfortunately, despite compelling examples of its utility, Wallace's classification scheme has had only a spotty application among pottery analysts. We hope that the coding manual and graphical guide presented here will promote the widespread acceptance and routine application of this objective, replicable, and systematic approach to Hohokam pottery classification.

Note

1. Wallace has recognized the appearance of three mutually distinctive horizon styles as major points of stylistic innovation. But instead of promoting clear temporal breaks in the stylistic variation, they represent what Wallace (2001a:258) calls, "a process of style introduction followed by a period of elaboration and experimentation, and ultimately a trend toward simplification, replication, and an overall reduction in stylistic diversity." Like the waxing and waning of individual attributes, each of Wallace's horizon styles also progressed through its own cycle of popularity, overlapping at some times with other horizon styles, and contributing to a continuum of stylistic change.

Acknowledgments. We are thankful to two anonymous reviewers for their support and constructive comments. We are especially grateful to Linda Gregonis, whose many thoughtful and detailed suggestions significantly improved the manual. Thanks also to Emiliano Gallaga, whose artwork is incorporated into the coding manual.

REFERENCES CITED

Abbott, David R.
1994 Detailed Analysis of Sherds. In *The Pueblo Grande Project, Volume 3: Ceramics and the Production and Exchange of Pottery in the Central Phoenix Basin*, edited by David R. Abbott, pp. 261-370. Soil Systems Publications in Archaeology No. 20, Phoenix.
2002 Chronology at Palo Verde Ruin. In *Phoenix Basin to Perry Mesa: Rethinking the "Northern Periphery*," edited by Mark R. Hackbarth, Kelley Hays-Gilpin, and Lynn Neal, pp. 41-46. The Arizona Archaeologist No. 34. Arizona Archaeological Society, Phoenix.
2006 Hohokam Ritual and Economic Transformation: Ceramic Evidence from the Phoenix Basin, Arizona. *North American Archaeologist* 27:285-310.
2007 The Palo Verde Chronology. In *Archaeological Investigations at Palo Verde Ruin, AZ T:8:68(ASM): The Terramar Project: Vol. 1. Project Background, Feature Descriptions, and Chronology*. Anthropological Papers No. 02-02. Northland Research, Tempe.
2009 Extensive and Long-Term Specialization: Hohokam Ceramic Production in the Phoenix Basin, Arizona. *American Antiquity* 74:531-557.

Amsden, Charles A.
1936 *An Analysis of Hohokam Pottery Designs*. Medallion Papers No. 22. Gila Pueblo, Globe, AZ.

Crown, Patricia L.
1981 Analysis of the Las Colinas Ceramics. In *The 1968 Excavations at Mound 8, Las Colinas Ruins Group, Phoenix, Arizona,* edited by L. C. Hammack and A. P. Sullivan, pp. 87-169. Archaeological Series No. 154. Arizona State Museum, University of Arizona, Tucson.

Dean, Jeffrey S.
1991 Thoughts on the Hohokam Chronology. In *Exploring the Hohokam: Desert Dwellers of the Southwest*, edited by George Gumerman, pp. 61-150. University of New Mexico Press, Albuquerque.

Doyel, David E.
1977 Classic Period Hohokam in the Escalante Ruin Group. Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

Gladwin, Winifred, and Harold S. Gladwin
1929 *The Red-on-buff Culture of the Gila Basin*. Medallion Papers No. 3. Gila Pueblo, Globe, Arizona.
1933 *Some Southwestern Pottery Types, Series III*. Medallion Papers No. 13. Gila Pueblo, Globe, Arizona.

Haury, Emil W.
1932 *Roosevelt 9:6: A Hohokam Site of the Colonial Period.* Medallion Papers No. 1. Gila Pueblo, Globe, Arizona.
1937 Pottery Types at Snaketown. In *Excavations at Snaketown: Material Culture*, by Harold S. Gladwin, Emil W. Haury, E. B. Sayles, and Nora Gladwin, pp. 169-299. Medallion Papers No. 25. Gila Pueblo, Globe, Arizona.
1945 *The Excavation of Los Muertos and Neighboring*

Ruins in the Salt River Valley, Southern Arizona. American Archaeology and Ethnology Papers No. 24(1). Peabody Museum, Harvard University, Cambridge.

1976 *The Hohokam: Desert Farmers and Craftsmen: Excavations at Snaketown, 1964-1965*. University of Arizona Press, Tucson.

Lascaux, Annick

1993 Ceramic Collection. In *The Maricopa Road Site: A Pre-Classic Hohokam Village, AZ T:16:13 ASU, Pinal County, Arizona*, edited by John C. Ravesloot and Annick Lascaux, pp. 119-160. Anthropological Field Studies No. 28. Office Cultural Resource Management, Arizona State University, Tempe.

Marmaduke, William S.

1993 Research Precepts at Shelltown and the Hind Site. In *Shelltown and the Hind Site: A Study of Two Hohokam Craftsmen Communities in Southwestern Arizona: Vol 1*, edited by William S. Marmaduke and Richard J. Martynec, pp. 15-35. Northland Research, Flagstaff.

Neitzel, Jill E.

1984 The Regional Organization of the Hohokam in the American Southwest: A Stylistic Analysis of Red-on-buff Pottery. Ph.D. dissertation, Arizona State University, Tempe.

Wallace, Henry D.

1992 Cross-dating the Gila Butte Phase, and a Reconsideration of the Ceramic Type Gila Butte Red-on-buff. In *The Rye Creek Project: Archaeology in the Upper Tonto Basin: Vol. 3. Synthesis and Conclusions*, by Mark D. Elson and Douglas B. Craig, pp. 29-54. Anthropological Papers No. 11. Center for Desert Archaeology, Tucson.

1995 Decorated Buffware and Brownware Ceramics. In *The Roosevelt Community Development Study: Vol. 2. Ceramic Chronology, Technology, and Economics*, edited by James M. Heidke and Miriam T. Stark, pp. 19-84. Anthropological Papers No. 14. Center for Desert Archaeology, Tucson.

2001a Time Seriation and Typological Refinement of the Middle Gila Buffware Sequence: Snaketown through Soho Phase. In *The Grewe Archaeological Research Project: Vol. 2: Material Culture, Part I: Ceramic Studies,* edited by David R. Abbott, pp. 177-262. Anthropological Papers No. 99-1. Northland Research, Tempe.

2001b Middle Gila Buffware Ceramic Illustrations. In *The Grewe Archaeological Research Project: Vol. 2:Material Culture, Part I: Ceramic Studies*, edited by David R. Abbott, pp. 417-439. Anthropological Papers No. 99-1. Northland Research, Tempe.

2004 Update to the Middle Gila Buff Ware Ceramic Sequence. In *Hohokam Farming on the Salt River Floodplain: Refining Models and Analytical Methods*, edited by T. Kathleen Henderson, pp. 45-124. Anthropological Papers No. 43. Center for Desert Archaeology, Tucson.

Walsh-Anduze, Mary-Ellen

1994 The Pueblo Grande Whole Vessel Study: An Examination of Production and Short-distance Exchange. In *The Pueblo Grande Project: Vol. 3. Ceramics and the Production and Exchange of Pottery in the Central Phoenix Basin, part 1*, edited by David R. Abbott, pp. 149-259. Publications in Archaeology No. 20. Soil Systems, Inc., Phoenix.

Wasley, William W., and Alfred E. Johnson

1965 *Salvage Archaeology in Painted Rocks Reservoir, Western Arizona.* Anthropological Papers No. 9. University of Arizona Press, Tucson.

Appendix 1. Graphical guide of temporally sensitive attributes on Hohokam decorated pottery.

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	ES	SW	ESN	LSN	EGB	LGB	SC	ESAC	MSACI	MSACII	LSAC	SOHO
290	Coil-based incising, thickest lines ≥4 mm in width												
291	Thickest lines ≥4 mm in width, paste gray or brown, surface fire-clouded												
292	Thickest lines ≥6 mm in width, polished												
293	Tool polishing over painted lines (smearing visible)												
294	Red slip or wash on bowl exterior												
157	Coil-based incising												
295	Coil-based incising with either (1) line width <4 mm OR (2) Snaketown Style Design												
300	Hachure-sectioning, negative star layout, and hachure line spacing ≥ thickness of hatchure lines												
302	Incising, imitation of coil-based incising (very deep, regular, and continuous)												
1	Deep, Regular Incising												
305	Snaketown Style layout, AND thickest line <2.5 mm wide, and polished surface												
165	Hachure-filled design plus thickest line width <2.1mm												
307	Repeated negative life form and Snaketown Style layout												
310	Polish, lustrous												
311	Polish												
312	polish and gray paste												
4	Snaketown Style Layout												
17	Estrella Style[1]												
18	Sweetwater Style[2]												
21	Flying Bird, Negative (Snaketown Style)												
5	Exterior Bowl Design (more than trailing lines)												
22	Massed Hachure												
315	Filled-in or partly filled-in Snaketown Style design AND bowl with exterior trailing lines Or no painted exterior design												
32	Snaketown Style Design AND hachure framing lines thicker than hachure lines												
318	Surface coating present AND Snaketown Style design present												
319	Surface coating absent AND fire-clouding present												
320	Surface coating absent AND sooted surface present												
321	Surface coating absent AND gray paste												
12	Bowl[3]												
15	Incising												
25	Multiple Dots												
23	Key												
29	Incising (discontinuous)												
41	Design Ticking												
324	Full-field negative design, not hachure-filled												
26	Trailing Lines												
24	Trailing Line Spacing < 3 cm at rim												
175	Trailing line , short (<3cm), more than 3 lines, spacing <4cm at rim												
345	Trailing lines present, spaced ≥3cm (or unknown spacing), AND large solid AND thickest line ≥2.5mm avg. width												
73	Trailing Lines ≥3 cm apart or of unknown spacing PLUS Large Solid AND Thickest Line ≥2.5 mm avg.												
347	Trailing lines present; number of trailing lines/bowl <6												
172	All-over layout, spiraling small elements, elements touching or average <2mm apart from one another												
326	Repeated negative life form, not in a rim solid, not Snaketown Style												
51	Slanted Railroad Tie Hachure												
179	Compressed globular-body jar with short flared rim												
186	Outcurved or flare-rim bowl, shallow, flat-bottomed												
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	ES	SW	ESN	LSN	EGB	LGB	SC	ESAC	MSACI	MSACII	LSAC	SOHO

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	ES	SW	ESN	LSN	EGB	LGB	SC	ESAC	MSACI	MSACII	LSAC	SOHO
190	Small, geometric element group D, nos.: 18, 19, 20, 21, 26, 28, 29, 40, 41												
330	Surface coating absent												
333	Serrated curvilinear scroll (serrations not straight-line equilateral triangles)												
34	Filler-space Hachure												
35	Motif Serration (not Snaketown Style)												
36	Long Scroll Serration (not Snaketown Style)												
28	Linebird (pendant dash motif)												
62	Cuneiform Hatch												
335	Avg. thickest line ≤2.2mm AND either linebird or organizational banding												
37	Flying Bird, Negative (not Snaketown Style)												
53	Flying Bird, Positive												
52	Organizational Banding Layout												
338	Thickest line ≤2.2mm avg. width AND surface coating present												
340	Organizational banding layout AND full rim line												
342	Large solid (>5cm²) and thickest line <2.5mm avg. width; in combination with other traits that place sherd post-SC												
207	Large, repeated life form or geometric element (average max. length > 5cm)												
74	Diamond Panel Layout												
260	Banded layout, a-b-a or aa-b-aa with b bands composed of a single thick line (width > 5mm)												
91	Crenulated Line in a Panel												
224	Design element diversity >4												
233	Panel, at least partly line demarcated, >1 centerline motif												
235	Panel, at least partly line demarcated, zipper, curvilinear scroll, or other border elaboration (except fringing, ticking, or sawteeth)												
238	Panel, at least partly line demarcated, multiple duplicate elements used as panel centerline												
230	Two or more voids within single solid with small elements												
227	Zipper motif												
245	Cauldron (concave wall)												
250	Small, geometric element group E, nos.: 32, 33, 65, 78, 82, 89, 98, 101, 110, 115, 116, 118, 123, 125												
246	Cauldron with Gila shoulder												
257	Panel, at least partly line demarcated (does not have any parts where panel border elaboration is attached to an adjacent solid)												
255	Panel, isolated (completely line demarcated)												
92	Gila Shoulder <120 degrees												
93	Gila Shoulder, Knife-edged												
54	Life Forms (except birds and lizards)												
55	Quail												
195	Small element group A, nos.: 30, 34, 35, 58, 63, 70, 1, 2, 73, 80, 81, 83, 84, 85, 86, 95, 96, 99, 103, 113, 114												
222	Small elements used as panel centerline												
185	Flare-rimmed bowl												
56	Free-Floating Fringe*												
57	Single-Capped Fringe*												
59	Indeterminate Free-Floating or Single-Capped Fringe												
247	Cauldron (vertical wall)												
348	Gila shoulder angle ≤110°												
58	Large Solids (> 5 cm^2)												
75	Double-Capped Fringe (straight or wavy), in Sectioned Layout												
103	Double-Capped Fringe (straight or wavy), as Panel or Panel Border												
209	Wipe-marked jar interior												
76	Everted Jar Rim												
77	Gila Shoulder												
80	Wavy-capped Fringe (single- or double-capped)												
349	Thick serrated line												
203	Fringed curvilinear scroll												
200	Crenulated Line												
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	ES	SW	ESN	LSN	EGB	LGB	SC	ESAC	MSACI	MSACII	LSAC	SOHO

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	ES	SW	ESN	LSN	EGB	LGB	SC	ESAC	MSACI	MSACII	LSAC	SOHO
350	Large solid and thickest line >3.1mm								▒	▒	▒	▒	▒
280	Small, geometric element group B, nos.: 65, 66, 87, and any variation thereof								▒	▒	▒	▒	▒
217	Line-demarcated panels (>50% line demarcated)								▒	▒	▒	▒	▒
220	Jar with sectioned design								▒	▒	▒	▒	▒
81	Panel with a Serrated Margin								▒	▒	▒	▒	▒
78	Panel with a Centerline Motif								▒	▒			
284	Small, geometric element group C, no.: 64, 67, 68, 69, 90, and minor variations thereof									▒	▒	▒	▒
96	Rectilinear Scroll									▒	▒	▒	▒
95	Outline Line and Stagger											▒	
270	Design field separation from rim, bowl interiors only											▒	
275	Semi-flare-rimmed hemispherical bowl											▒	
101	Lines Motif									▓	▒	▒	▒
114	Pitcher											▓	▒
111	Tapered Lines											▒	▒
112	Upper Freeline (jars only)										▓	▒	▒
102	Solid Void Motif										▒	▒	▒
277	interlocking rectilinear fret											▒	▒
121	Open Panel												▒
124	Tall Neck (jars only)												▒
123	Classic (mold inset) Shoulder												▒
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	ES	SW	ESN	LSN	EGB	LGB	SC	ESAC	MSACI	MSACII	LSAC	SOHO

Key:
▒ present
▓ present but rare

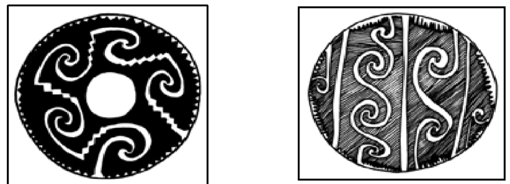
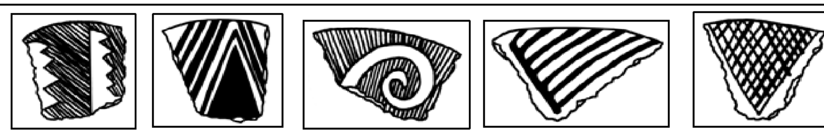
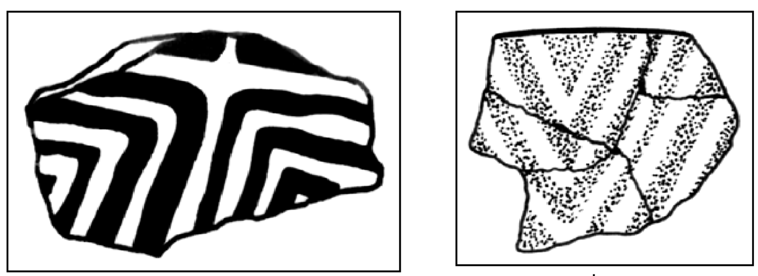
[1]Not a Wallace (2004) designation, but refers to those sherds with gray or brown paste, thick linework (≥4mm), simple designs (e.g. nested chevrons, straight hachure, isolated curvilinear scrolls, and commas), often polished; and it does not have deep, regular incising (with the exception of coil-based incising) nor Snaketown style layout

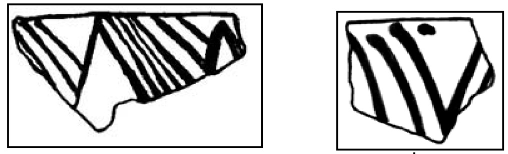
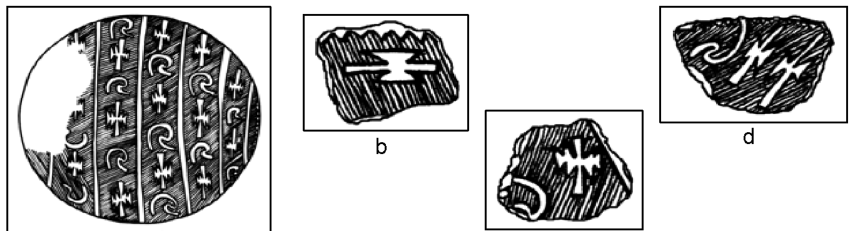
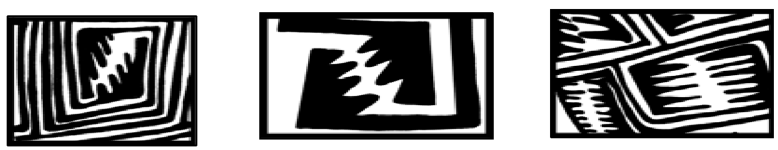
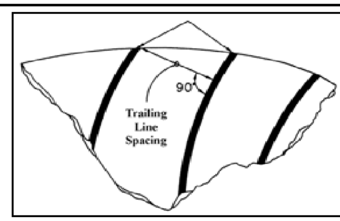
[2]Not a Wallace (2004) designation, but refers to those sherds with gray or brown paste, average line width ≤4mm, hatch framing lines same width as hachure lines, spacing between hachure lines greater than hachure line thickness, possible Snaketown style layout

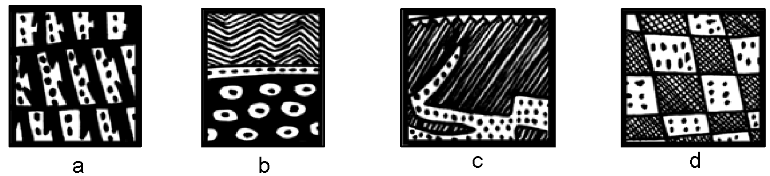
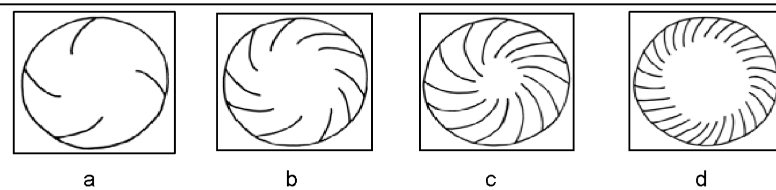
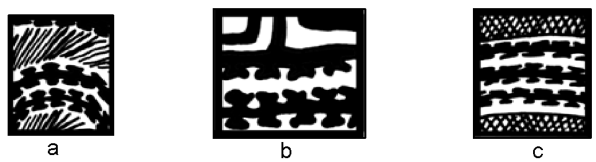
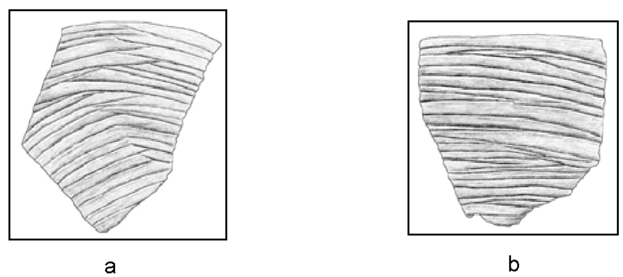
[3]Not used by Wallace in Table 3.7 or Figure 3.22 (2004), but is diagnostic in Table 3.6

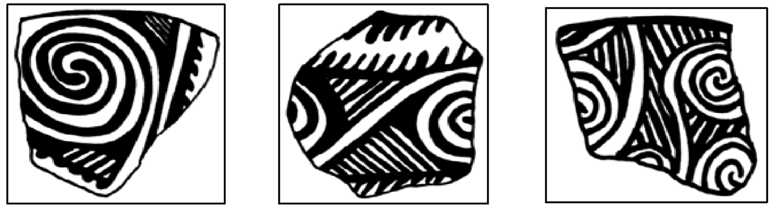
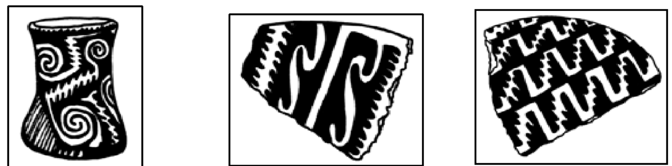
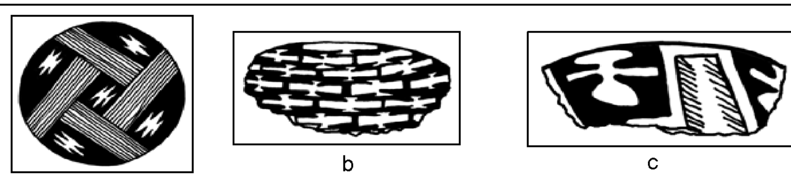
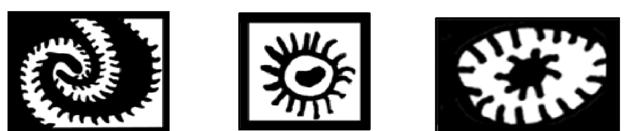
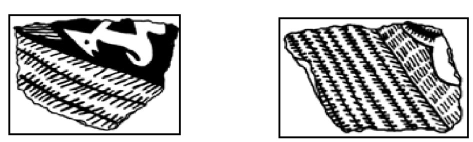
*Wallace suggested an MSAC2 ending date for these attributes, but we feel more comfortable with an LSAC ending date in our experience with different assemblages.

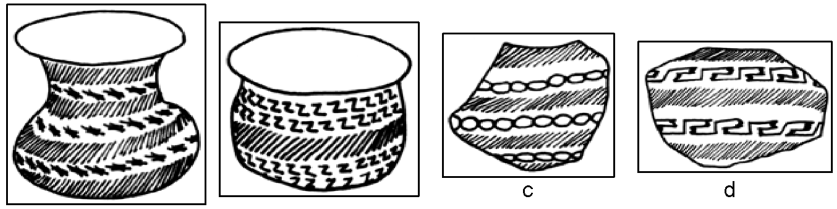
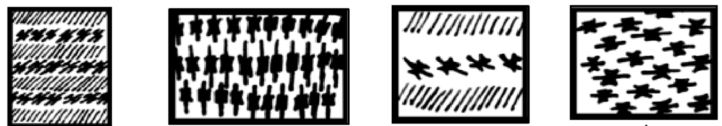
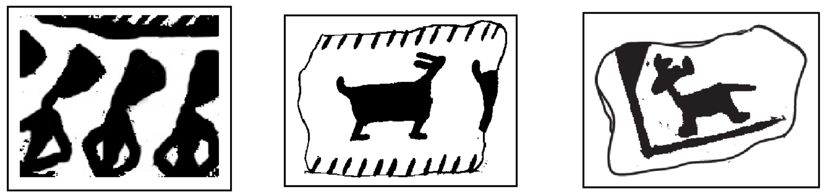
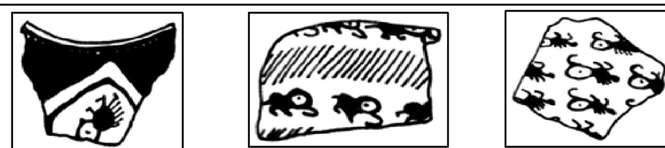
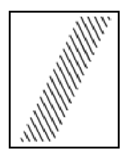
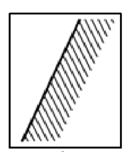
Appendix 2. Coding manual for Hohokam decorated pottery.

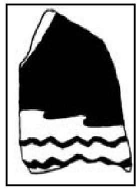
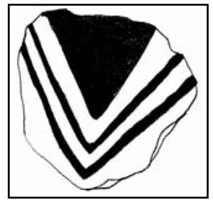
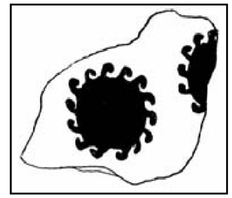
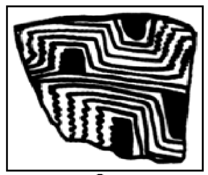
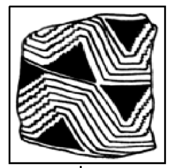
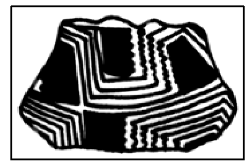
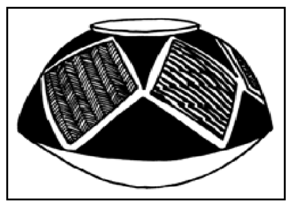
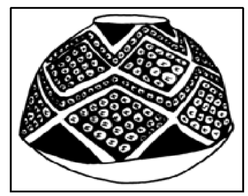
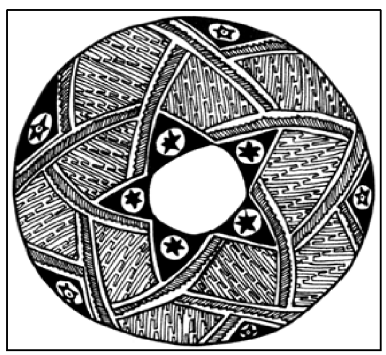
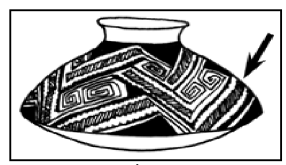
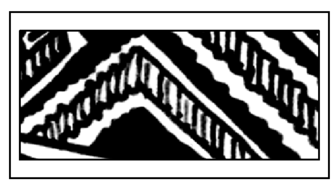
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
1	Deep, regular incising	SW-ESN	 a b	Haury 1937: Plate CLXXXIIIj, k. l, p See incising comparisons Compare to codes 15, 29, 157, 290, 295, 302
4	Snaketown Style Layout	SW-LSN	 a b	Haury 1937:Figure 83, Plate CLXXVIm; Haury 1976:Figures 12.33b row 1, center and right sherds, 12.40a-c, e-g; Wallace 2001b:Figures I.1a-d, g, l, j-m, I.3a-m
5	Exterior Bowl Design (more than trailing lines)	ES-EGB	 a b c d e	Haury 1937:Plate CLXXXIIIc-l, r, x; Wallace 2001b:Figures I.2a-g, I.5a-d Compare to code 26
12	Bowl[1]	ES-LSAC	no illustration	-
15	Incising	ES-LGB	no illustration	Wallace 2001b: Figure I.5a, b, d, g, h, I.7c-e Compare to codes 1, 29, 157, 290, 295, 302
17	Estrella Style[2] (gray or brown paste, thick linework (≥4mm), simple designs [e.g. nested chevrons, straight hachure, isolated curv. scrolls, and commas], often polished; and it does not have deep, regular incising [excepting coil-based incising] nor Snaketown style layout)	ES	 a b	Haury 1976:Figures 12.52, 12.53

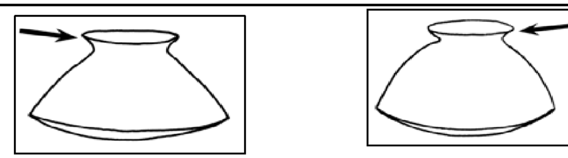
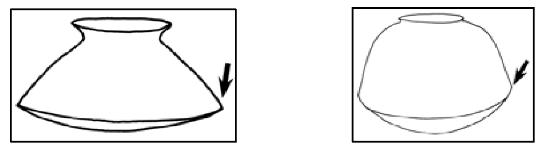
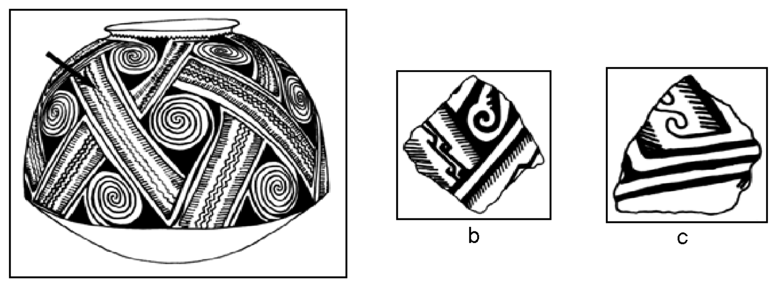
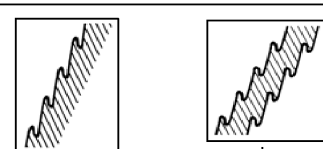
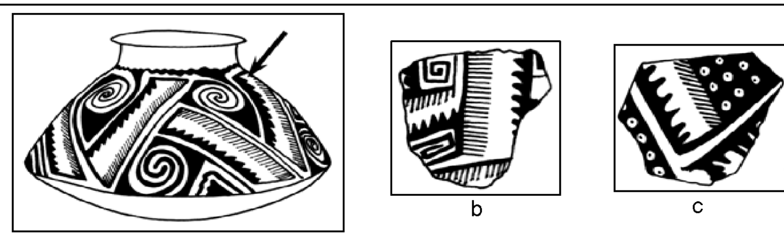
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
18	Sweetwater Style[2] (gray or brown paste, average line width ≤4mm, hatch framing lines same width as hachure lines, spacing between hachure lines greater than hachure line thickness, possible Snaketown style layout)	SW	 a b	Haury 1976:Figures 12.44-12.47, 12.49-12.51
21	Flying Bird, Negative (Snaketown Style)	ESN-LSN	 a b c d	Haury 1976:Figures 12.41a, 12.96t-z Compare to codes 37 and 53
22	Massed Hachure (filled-in or partly filled-in Snaketown Style design)	LSN, trace in ESN and EGB	 a b	Haury 1937:Plate CLXXVIm; 1976:Figures 12.33b row 1, center and right sherds, 12.37a; Wallace 2001b:Figures I.1a-e, I, I.3, especially a, d, h, j See hachure comparisons
23	Key	SN-LGB	 a b c	Haury 1937:Plate CLXXVIIa-d, f; Wallace 2001b:Figure I.13g
24	Trailing Line Spacing < 3 cm at rim (Note potential for confusion with Snaketown hachured penant triangle motifs on small sherds)	SN-LGB	 a	Haury 1937:Plate CLXXVa, b, d Compare to codes 5, 26, 175, 345, 347

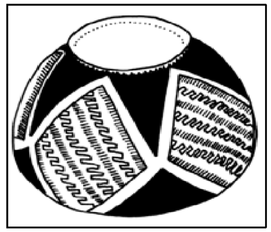
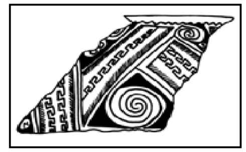
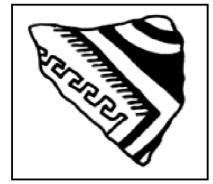
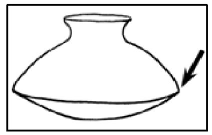
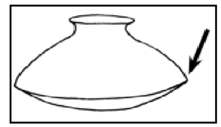
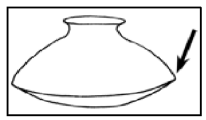
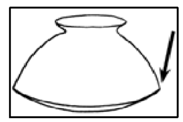
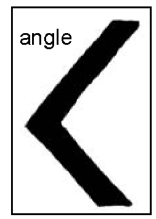
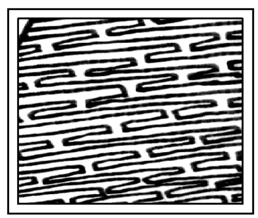
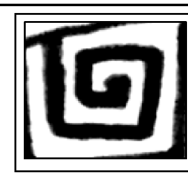
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
25	Multiple Dots	SN-LGB		Haury 1937:Plates CLXXVIIIh, m, n, s, t, c1-e1, CLXXXIIc, d
26	Trailing Lines	ESN-MSAC1		Haury 1937:Plates CLXb, c, CLXXIIIa1, b1 Compare to codes 5, 24, 175, 345, 347
28	Linebird (pendant dash motif)	EGB-SC		Haury 1937:Plates CLXIc, CLXXVIIIh; Haury 1976:Figure 12.95u; Wallace 2001b:Figure I.8g
29	Incising, discontinuous (Does not apply to cases of patterned incising)	LSN-LGB		Haury 1937:Plate CLXXVd, e, f, i, j; 1976:Figure 12.38a' See incising comparisons Compare to codes 1, 15, 157, 290, 295, 302
32	Snaketown-style design AND hachure framing lines thicker than hachure lines	LSN		Wallace 2001b:Figure I.4b

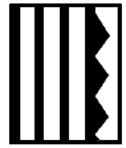
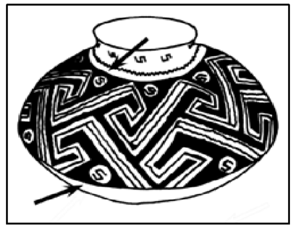
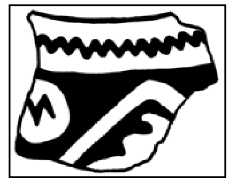
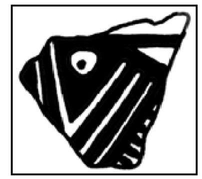
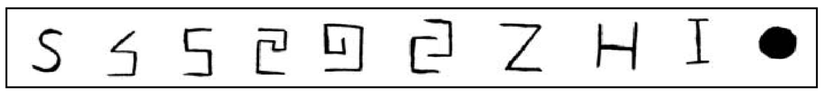
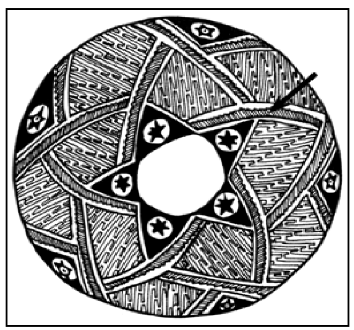
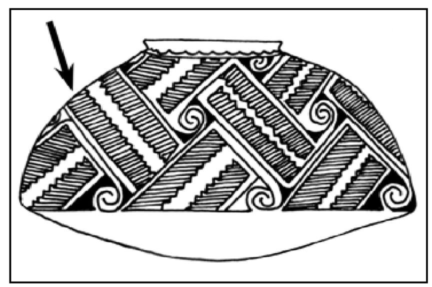
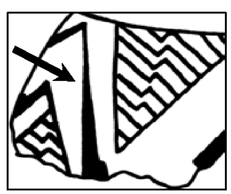
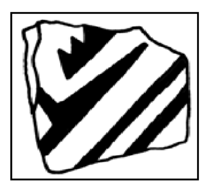
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
34	Filler-space Hachure (Does not refer to large secondary spaces in sectored designs)	LSN-SC, trace thereafter	 a b c	Haury 1937:Plate CLXXVIe, r-t; Haury 1976:Figure 12.37i; Wallace 2001b:Figure I.9m See hachure comparisons
35	Motif Serration (not Snaketown Style)	LSN-SC	 a b c	Haury 1937:Plates CLVIIg, CLXXVIb, d, f-l, p, u, CLXXVIIa-d, f, g; Wallace 2001b:Figures I.8a-d, I.13d, g, l Compare to codes 36 and 81
36	Long Scroll Serration (not hatched)	LSN-SC	 a b	Haury 1937:Plate CLXXVIb, f-h, k, l; Haury 1976:Figure 12.29f; Wallace 2001b:Figures I.6c, I.8a, c, d Compare to codes 96, 203, 333 Compare to codes 35 and 81
37	Flying Bird, Negative (not Snaketown Style)	LSN-ESAC	 a b c	Haury 1976:Figure 12.96a-j, h-s Compare codes 21 and 53
41	Design Ticking	EGB-LGB	 a b c	Haury 1937:Plates CLXXVIo, CLXXVIIIu, v, y
51	Slanted Railroad Tie Hachure	LGB-SC	 a b	Haury 1937:Plate CLXXf; Haury 1976:Figure 12.32c See hachure comparisons

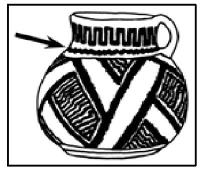
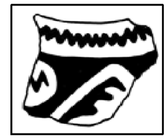
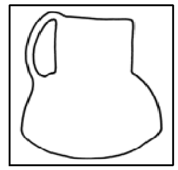
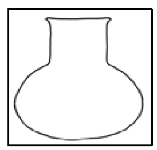
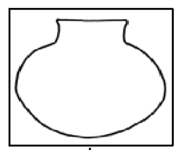
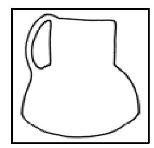
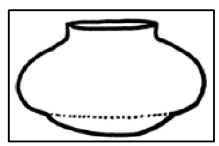
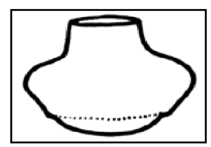
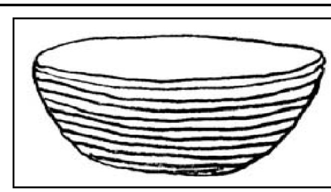
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
52	Organizational Banding Layout	LGB-ESAC	 a b c d	Haury 1937:Plates CLVc, d, g, h, CLXIc-h, CLXIXe-g, l-n; Wallace 2001b:Figures I.13c, I.16a; Wasley and Johnson 1965:Figure 57d Compare to code 260
53	Flying Bird, Positive	EGB-ESAC	 a b c d	Haury 1937:Plates CLXXIIIa, CLVd-f; Haury 1976:Figures 12.95a-j, h-s, 12.97; Wallace 2001b:Figures I.9g-j, I.11e-h, I.26f Compare to codes 21 and 37
54	Life forms, except birds and lizards (because some bird and lizard forms occur pre-LGB, they are excluded)	LGB-MSAC1, rare post-MSAC1	 a b c	Haury 1976:232-241
55	Quail	LGB-MSAC1	 a b c	Haury 1976:Figures 12.68, 12.73; Wallace 2001b:Figure I.14a
56	Free-Floating Fringe	LGB-LSAC³	 a	Haury 1937:Plates CLVc, d, g, h, CLXIc-h, CLXIXe, j, k, m, u; Haury 1976:Figure 12.32a, q; Wallace 2001b:Figures I.13c, I.16a, i, I.24a See fringe comparisons
57	Single-Capped Fringe (straight)	EGB-LSAC³	 b	Haury 1937:Plates CXLIVf-h, CXLVa, h, i; Wallace 2001b:Figures I.27a, e, I.30d, I.32b, I.33b, c, I.35d See fringe comparisons

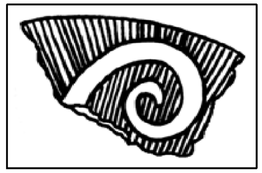
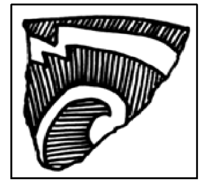
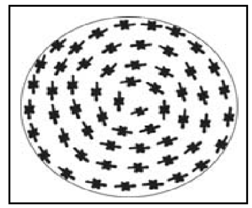
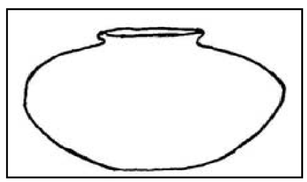
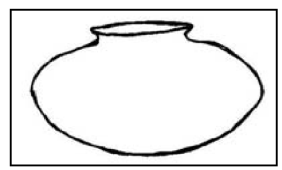
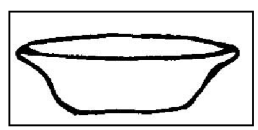
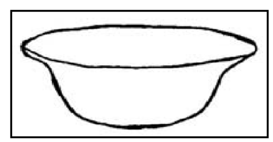
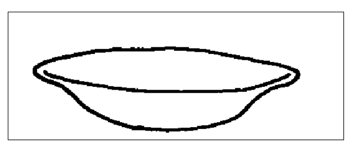
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
58	Large solid (>5cm²)	EGB, ESAC-LSAC	 a  b  c	Wallace 2001b: Figures I.29j, I.31a, I.36b Compare to code 350
59	Indeterminate free-floating or single-capped fringe	EGB-LSAC	no illustration	Haury 1976: Figure 12.69d, 12.78a, 12.82c, d, g See fringe comparisons
62	Cuneiform Hatch	SC	 a  b  c	Haury 1937:Plate CLVIIa; Haury 1976:Figure 12.32g, r, s; Wallace 2001b:Figure I.16k See hachure comparisons
74	Diamond Panel Layout (floating diamond layout)	MSAC1	 a  b	Haury 1937:plate CXLIXg-i; Wallace 2001b:Figures I.28b, I.36b; Wasley and Johnson 1965:Figure 56a, b See panel comparisons
75	Double-Capped Fringe (straight or wavy), in Sectioned Layout	ESAC-LSAC	 a  b  c	Amsden 1936:Figure 3; Haury 1937:Plates CXLIIIb, CXLIVa, b; Lascaux 1993:Figure 6.6; Wallace 2001b:Figure I.37a See fringe comparisons

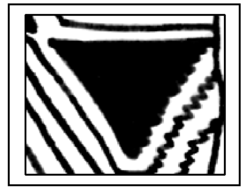
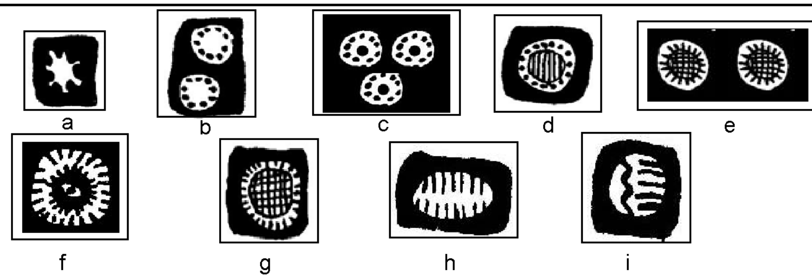
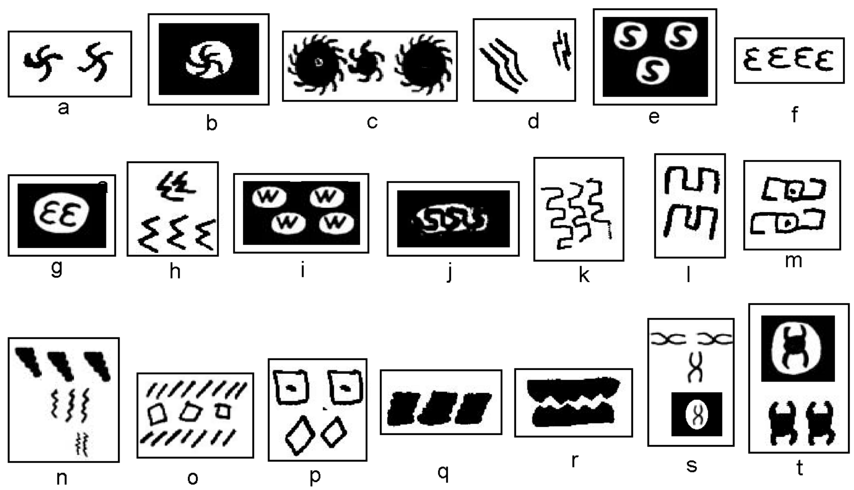
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
76	Everted Jar Rim	ESAC-LSAC	 a b	Haury 1937:Plates CXLb-d, CXLIa, c, e, f, CXLIIc-f, CXLIVd, e, g, h
77	Gila Shoulder	ESAC-LSAC, rare SOHO	 a b	Haury 1937:Plates CXL, CXLI, CXLII, CXLIV; Wallace 2001b:Figures I.29j, I.32h, I.36d, f Compare to codes 92, 93, 348
78	Panel with a Centerline Motif	ESAC-MSAC1	 a b c	Haury 1937:Plate CXLIVg; Haury 1976:Figure 12.18b; Wallace 2001b:Figures I.30d, I.33c, I.35d See panel comparisons
80	Wavy-capped Fringe (single- or double-capped)	MSAC1-LSAC	 a b	Haury 1937:Plates CXLIIIb, CXLIVa, b See fringe comparisons
81	Panel with a Serrated Margin	ESAC-SOHO	 a b c	Haury 1937:Plates CXLIVc, CXLVi; Haury 1976:Figure 11.9d, e; Wallace 2001b:Figure I.32a Compare to codes 35 and 36 See panel comparisons

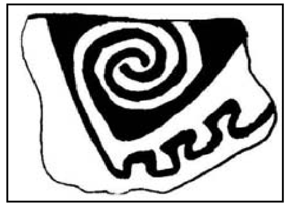
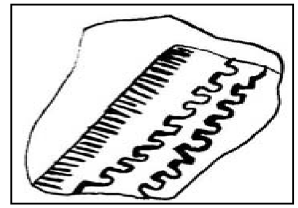
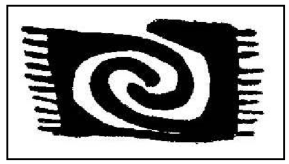
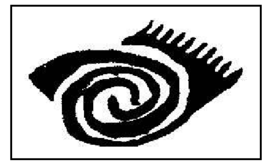
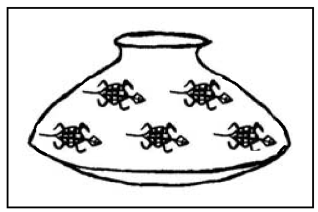
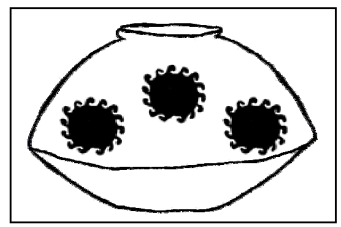
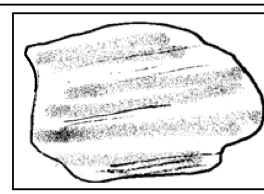
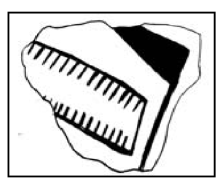
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
91	Crenulated Line as centerline motif in a Panel (Appears uncommon in MSAC2)	MSAC1-MSAC2	 a  b  c	Lascaux 1993:Figure 6.4; Wallace 2001b:Figure I.35d; Wasley and Johnson 1965:Figure 56a Compare to code 200
92	Gila Shoulder ≤120 Degrees	MSAC1-MSAC2	 a  b	Haury 1937:Plates CXLIb, CXLIVb Compare to codes 72, 93, and 348
93	Gila Shoulder, Knife-edged	MSAC1-LSAC	 a  b  c	Haury 1937:Plates CXLIb, CXLIVa-c Compare to codes 72, 92, 348
95	Outline Line and Stagger	LSAC	 a	Haury 1937:Plates CXLIId, CXLIIIb
96	Rectilinear Scroll	MSAC1-SOHO	 a  b	Haury 1937:Plate CXLIVb, d; Wallace 2001b:Figure I.37f; Wasley and Johnson 1965:Figure 64 Compare to codes 36, 203, 333

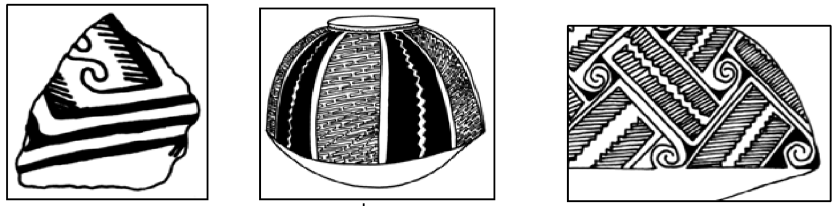
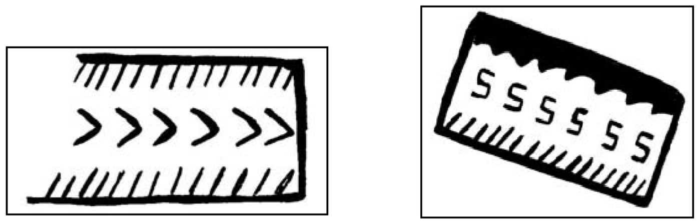
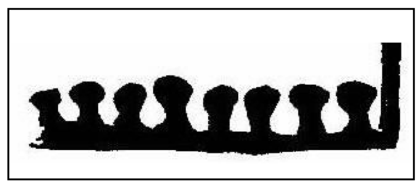
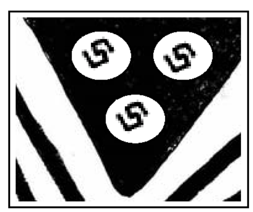
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
101	Lines Motif	MSAC2-SOHO, rare MSAC1	 a	Haury 1945:Figure 31c
102	Solid Void Motif (must have one of Wallace's specific geometric motifs)	MSAC2-SOHO	 a  b  c Must have one of these geometric elements to be temporally diagnostic to the MSAC2-CG (Wallace 2004:Figure 3.21) 	Haury 1945:Figure 32c, d; Wallace 2001b:Figures I.37e, f, I.38d, I.42d; Wasley and Johnson 1965:Figure 56e; Walsh-Anduze 1994:Figure 5.19a
103	Double-Capped Fringe (straight or wavy), as Panel or Panel Border	MSAC2-LSAC, rare in transitional MSAC1/MSAC2	 a  b	Amsden 1936:Figure 3; Lascaux 1993:Figure 6.6 See fringe comparisons See panel comparisons
111	Tapered Lines	LSAC-SOHO	 a  b	Crown 1981:Figure 103c; Wallace 2001b:Figure I.39c

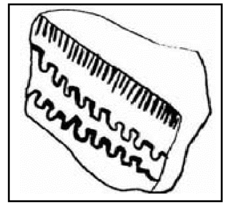
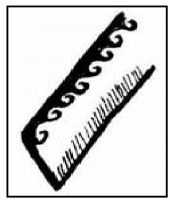
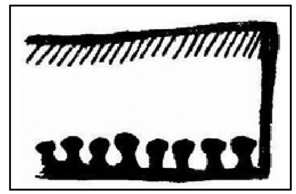
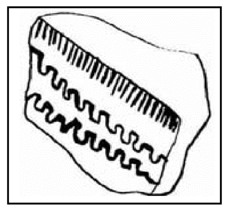
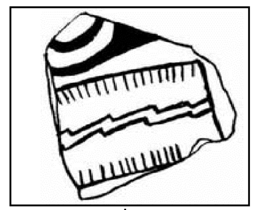
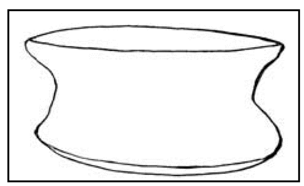
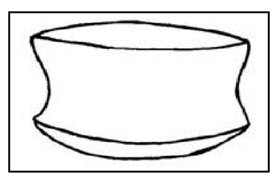
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
112	Upper Freeline, jars only (Do not confuse with upper band envelope line on MSAC1 jars and cauldrons)	LSAC-SOHO, MSAC2-SOHO rare	 a  b	Crown 1981:Figures 100a-c, e, g-i, 103a, c, 105; Wallace 2001b:Figures I.37e, I.40a-f; Walsh-Anduze 1994:Figure 5.23a-k
114	Pitcher	LSAC-SOHO, possibly only SOHO	 a	Haury 1976: Figure 12.11b-d
121	Open Panel (difficult to identify on small sherds)	SOHO	 a	Haury 1945:Figure 34a; Walsh-Anduze 1994:Figure 5.23a, d See panel comparisons
124	Tall Neck (jars and pitchers only)	SOHO	 a  b  c	Doyel 1977:Plate 11a, b; Walsh-Anduze 1994:Figure 5.23d-h
123	Classic (mold inset) Shoulder	SOHO	 a  b	Amsden 1936:Plate 1; Haury 1945:Figure 17c-e
157	Coil-based incising	ES-SW	 a	Haury 1976: Figure 12.51 See incising comparisons Compare to 1, 15, 29, 290, 295, 302

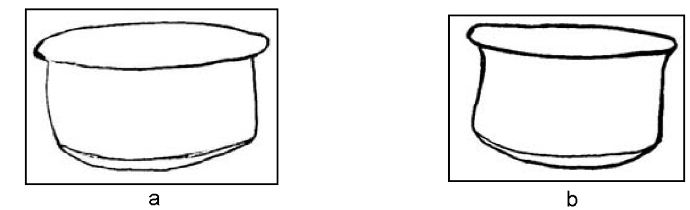
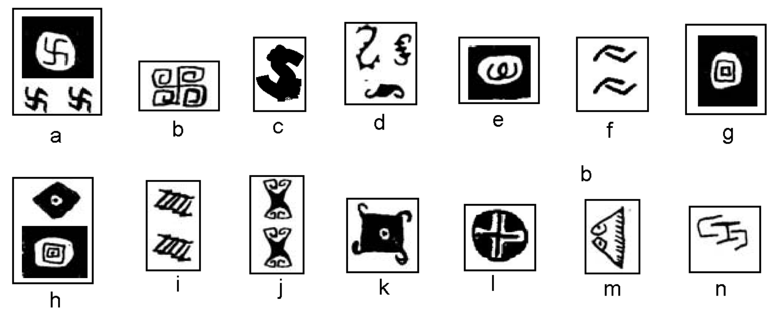
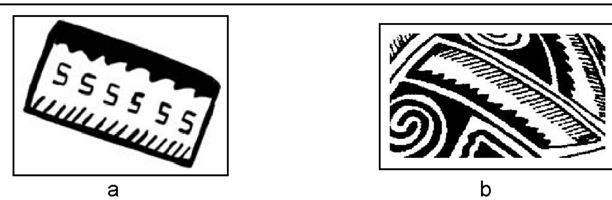
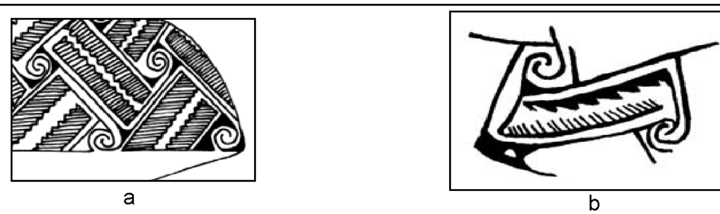
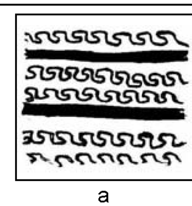
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
165	Hachure-filled design plus thickest line width <2.1mm (Assumes <10% of hachure lines touch)	ESN, rare in SW and LSN	 a  b	Haury 1937: Plate CLXXXIn, p, r
172	All-over layout, spiraling small elements, elements touching or average <2mm apart from one another	LGB	 a	Wallace 2004: Figure 3.6
175	Trailing line, short (<3 cm), more than 3 lines, spacing <4 cm at rim	LGB, rare in EGB	no illustration	Wallace 2004: Figure C.11h Compare to codes 5, 24, 26, 345, 347
179	Compressed globular-body jar with short flared rim (not applicable to miniatures or very small jars)	LGB-SC	 a  b	Haury 1976: Figure 12.30a, b
185	Flare-rimmed bowl	ES-LSAC	 a  b  c	Haury 1976: Figure 12.26a-d, Figure 12.27a, a', b
186	Outcurved or Flare-rimmed bowl, shallow, flat-bottomed	LGB-SC	 a	Haury 1976:Figure 12.34; Wallace 2004: Figure D.4e-f

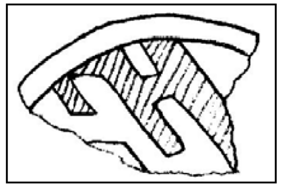
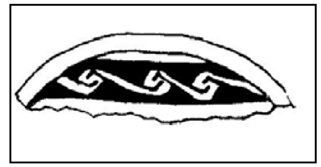
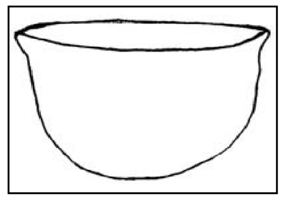
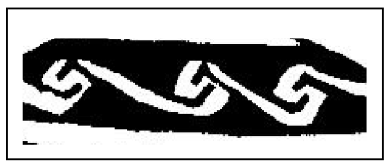
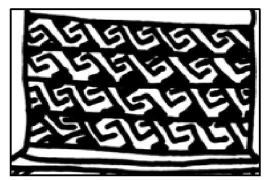
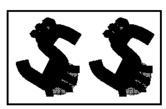
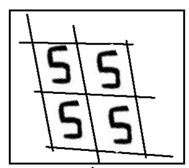
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
188	wavy-edged solid (does not include cases at design field margins)	EGB-LSAC; most abundant in LGB and SC	 a	Wallace 2004: Figures 3.6f, j, 3.14c, C.4b-c,m
190	Small, geometric element group D, nos.: 18, 19, 20, 21, 26, 28, 29, 40, 41 (Date range only applies to primary design field. All elements are sometimes present in secondary design fields.)	LGB-SC		Haury 1976: Figure 12.99 Compare to codes 195, 222, 250, 280, 284
195	Small, element group A, nos.: 30, 34, 35, 58, 63, 70, 71, 72, 73, 80, 81, 83, 84, 85, 86, 95, 96, 99, 103, 113, 114 (Date range only applies to primary design field. All elements are sometimes present in secondary design fields.)	LGB-MSAC1		Haury 1976: Figure 12.99 Compare to codes 190, 222, 250, 280, 284

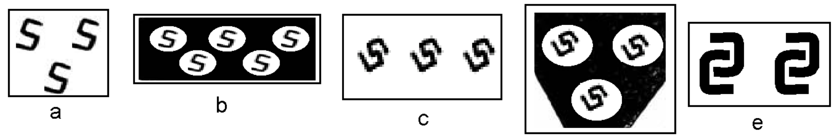
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
200	Crenulated line	LGB-SOHO	 a  b	Wallace 2001b: Figure I.28k, I.31b, g; Haury 1937: Plate CLII, CLIj; Haury 1976: Figure 11.9c, 12.24b, 12.18e; Wasley and Johnson 1965: Figure 56a Compare to code 91
203	Fringed curvilinear scroll	LGB-SOHO	 a  b	Wallace 2001b: Figure I.34a; Haury 1937: Plate CLVId, CLVIId Compare to codes 36, 96, 333
207	Large, repeated life form or geometric element (average max. length > 5cm)	ESAC-MSAC2	 a  b	Haury 1937: Plate CXLIXb, e
209	Wipe-marked jar interior	ESAC-LSAC	 a	Haury 1976: Figure 12.16d Compare to codes 318, 319, 320
217	Line-demarcated panels (> 50% line demarcated)	ESAC-SOHO	 a  b	Wallace 2001b: Figures I.33b, c, I.35c, d, I.36b; Haury 1937:183, Plates CXLIVc, f, g, h CXLVa, h See panel comparisons

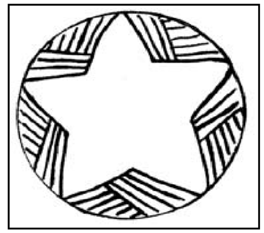
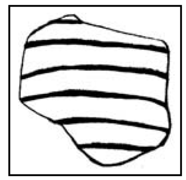
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
220	Jar with sectioned design	ESAC-SOHO	 a b c	Wallace 2001b: Figures I.30f, g, I.32a, b, I.33b, c
222	Small elements used as panel centerline	ESAC-MSAC1	 a b	Haury 1976: Figure 12.18b Compare to codes 190, 195, 250, 280, 284
224	Design element diversity > 4	MSAC1	no illustration	Wallace 2004: Figure D.11f, D.13a Haury 1976, Figure 12.17
227	Zipper motif (May only occur [and may only be diagnostic] as a panel border elaboration)	MSAC1	 a	Haury 1976: Figure 12.18d
230	Two or more voids within single solid with small elements	MSAC1	 a	Wallace 2004: Figure C7

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
233	Panel, at least partly line demarcated, >1 centerline motif	MSAC1	 a	Haury 1937: Plate CXLIVg, CLIIc; Wallace 2004: Figure C.6c See panel comparisons
235	Panel, at least partly line demarcated, zipper curvilinear scroll, or other border elaboration (except fringing, ticking, or sawteeth)	MSAC1	 a  b	Haury 1976: 207, Figure 12.18d, Figure 12.16a See panel comparisons
238	Panel, at least partly line demarcated, multiple duplicate elements used as panel centerline (Most common are wavy or zigzag/job lines, crenulated lines, and free-floating fringes)	MSAC1	 a  b	Haury 1937: Plate CXXXIXe, CXLIVg, CLI (L), CLIIc; 1976:209, Figure 12.23a See panel comparisons
245	Cauldron (concave wall)	MSAC1, possible cases in MSAC2	 a	Haury 1937: Plate CXLIIa, b, CXXXVIIId; Haury 1976 Figure 12.19d
246	Cauldron with Gila shoulder	MSAC1-MSAC2	 a	Haury 1937: Figure 64f, Plate CXLIIa, b

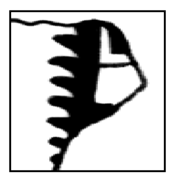
CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
247	Cauldron, vertical wall	MSAC1-MSAC2, possible cases in ESAC		Haury 1937:Plate CXXXVIIId
250	Small, geometric element group E, nos.: 32, 33, 65, 78, 82, 89, 98, 101, 110, 115, 116, 118, 123, 125 (Date range only applies to primary design field. All elements are sometimes present in secondary design fields.)	MSAC1, unknown if also MSAC2 and LSAC		Haury 1976: Figure 12.99 Compare to codes 190, 195, 222, 280, 284
255	Panel, isolated, completely line demarcated (Does not include cases where double-capped fringes are used as panels)	MSAC1-MSAC2		Haury 1976: Figure 12.18b, c, Figure 12.19b, d See panel comparisons
257	Panel, at least partly line demarcated (does not have any parts where panel border elaboration is attached to an adjacent solid)	MSAC1-MSAC2		Haury 1937: Plate CXLVa, h, i; 1976:208, Figure 12.19a, p. 209 See panel comparisons
260	Banded layout, a-b-a or aa-b-aa with b bands composed of a single thick line (width > 5mm)	MSAC1-MSAC2		Haury 1937: Plate CXLb Compare to code 52

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
270	Design field separation from rim, bowl interiors only (may not be applicable to flare-rim bowls and interior-decorated cauldrons)	LSAC	 a  b	Abbott 1994: Figures 6.25 and 6.26
275	Semi-flare-rimmed hemispherical bowl	LSAC	 a	Wallace 2004: Figure B.1
277	Interlocking rectlinear fret	LSAC-SOHO	 a  b	Abbott 1994: Figure 6.26; Haury 1945: Figure 35c; Walsh-Anduze 1994: Figure 5.20
280	Small, geometric element group B, nos.: 65, 66, 87, and any variation thereof (from Haury Figure 12.99) (Date range only applies to primary design field. All elements are sometimes present in secondary design fields.)	ESAC-SOHO	 a  b  c	Haury 1976: Figure 12.99 Compare to codes 190, 195, 222, 250, 284

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
284	Small, geometric element group C, nos.: 64, 67, 68, 69, 90, and minor variations thereof (from Haury Figure 12.99) (Date range only applies to primary design field. All elements are sometimes present in secondary design fields.)	MSAC1-SOHO	 a b c d e	Haury 1976: Figure 12.99 Compare to codes 190, 195, 222, 250, 280
290	Coil-based incising, thickest lines ≥4 mm in width	ES	no illustration	Discussed in Wallace 2004:73-74 See incising comparisons Compare to codes 1, 15, 29, 157, 295, 302
291	Thickest lines ≥4 mm in width, paste gray or brown, surface fire-clouded	ES	no illustration	Discussed in Wallace 2004:73-74
292	Thickest lines ≥6 mm in width, polished	ES	no illustration	Discussed in Wallace 2004:73-74 Compare to codes 293, 310, 311, 312
293	Tool polishing over painted lines (smearing visible)	ES	no illustration	Discussed in Wallace 2004:73-74 Compare to codes 292, 310, 311, 312
294	Red slip or wash on bowl exterior	ES, rare in SW	no illustration	Discussed in Wallace 2004:73-74
295	Coil-based incising with either (1) line width <4 mm OR (2) Snaketown Style Design	SW	no illustration	Discussed in Wallace 2004:76-79 See incising comparisons

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
300	Hachure-sectioning, negative star layout, and hachure line spacing ≥ thickness of hatchure lines	SW	 a	Haury 1976:Figure 12.46b, first and second sherds
302	Incising, imitation of coil-based incising (very deep, regular, and continuous)	SW	 a	Haury 1976: Figure 12.49a See incising comparisons Compare to codes 1, 15, 29, 157, 290, 295
305	Snaketown Style layout, AND thickest line <2.5 mm wide, and polished surface	ESN	no illustration	Discussed in Wallace 2004:79-82
307	Repeated negative life form and Snaketown Style layout	ESN-LSN, rare in EGB	 a	Haury 1937: Plate CLXXXIIk
310	Polish, lustrous	ESN-LSN, rare thereafter	no illustration	Discussed in Wallace 2004:79-82 Compare to codes 292, 293, 311, 312
311	Polish	ES-LSN, trace thereafter	no illustration	Discussed in Wallace 2004:73-82 Compare to codes 292, 293, 310, 312
312	polish and gray paste	ES-LSN	no illustration	Discussed in Wallace 2004:73-82 Compare to codes 292, 293, 310, 311

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
315	Filled-in or partly filled-in Snaketown Style design AND bowl with exterior trailing lines Or no painted exterior design	LSN	no illustration	Discussed in Wallace 2001: 224-226, 2004:79-82
318	Surface coating present AND Snaketown Style design present	LSN	no illustration	Wallace 2001b:Figure I.1c, e Compare to codes 209, 319, 320
319	Surface coating absent AND fire-clouding present	ES-LGB	no illustration	Discussed in Wallace 2001:224-232, 2004:73-83 Compare to codes 209, 318, 320
320	Surface coating absent AND sooted surface present	ES-LGB	no illustration	Discussed in Wallace 2001:224-232, 2004:73-83 Compare to codes 209, 318, 319
321	Surface coating absent AND gray paste	ES-EGB	no illustration	Discussed in Wallace 2001:224-232, 2004:73-83
324	Full-field negative design, not hachure-filled	EGB-LGB	no illustration	Haury 1937: Plate CLXXXa, e, f, i
326	Repeated negative life form, not in a rim solid, not Snaketown Style	EGB-SC	no illustration	Haury 1937: Plate CLXXd, k, Plate CLXXXa, d-f, i
330	Surface coating absent	ES-SC	no illustration	Discussed in Wallace 2001:224-234, 2004:73-86
333	Serrated curvilinear scroll (serrations not straight-line equilateral triangles)	ESN-MSAC1	 a	Wallace 2001b: Figure I.6c, I.8a, c, d, I.11i, j Compare to codes 36, 96, 203
335	Avg. thickest line ≤2.2mm AND either linebird or organizational banding	SC	no illustration	Discussed in Wallace 2001:232-234

CODE	ATTRIBUTE OR SET OF ATTRIBUTES	TEMPORAL RANGE	ILLUSTRATION	REFERENCES
338	Thickest line ≤2.2mm avg. width AND surface coating present	SC-ESAC, SOHO	no illustration	-
340	Organizational banding layout AND full rim line	ESAC	no illustration	Discussed in Wallace 2001:235
342	Large solid (>5cm²) and thickest line <2.5mm avg. width; in combination with other traits that place sherd post-SC	ESAC	no illustration	Discussed in Wallace 2001:234-236
345	Trailing lines present, spaced ≥3cm (or unknown spacing), AND large solid AND thickest line ≥2.5mm avg. width	ESAC	no illustration	Discussed in Wallace 2001:234-236 Compare to codes 5, 24, 26, 175, 347
347	Trailing lines present; number of trailing lines/bowl <6	SC-ESAC, trace in MSAC1	no illustration	- Compare to codes 5, 24, 26, 175, 345
348	Gila shoulder angle ≤110°	Transitional MSAC1/MSAC2-MSAC2	no illustration	Haury 1937: Plate CXXXVIIIh, CXLIVa, b Compare to codes 77, 92, 93
349	Thick serrated line	LSN-EGB and E/M SAC-SOHO	 a	Wallace 2001b: Figures I.9o, I.37a, e-g
350	Large solid and thickest line >3.1mm	ESAC-SOHO	no illustration	- Compare to code 58

[1]Not used by Wallace in Table 3.7 or Figure 3.22 (2004), but is diagnostic in Table 3.6

[2]Not a Wallace (2004) designation

[3]Wallace suggested an MSAC2 ending date for these attributes, but we feel more comfortable with an LSAC ending date in our experience with different assemblages.

ADVANCES IN GROUND-PENETRATING RADAR EXPLORATION IN SOUTHERN ARIZONA

Lawrence B. Conyers

ABSTRACT

Ground-penetrating radar mapping has the potential to discover and map many archaeological features in southern Arizona that are buried in a variety of geological settings. When earthen features are buried in sediment of a different composition, distinct reflections are generated and readily visible in reflection profiles and amplitude slice maps. Walls composed of adobe and buried in material of the same composition are more challenging, but can be identified by areas of no reflection or delineated by the more highly reflective nature of the flanking adobe melt layers. Earth ovens and floors are readily visible in profile and amplitude maps in most burial conditions, as they produce distinct horizontal reflections at the burned surfaces. Irrigation canals and agricultural fields can also be challenging to see with GPR when the canal fill is the same composition as the surrounding sediment. However, when the sediments of the canal channel fill and surrounding matrix are composed of different materials, they are readily visible but can produce "phantom" reflections due to the complex way that radar energy travels in the ground. When archaeological sites are buried by approximately a meter in fluvial sediments that are electrically conductive, no radar energy passes to below that depth and GPR is unsuitable for discovery and mapping. In conditions where burial occurred above active floodplains where aeolian sediments and slope wash is common, energy penetration is greater and cultural features buried up to about 2 m can be readily identified in GPR images. This greater penetration is due to less clay and moisture in the ground, which tends to attenuate radar energy at shallow depths.

The necessity for locating, mapping, and understanding buried cultural materials in southern Arizona has long been appreciated by archaeologists (Sternberg and McGill 1995). Earthen architecture quickly erodes after abandonment, is re-deposited as adobe melt, and is then often covered and obscured by aeolian or alluvial sediment. Cultural features that were constructed in active floodplains can also be quickly buried and preserved, and are largely invisible today on the ground surface. The archaeological community has historically relied on surface surveys to locate these types of sites by locating artifact scatters or by using random shovels tests or backhoe trenches.

These common discovery methods can be statistically inaccurate or destructive, in the case of trenching or shovel testing, or not viable at all if artifacts are buried by sediment and have not been brought to the surface by some post-depositional mechanism. Geophysical surveys can be a potential alternative to discover and then map buried cultural features of many types and their associated stratigraphy. The most commonly employed geophysical methods for the shallow subsurface are magnetics, electrical resistance, and ground-penetrating radar (GPR), all of which have the potential to identify buried cultural materials (Gaffney and Gater 2003; Campana and Piro, eds. 2009). None have been widely used in southern Arizona.

Ground-penetrating radar is the only near-surface geophysical method that produces a data set in three-dimensions and can therefore potentially map many deeply buried or stratigraphically complex archaeological sites in southern Arizona. The use of GPR in southern Arizona was first published by Sternberg and McGill (1995), with examples from Hohokam sites at Marana Mound, Los Morteros and Casa Grande, and the late Archaic period site of Milagro. These results demonstrated the method's usefulness using two-dimensional radar reflection profiles to identify a number of buried features, including floors, ovens, canals, and middens. Preliminary testing of amplitude analysis for mapping in three-dimensions was conducted at the Valencia Viejo site in Tucson (Conyers and Cameron 1998; Conyers and Wallace 2004). The testing demonstrated a new method for areally extensive mapping using GPR in southern Arizona. Recent advances in GPR data processing, including filtering and three-dimensional image production, now allow geophysical

Lawrence B. Conyers / Department of Anthropology, University of Denver / lconyers@du.edu

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 80-91

Figure 1. A GSSI Inc. SIR-3000 system with an attached survey wheel for distance measurement. The 400 MHz antennas are positioned in the fiberglass box. Antennas that transmit radar waves into the ground are connected by a cable to the control box for immediate viewing and digital recording to disk.

archaeologists greater flexibility in their interpretation of radar reflections generated in the ground (Conyers 2004, 2010). As a result of these advances in software and the speed and flexibility of computer and GPR hardware, the GPR method was again tested in southern Arizona on stratigraphically complex and buried sites beginning in 2007.

At Marana Mound, north of Tucson on the lower piedmont of the Tortolita Mountains near the Santa Cruz River, earthen architecture buried by alluvial sand and silt was mapped in two and three-dimensions. University Indian Ruin in east Tucson presents a different burial medium for similar architecture, as it is high above any active fluvial or alluvial depositional center. The burial there was by thin deposits of aeolian sand and extensive erosion and re-deposition of the architectural features themselves. The Las Capas and Rillito Fan sites, both in the prehistorically active floodplain of the Santa Cruz River, provided tests of the method in this depositional environment where agricultural fields and irrigation canals were rapidly covered by fluvial sand and silt. Other sites along the Gila River floodplain near Casa Grande National Monument, where higher amounts of carbonate and salt was precipitated in the fluvial sediments, provided an example of GPR in a more electrically conductive medium, which tended to attenuate energy with depth and create somewhat lesser reflected wave definition.

These sites, while not inclusive, provided tests for many different types of cultural features and geological conditions common in southern Arizona. Variations in the type of equipment changed for each site, and the methods of data processing and interpretation were also modified for specific site conditions. The results of those tests for the discovery and mapping of those features are presented here.

THE GPR METHOD

Ground-penetrating radar is a near-surface geophysical technique that allows archaeologists to discover and map buried archaeological features in ways not possible with traditional field methods. The method consists of measuring the elapsed time between pulses of radar energy that are transmitted from a surface antenna, reflected from buried discontinuities, and then received back at the surface (Conyers 2004). Discontinuities that reflect radar energy can be changes in lithology, contacts between cultural features and surrounding matrix, or water saturation differences due to sediment property differences. When the distribution and amplitudes of those radar wave reflections can be related to certain aspects of archaeological sites, such as the presence of architecture, use areas, or other associated cultural features, high definition three-dimensional maps and images of buried archaeological remains can be produced. Ground-penetrating radar is a geophysical technique that is most effective at buried sites where artifacts and features of interest are located within 2 to 3 m of the surface, but has occasionally been used for more deeply buried deposits (Conyers 2004:49; Conyers 2009).

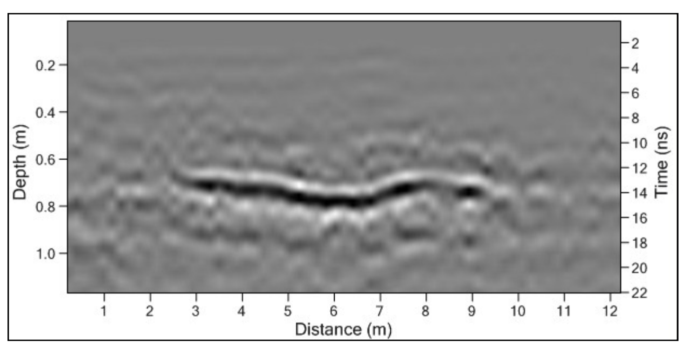


Figure 2. Reflection profile using the 400 MHz antennas at Compound Mound 1, Marana Mound site. A house floor is visible as high amplitude horizontal reflections at Compound 1, Marana Mound site. The floor at 14 nanoseconds (two way radar travel time) correlates to about 65 cm depth at this location.

A growing community of archaeologists has been incorporating GPR as a routine field procedure in many parts of the world (Conyers 2004; Gaffney and Gater 2003) and in a more limited way in southern Arizona (Conyers and Cameron 1998; Conyers and Wallace 2004; Sternberg and McGill 1995). Resulting GPR maps and images can act as primary data that can be used to guide the placement of excavations, define sensitive areas containing cultural remains to avoid, place archaeological sites within a broader environmental context, and study human interaction with, and adaptation to, ancient landscapes (Conyers 2009, 2010; Kvamme 2003).

As radar pulses are transmitted through various materials on their way to the buried target features, their velocity will change, depending on the physical and chemical properties of the material through which they are traveling (Conyers 2004:45). Each abrupt velocity change generates a reflected wave, which travels back to the surface to be recorded. Velocities of radar energy in the ground are important, because only the wave travel times are measured and not their actual depth in the ground. However, if velocity through the ground can be calculated, then distance (or depth in the ground) can be accurately estimated (Conyers 2004:99). Distance estimates can be used to produce useful three-dimensional reflection data to produce accurate images in space.

Most typically in archaeological projects, GPR radar antennas are moved along the ground in transects (Figure 1) and two-dimensional profiles of a large number of reflections at various depths are created. This process produces profiles that are images of subsurface stratigraphy and buried archaeological features along lines (Figure 2). When data are acquired in a closely-spaced series of transects within a grid, and reflections are correlated and processed, an accurate three-dimensional picture of buried features and associated stratigraphy can be constructed (Conyers 2004:148). This can be done visually by analyzing each profile, or with the aid of computer software that can create maps of many thousands of reflection amplitudes from all profiles within a grid that produces maps at various depths.

Ground-penetrating radar surveys allow for a relatively wide aerial coverage in a short period of time, with excellent subsurface resolution of both buried archaeological materials and associated geological stratigraphy. This three-dimensional resolution gives GPR an advantage over other near-surface methods with respect to buried archaeological feature resolution.

Different antenna frequencies are used for varying depth penetration and subsurface resolution (Conyers 2004:39). The higher the frequency waves are, the shallower the depth of energy penetration will be, but the greater the resolution of subsurface features will be also (and vice-versa for lower frequency antennas). In this study the 400 MHz antennas were capable of resolving features of approximately 20-30 cm in dimension and transmit energy to a maximum depth of 2.5 m. The 900 MHz antennas could resolve features approximately 5-10 cm in size, but were only capable of resolving those features to a maximum depth of 80 cm.

While the GPR method has wide applicability in many different sediment and soil types, the best energy penetration and subsurface resolution occurs when the ground is electrically resistive (Conyers 2004:33; Conyers and Connell 2007). In southern Arizona this type of ground is usually aeolian or alluvial sediment that has a low concentration of electrically conductive clay, carbonate, or salt. These environments are usually found above active floodplains, where running water or wind has winnowed out the clay in sediments and salt and carbonate precipitation is lower. Retained moisture in a sediment or soil that contains any of these electrically conductive constituents produces a material with a high cation-exchange capacity, which effectively attenuates radar energy (Conyers and Connell 2007). In even moderately electrically conductive ground, radar energy can be attenuated at a shallow depth regardless of the frequency of the antenna used for transmission (Conyers 2004). Those attenuating environments are mostly confined to floodplain environments in southern Arizona.

DATA PROCESSING AND INTERPRETATION

Raw GPR reflection data are a collection of many individual traces, spaced at varying intervals, along two-dimensional transects within a grid. Each reflection trace from one location on the ground contains a series of stacked waves received from certain depths in the ground that vary in amplitude depending on the amount and intensity of energy reflection that occurred at buried interfaces. When traces are stacked vertically and in sequence, standard two-dimensional profiles are created. These profiles show variations in amplitudes of reflected waves that vary along transects (see Figure 2). They can be viewed much like profiles along vertical faces of excavations. An analysis of the varying amplitudes in space can potentially show subsurface changes in stratigraphy and physical properties of cultural materials within the matrix of sediments and soils. The higher the compositional contrast in buried materials along a buried interface are, the greater the amplitude of the reflected wave generated at that contact. These contrasts are usually sediment grain size and porosity variations, which control the amount of retained water in the various media

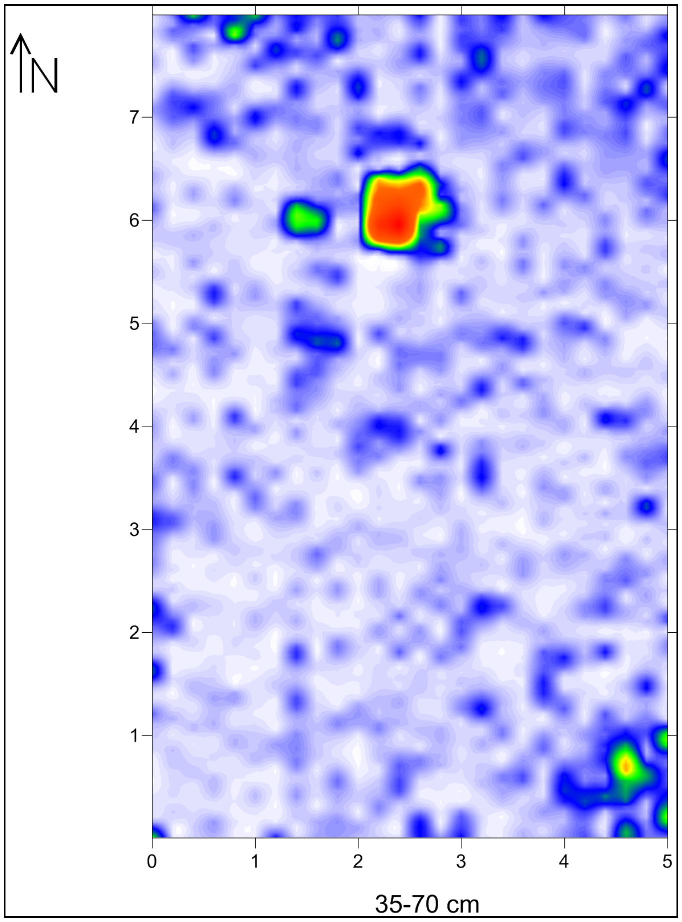


Figure 3. Amplitude slice-map of the base of an earth oven. The image was constructed using 21 parallel reflection profiles collected in this grid. This 5 x 8 m map shows the relative strength of reflections from 35-70 cm in the ground. Dark gray denotes areas of high amplitude and white and lighter gray homogeneous non-reflective ground.

(Conyers 2004:45). When viewed in profile, the higher amplitude reflections are the areas of black and brighter shades of white visible within a gray-scale image, while the areas of little to no reflection are neutral gray in color (see Figure 2). If amplitude changes can be related to important buried features and stratigraphy, the location of higher or lower amplitudes at specific depths can be used to reconstruct the location and nature of subsurface materials in three-dimensions. Areas of low amplitude waves usually indicate homogeneous materials, while those of high amplitude denote areas of high subsurface contrast, such as the contacts of archaeological features and the surrounding matrix.

The spatial location of amplitudes in a three-dimensional volume can help greatly in subsurface interpretation when slice-maps at specific depths in the ground are produced. Maps of this sort are generated by re-sampling all reflection amplitudes in all profiles within a grid and then averaging the amplitudes in slices of a given thickness. Reflection amplitudes are then gridded and interpolated to provide a uniform placement of radar reflection strengths throughout the mapped area (Conyers 2004:148). When viewed in map-form, each slice can portray in plan view the distribution of all reflected wave amplitudes at a desired depth, with slices analogous to maps of arbitrary excavation levels in archaeological excavations (Figure 3). In these maps, low amplitude variations within a slice denote little subsurface reflection and therefore the presence of homogeneous material, while high amplitudes indicate significant subsurface discontinuities, and, in many cases, detect the presence of buried features or very different compositions of sediment layers. Degrees of amplitude variation in each amplitude slice can be assigned arbitrary colors or shades of gray along a nominal scale.

GPR IN SOUTHERN ARIZONA

There are a variety of burial conditions in southern Arizona that cover and preserve cultural remains and that serve as excellent tests for GPR. Alluvial environments, such as along the Santa Cruz, Gila, and Rillito Rivers, often bury materials, sometimes to depths of many meters. At the Rillito Fan (Huckleberry 2009) and Las Capas (Nials 2008) sites, GPR was used to image Early Agricultural period irrigation canals and associated agricultural beds below approximately 1 m or less of silt and sand sedimentary cover. At Marana Mound the Classic period Hohokam features were covered with about 50-100 cm of alluvial silts and sands (Pearthree et al. 1992; Waters and Field 1986). At University Indian Ruin cultural features were covered with minor amounts of aeolian material, with most of the matrix surrounding cultural features consisting of adobe melt from what were once above-ground compacted earthen structures (McKittrick 1988). Each environmental condition required different GPR data collection and processing procedures.

A number of important cultural features were studied with GPR at these sites. Often, buried features that were smaller than approximately 20 cm in dimension were difficult to image with GPR, because they could not be readily differentiated from smaller natural sedimentary layers or rocks. In general, large irrigation canals 1 m in width, agricultural beds, and horizontal floors, when filled with certain types of sediments, were the most visible cultural deposits in both reflection profiles and amplitude slice-maps, because these features of interest differed in composition from the surrounding matrix. Architectural walls composed of the same material as the surrounding ground tended to be much more difficult to identify using GPR, as they are composed of homogeneous earth that is non-

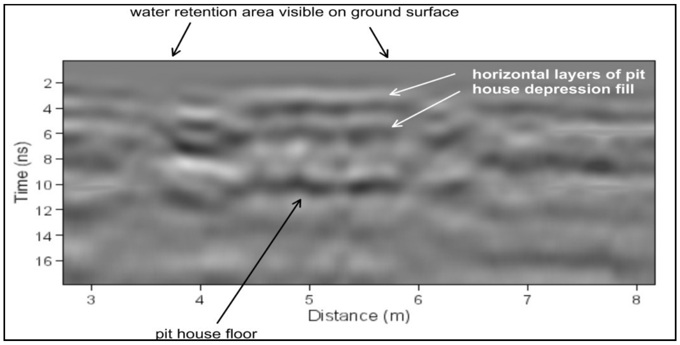


Figure 4. Reflection profile using the 400 MHz along the Gila River floodplain. The profile shows a subtle pit-house floor and overlying fill sediment reflections directly below a noticeable surface depression.

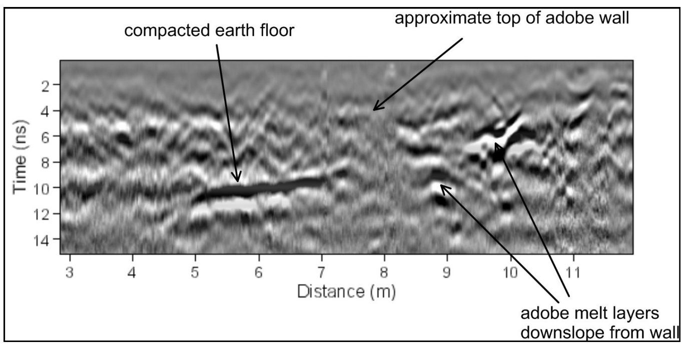


Figure 5. Reflection profile using the 900 MHz antennas of compacted earthen floors at University Indian Ruin. The profile shows compacted earthen floors that produce strong reflections and an associated wall that is non-reflective and therefore almost invisible. This profile is not corrected for topography. The ground slopes to the right of the image, which is why the adobe melt layers are located on that side of the wall.

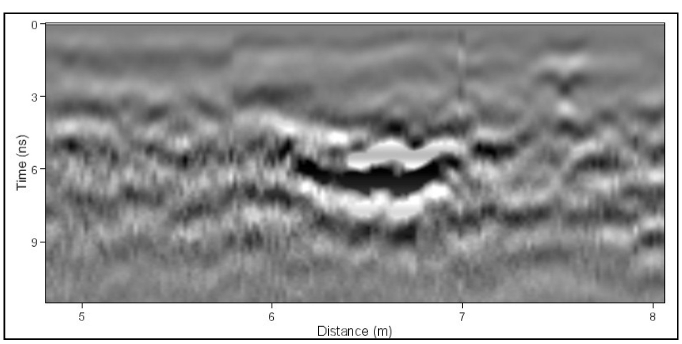


Figure 6. Reflection profile using the 900 MHz antennas across the base of an earth oven at University Indian Ruin.

reflective to radar waves. Earthen features of this sort are often bounded or buried by adobe melt layers consisting of almost the same composition, which produces little in the way of compositional differences that might reflect energy at their interface.

Floors and other horizontal features

Horizontal features, when buried by material that is different in composition, are readily visible in GPR profiles. At Marana Mound, features in Compound 1, Locus 2 (Fish et al. 1992) were covered by sediment deposited on the toe of alluvial fans that drain the Tortolita Mountains to the east. House floors of pit structures and above ground buildings are composed of primarily compacted earth, which is sometimes partially burned. These floors are readily visible as high amplitude horizontal reflections (see Figure 2).

In a flat area on the first terrace above the Gila River floodplain near Coolidge, a number of very subtle depressions, which tend to collect moisture in the winter, are visible on the surface. These features have not been excavated, but the buried floors are still visible in GPR profiles. Directly below the areas of surface water retention, horizontal layers directly below the ground surface are likely layers of sediment that filled pit house depressions (Figure 4). The pit house floor is visible at about 10 nanoseconds (approximately 60 cm depth) below the surface. The radar reflections are much less distinct here than at Marana Mound, because the ground contains much more precipitated salt and carbonate, which tends to attenuate radar energy in the ground. In this area radar waves rarely penetrate deeper than about 1 m because of the electrically conductive precipitates in the burial medium.

Compacted earth floors associated with walls are often visible in profiles, while the walls, composed of similar material, are non-reflective and therefore almost invisible (Figure 5). The floor in Figure 5 is horizontal, but it is somewhat distorted because the profile was collected on a sloping ground surface and not adjusted for topography. The wall, which was later excavated, is non-reflective because it is composed of homogeneous earth that contains no discontinuities that reflect radar waves. The down-slope adobe melt layers to the right of the wall, derived from the wall's erosion after abandonment, are readily visible as high amplitude reflective layers. Adobe melt layers, when they are interbedded with materials of a different composition such as thin layers of wind blown sand, readily reflect radar energy from the bed contacts.

Other horizontal cultural features, such as the bottoms of baking ovens, appear much like house floors in reflection profiles, but are smaller in dimension and tend to be bowl-shaped (Figure 6). The burned portion of the oven covered by natural fill is the interface that produced the high amplitude reflec-

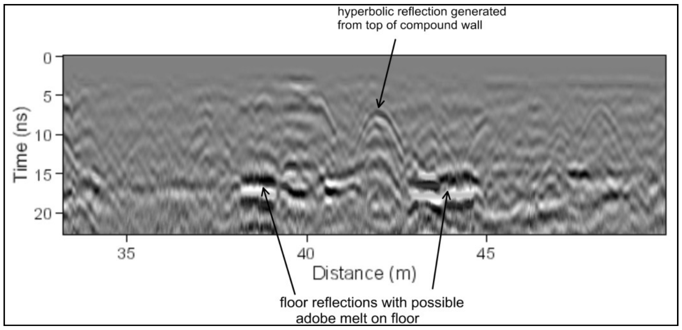


Figure 7. A 400 MHz reflection profile crossing the compound wall at Marana Mound site. The top of which is visible as a distinct hyperbolic reflection. Adjacent to the wall are horizontal reflections generated from floors or other flat cultural surfaces.

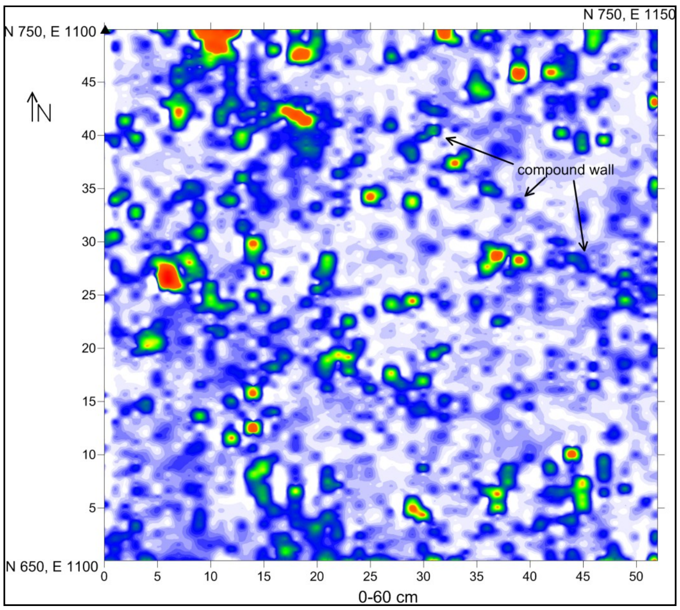


Figure 8. Amplitude map of reflections within the upper 60 cm. The map shows the location of the hyperbolic reflections from a partially eroded compound wall. Dark gray indicates areas of high amplitude reflection, while white and light gray are areas of little or no reflection.

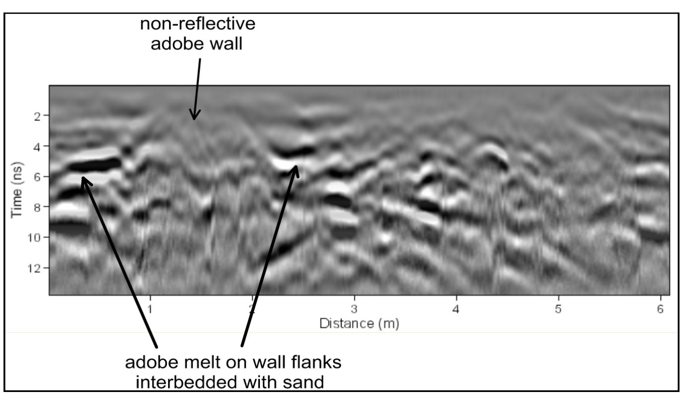


Figure 9. Reflection profile of 400 MHz reflections at University Indian Ruin. The map shows a non-reflective adobe wall bounded by interbedded sand and adobe melt layers that are highly reflective.

tion. While this feature was not excavated, the ground surface around it contains concentrations of ash and fire-cracked rock. Its dimensions, seen in both profile and map view, and its cuspate shape are all indicative of an earth oven, others of which have been excavated nearby. When many profiles in a grid over this oven were processed into amplitude slice-maps, the outline of the base of the oven can be viewed in horizontal map-view (see Figure 3).

Walls

Walls are one of the most challenging cultural features to visualize with GPR profiles and maps in southern Arizona. Many, if not most Hohokam walls tend to be composed of compacted and homogeneous earth that was locally obtained with some additional binding material of sand and gravel. These materials, which were mixed prior to construction, produce an architectural feature that is almost devoid of distinctly different compositional interfaces; therefore, the internal structures of walls have little ability to reflect radar waves traveling through them. In addition, the standing vertical portions of un-eroded walls are mostly oriented parallel to the direction of radar traveling into the ground from the surface antennas, and do not provide a surface from which to reflect energy. Walls therefore are not readily visible in profiles as reflections, but instead are distinguishable as areas of little or no reflection. They can often be identified by studying the placement of materials that were eroded and deposited on either side of them, not the walls themselves. Those adjacent features are usually adobe melt layers or layers of sediment deposited after abandonment.

When the partially intact walls are buried by sediment of a very different composition, their tops produce a distinct hyperbolic-shaped reflection (Figure 7), as the wall tops act as a point-source target (Conyers 2004:54). At Marana Mound, the bounding wall of Compound 1 is visible as a subtle hyperbola, bounded by highly reflective layers that are either floors or layers of adobe melt. When many profiles are processed into amplitude slice-maps, the compound wall that produced distinct point-source hyperbolas in many parallel reflection profiles within a grid can be mapped in distinct slices (Figure 8).

The non-reflective nature of typical Hohokam earthen walls has been observed in GPR data at a number of sites. Only when walls are preserved in special burial conditions, as seen at Marana Mound where they are buried by and in stratigraphic contact with sandy alluvial material, are hyperbolic reflections generated. At University Indian Ruin, very thick earthen walls are bounded by layers of adobe melt, and, while the walls are not visible as distinct reflections, the bounding melt layers, interbedded with aeolian sand,

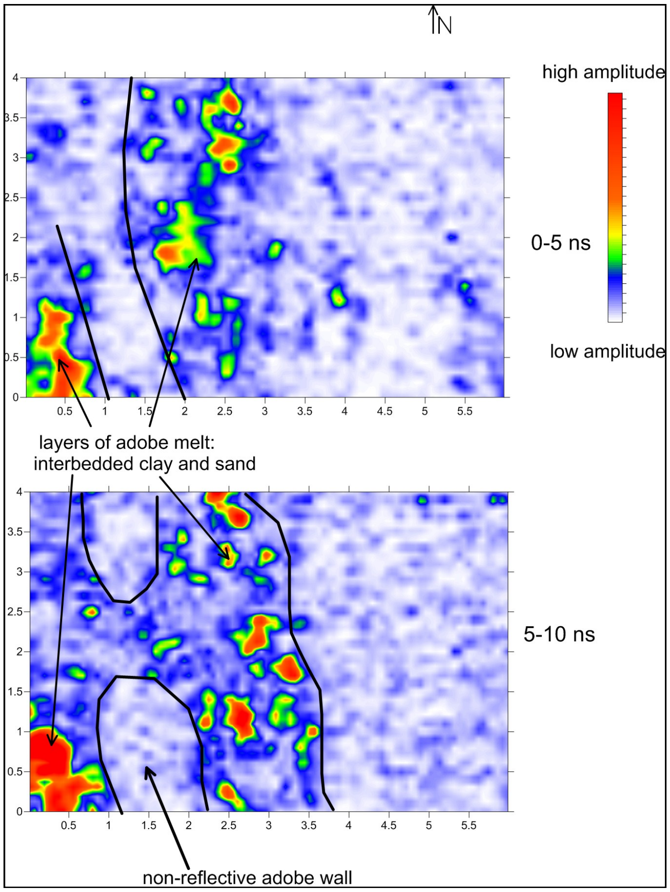


Figure 10. Amplitude maps showing areas of adobe melt that produce high amplitude reflections adjacent to a non-reflective adobe wall at University Indian Ruin.

produce distinct sub-horizontal layers (Figures 5 and 9).

In order to produce a map of the walls where no distinct wall hyperbolas were generated, amplitude slices are created to delineate the non-reflective areas. These non-reflective areas are the walls, and the high reflective areas bounding them are interbedded adobe melt and sand layers on the walls' flanks (Figure 10). In environments such as this, when the burial mechanism is erosion of the architectural features themselves, the addition of minor sediment to the melt layers can produce stratigraphic surfaces that generate high amplitude reflections. The walls produce almost no reflections, but are still visible as areas of no contrast in both profiles and in slice maps.

Canals and Agricultural Beds

Buried cultural features that are composed of sediment and soil that are covered by sediment of roughly the same composition are difficult for the human eye to see, even when exposed. They provide a challenging problem for geophysics in general. However, as GPR has the ability to produce images in three-dimensions, the method can be potentially successful. As a test of the GPR method, reflection data were collected at the Rillito Fan site near the confluence of the Rillito and Santa Cruz Rivers. At this site excavations along a pipeline corridor had discovered a number of Early Agricultural canal systems that transported water from the Rillito south and then west to the Santa Cruz floodplain, where agricultural fields were located (Huckleberry 2009). The tops of the canals were visible in backhoe trenches approximately 1.5 m below the present day ground surface. Excavations had removed between 80 and 100 cm of the overburden prior to the collection of the GPR data. The overburden sediment in this area is Rillito Creek alluvium, which consists of arkosic mineralogy and abundant muscovite grains. This clay-rich sediment is somewhat electrically conductive and little radar energy penetrated below 1.2 m. This high electrical conductivity precluded GPR testing of these features without the removal of some of the overburden sediment.

Two distinct canals at Rillito Fan are preserved just upstream from the confluence of the Rillito Creek and Santa Cruz River where this test was conducted. The canals had been filled with sandy sediment during floods, and portions had been constantly renovated, cleaned out, and re-constructed during their use life. The GPR reflection profiles that crossed the canals at right angles showed the edges of the canals as only faint reflections. The bulk of the sediment that filled the canals and the adjoining floodplain is composed of almost the same material; thus, there was little compositional discontinuity from which to reflect radar energy. The faint reflections that were produced from the canal edges were probably generated at boundaries that placed somewhat finer grained sediment or a thin clay drape next to the sand and silt through which the canal was excavated. Also, the edges of the canals slope at an angle such that radar energy that encounters them is reflected away from the surface antenna and not recorded. For this reason, only minimal reflection was recorded from canal edges. However, a very distinct series of reflections was produced at the very bottom of the canal, which generated what appears as stacked point-sources hyperbolas. This occurred where the base of the canals contain coarser sand fill, which directly lies on finer-grained floodplain deposits. The sediment discontinuity is therefore dramatic in these conditions, and the contact produced high amplitude reflections. Reflections at this interface were enhanced where the base of the canal is shaped like a bowl, which tends to focus radar. The energy recorded from this interface was high in amplitude.

The hyperbolic geometry of the reflections from the base of the channel is also distinctive. It is the product of the method with which radar energy is transmitted from the surface antenna and reflected from interfaces in complex ways. Radar waves propagate outward from antennas in a cone and spread with depth (Conyers 2004:62). The antennas recorded energy that reflected from the farthest edge of the canal prior to the surface antenna passing over it (Figure 11). That energy traveled to and from the antenna at an angle but was recorded as if the arrivals occurred from directly below the antenna's location. This phenomena produced a series of "phantom" reflections in the shape of a hyperbola as the antenna moved toward the canal and then away from it. Energy reflected from the canal's other side was recorded in the same way as the antennas passed away from the buried feature. Also, the canal's farthest edge dipped toward the surface antenna and therefore reflected much of the radar energy. The energy reflected from the interface traveled directly back to the surface antenna and produced the very high amplitude reflections visible in Figure 12.

When multiple canals are superimposed and interbedded with floodplain deposits, GPR reflection profiles can produce complex pictures of the stratigraphy. At the Rillito Fan site, in the adjacent floodplain, Channel III is associated with a clay layer that is interpreted as the ancient agricultural field or floodplain sediments (Figure 13). The clay layer produces a very distinct reflection, while its associated channel is visible but less distinct. The overlying Channel II, of a later age, is incised almost to the depth of the older floodplain layer and is readily visible in the GPR profile.

Similar canals were studied at the Las Capas site, along the eastern margin of the Santa Cruz River near the mouth of the Cañada del Oro. At this site the canals were indistinct in GPR profiles, because they were filled with almost the same sediment as the bounding floodplain material that they were incised into (Figure

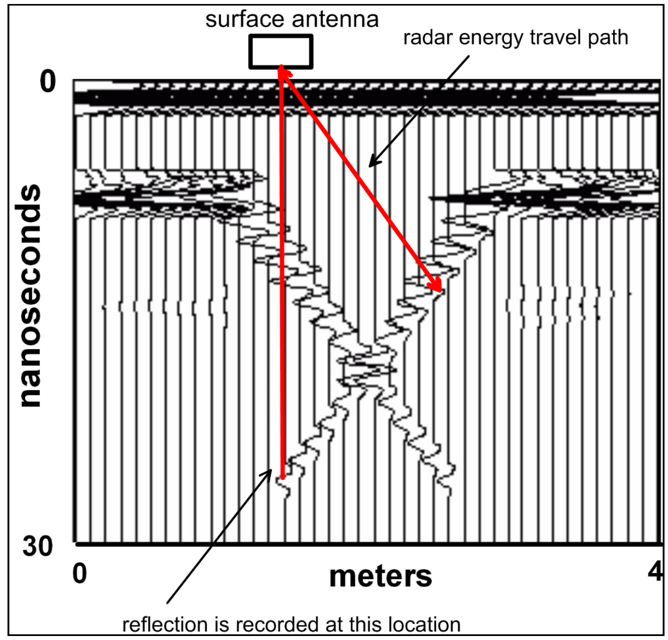


Figure 12. Model of a canal's reflections as an antenna is moved across it at a right angle. The actual edge of the canal is recorded directly below the antenna. In addition, "phantom" reflection hyperbola appear directly below the base of the canal. As energy is transmitted from the surface antenna in a cone, the farthest edge of the canal generates a reflection, which is recorded as if it were directly below the antenna.

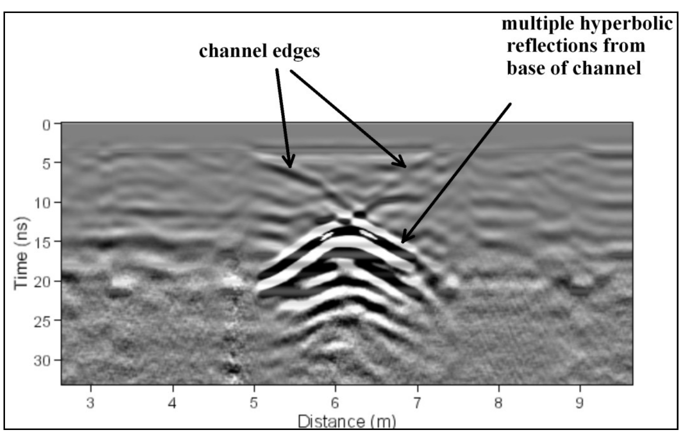


Figure 11. GPR reflection profile using 400 MHz energy crossing an Early Agricultural period irrigation canal at right angles at the Rillito Fan site. The channel edges are barely visible. However, distinct multiple point source hyperbolas were generated at the base of the canal where the bowl-shaped geometry of the bed boundary reflected almost all radar energy back to the surface.

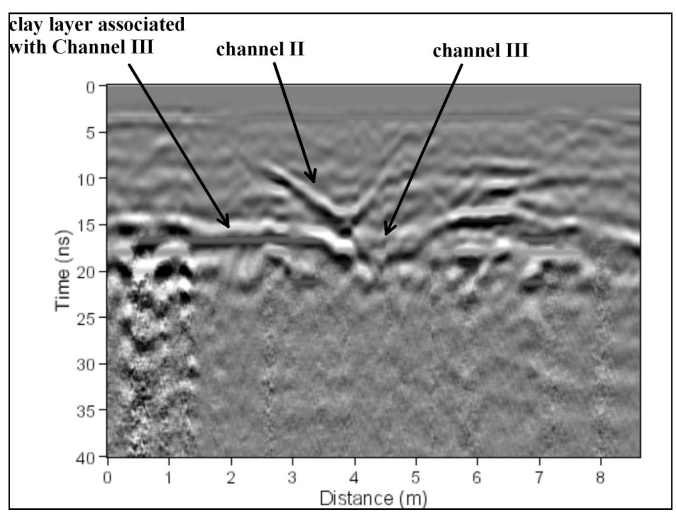


Figure 13. GPR reflection profile using the 400 MHz antennas at the Rillito Fan site. The profile shows two superimposed canals and an associated floodplain clay layer.

14). These canals were also wider with broader bases, and therefore did not focus radar energy like the narrower channels at Rillito Fan. While they are still visible, only low amplitude reflections were recorded.

Amplitude slice maps of irrigation canals constructed with many tightly spaced profiles collected in a grid can produce potentially misleading images of the channels and associated floodplain deposits. These horizontal amplitude maps that cross canals produce images of the differences in sediment types at bed boundaries. Therefore, they map the differences in sediment types that filled the canals, and not the canals themselves. In addition, the edges of the canals can often produce only very low amplitude reflections. It is usually only the sediment that is preserved in the bottoms of the canals that generates high amplitude reflections. The greatest lithologic change occurs at the base of the canals where the sand fill contrasts with the surrounding silt and clay. This contrast produces an interface that reflects radar energy. An amplitude slice map crossing two canals at Rillito Fan demonstrates this concept (Figure 15). At this site high amplitude reflections are generated only in places where sand was preserved in the channel. Associated clay and silt on the margins of the canal also produce high amplitude reflections. Portions of the channel, however, are totally invisible in the slice map, as the sediment that filled these features was the same composition as the surrounding material. Therefore, no distinct bed boundaries were present to reflect radar energy. A third channel at Rillito Fan was discovered with GPR and was originally interpreted as a previously unknown canal. Only after excavation was it found to be a natural channel produced during a prehistoric flood episode that eroded the irrigation canals (Huckleberry 2009). It was impossible to differentiate natural and constructed canals using GPR.

Early Agricultural period planting beds, which were extensively mapped at the Las Capas site, are challenging features for GPR, as they are very subtle and difficult to see even when exposed to view. As a test of GPR, a grid of reflection data was collected in an area that was scheduled for exposure by areally extensive excavations (Nials 2010). Using the 900 MHz antennas for higher resolution but shallower energy penetration, reflection data were acquired and an amplitude map was produced in the layer containing the agricultural beds at a depth of 20 cm. This map clearly shows changes in the soil layer due to creation of small catchment basins used for holding water. The square and rectangular beds are visible on GPR maps as amplitude features. These GPR readings may reflect prehistoric agricultural activities on the floodplain that involved the mixing of buried sandy sediments with surficial fine-grained sediments (Figure 16). These units would not be visible with GPR at this location without extensive removal of attenuating sediment prior to data collection.

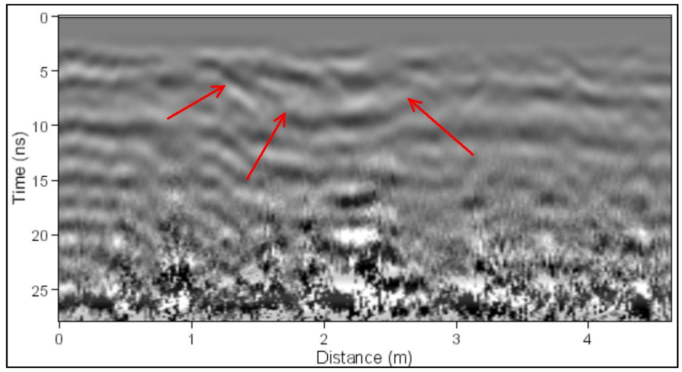


Figure 14. GPR reflection profile using 400 MHz energy crossing an Early Agricultural period irrigation canal at the Las Capas site. Reflections from this feature are much less distinct because the sediment that filled the canal is the same composition as the surrounding matrix. The similar composition produces only weak reflections. The channel is also wider at the base, which does not create a focusing boundary at its base to transmit radar energy back to the surface antenna.

CONCLUSIONS

A number of important archaeological features common in southern Arizona were successfully imaged using GPR technology. Horizontal floors of compacted earth or clay were the most readily visible in reflection profiles as distinct high amplitude reflections. When amplitude slice maps over large areas are constructed in layers that contain these floor reflections, the aerial extent of floor features can be mapped. Plaza surfaces and other intramural work areas, while not studied as part of this project, would likely be just as visible. In a similar way, earth ovens, which are smaller in extent, also produce high amplitude reflections visible in profile and horizontal amplitude maps. When these features are buried in sediment that contains salt or electrically conductive clay, which are common in desert environments, radar energy is attenuated during transmission and the features are less distinct or completely invisible if buried deeply enough. These sediments produce a medium that is not conducive to radar energy penetration, and all transmitted energy is attenuated close to the surface. In the Santa Cruz River floodplain, any features buried more than one meter in sediment are invisible due to this type of energy attenuation. The Gila River sediment appears to be even more electrically conductive due to greater amounts of carbonate and salt, and radar attenuation occurs at even shallower depths. With 400 MHz antennas, features located above the floodplain that are not covered by

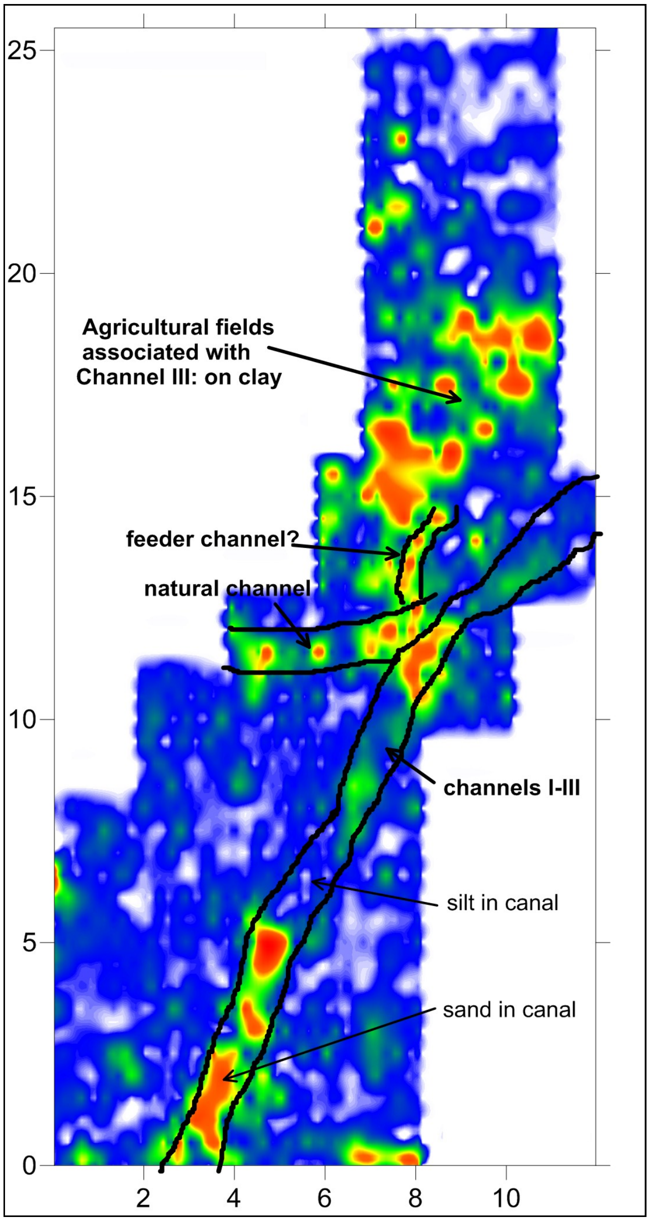


Figure 15. Amplitude slice map of a series of canals and associated agricultural beds at the Rillito Fan site. The map was produced from the 400 MHz reflection profiles. The channel margins that are visible in profile are drawn in black ,while the shades of gray are denote the strength of reflections. In the southern portion of the canal and a few other areas, sand fills the channel. This fill produces distinct reflections which are light gray. Elsewhere, the canal fill is the same composition as the surrounding sediment; therefore, only very weak or no reflections are produced (identified as white). These areas of the canals are indistinguishable from the surrounding floodplain sediment. A natural channel, produced during a flood, is also visible in a portion of the mapped area. The area north of the channels, originally interpreted as a feeder canal and agricultural fields, was mechanically stripped. No evidence of those features was found. The highly reflective areas were likely produced from interbedded floodplain sediments.

this attenuating fluvial sediment may be mapped with GPR to depths up to 2 m.

Standing walls constructed of earth produce few radar reflections and appear as areas of no reflection in profiles and amplitude slice maps. These walls were constructed of homogeneous clay and binding agents, and therefore produce a medium that is non-reflective and also attenuating to radar energy. Because these walls have usually been eroded over time and are bounded and buried by adobe melt and interbeds of sediment, radar reflections from these proximal units are distinct. The location of some walls can therefore be mapped by analyzing the layers that bound walls, which are those that produce the high amplitude reflections.

Agricultural canals and planting beds, which are buried in floodplain sediments, are potentially visible in GPR reflection profiles if they are not buried below the depth of radar energy attenuation. If buried below 1 m in the Santa Cruz and Gila River Valleys, overlying

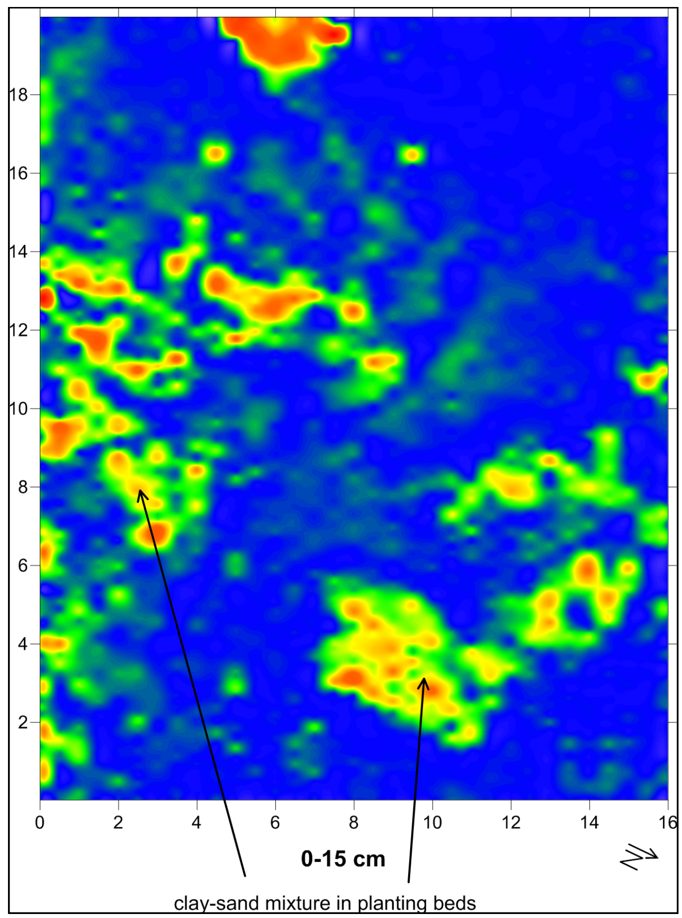


Figure 16. GPR amplitude map of planting beds at the Las Capas site. The map is composed of profiles collected with the 900 MHz antennas. The rectangular units contain an amalgamation of soil constituents within the small catchment basins, which are visible as high amplitude features.

sediment must be removed before GPR data collection. When sufficient energy is available for reflection from canals, they are readily visible in profile. Complex reflections can be produced from the channels as the sides of canals are often poor reflection surfaces; the sides slope away from the surface antennas and therefore scatter energy away from the surface. However, reflection will occur from the canal edges that are in front and behind the surface antennas when profiles are collected perpendicular to the canal orientations. This produces phantom reflections that appear in profiles below the actual location of the canals. These reflections can be confusing unless the nature of radar reflections in the ground is understood and taken into consideration. In addition, bases of some canals can often produce very high amplitude reflections if they are bowl-shaped and contain sediment fill that is compositionally different than the surrounding sediment. These surfaces are highly reflective and focus radar energy; they allow very high amplitude reflections to be transmitted back to the surface antennas and recorded. Subtle agricultural fields are also visible, such as the rectangular "waffle beds" at the Las Capas site. In all cases, soil and sediment distributions in canals and agricultural beds are highly variable and can potentially produce confusing amplitude slice maps. For instance, if canals are filled by both sandy and finer-grained sediment along their reaches, the amplitude maps will produce linear high amplitude features only when sand is bounded by silt and clay layers. When the canal fill is similar to the surrounding sediment, the amplitude maps will display areas of no reflection, because there is not enough variability in sediment to produce reflections.

Depending on the depth of burial, composition of the archaeological features, the surrounding burial material, and the geometry of these features, GPR can be of great value in discovering and mapping cultural resources in southern Arizona. While the method cannot be applied to all areas of interest, with considered and knowledgeable collection, processing, and interpretation, GPR has a wide range of applications in the area. A knowledge of not only the nature of buried archaeological features is important, but also the associated soil and sediment layers and their composition and chemistry. Software is now available that can readily be used to produce processed and filtered reflection profiles and amplitude slice maps to construct useful images of the subsurface.

Acknowledgements. Many thanks to Desert Archaeology, Northland Research and University of Arizona School of Anthropology, Gary Huckleberry and Paul and Suzanne Fish, Dave Ross, and Paul Swader for assistance in data collection. Many thanks to Gary Huckleberry for his comments, edits and suggestions, which improved this paper greatly.

REFERENCES CITED

Campana, Stefano, and Salvatore Piro (editors)
2009 *Seeing the Unseen-Geophysics and Landscape Archaeology.* CRC Press/Balkema: Taylor and Francis Group, London.

Conyers, Lawrence B.
2004 *Ground-penetrating Radar for Archaeology.* Altamira Press, Walnut Creek, California.
2009 Ground-penetrating Radar for Landscape Archaeology. In *Seeing the Unseen-Geophysics and Landscape Archaeology*, edited by Stefano Campana and Salvatore Piro, pp. 245-256, CRC Press/Balkema: Taylor and Francis Group, London.
2010 Ground-penetrating Radar for Anthropological Research. *Antiquity* 84:175-184.

Conyers, Lawrence B., and Henry D. Wallace
2004 Ground-penetrating Radar Techniques and Three-Dimensional Computer Mapping at the Valencia Site. In *Archaeological Excavations at Valencia Vieja*. Technical Report No. 2001-11, pp. 135-143, Desert Archaeology, Tucson, Arizona.

Conyers, Lawrence B., and Catherine M. Cameron
1998 Finding Buried Archaeological Features in the American Southwest: New Ground-penetrating Radar Techniques and Three-Dimensional Computer Mapping. *Journal of Field Archaeology* 25(4):417-430.

Conyers, Lawrence B., and Samuel Connell
2007 The Applicability of Using Ground-penetrating Radar to Discover and Map Buried Archaeological Sites in Hawaii. *Hawaiian Archaeology* 11:62-77.

Fish, Suzanne, Paul R. Fish, and John H. Madsen
1992 *The Marana Community in the Hohokam World.* Anthropological Papers of the University of Arizona, Number 56. University of Arizona Press, Tucson.

Gaffney, Chris, and John Gater
2003 *Revealing the Buried Past: Geophysics for Archaeologists.* Tempus, Stroud, Gloucestershire.

Huckleberry, Gary
2009 Prehistoric Canals within the Pima County Interconnect Project Corridor, Pima County, Arizona. Report submitted to Northland Research, Inc., Marana, Arizona.

Kvamme, Kenneth L.
2003 Geophysical Surveys as Landscape Archaeology. *American Antiquity* 63(3):435-457.

Pearthree, P. A., K. A. Dempsey, J. Onken, K. R. Vincent, and P. K. House
1992 Geomorphic Assessment of Flood-Prone Areas on the Southern Piedmont of the Tortolita Mountains, Pima County, Arizona. Arizona Geological Survey Open-File Report 91-11, Tucson.

McKittrick, M.
1988 Surficial Geologic Maps of the Tucson Metropolitan Area. Arizona Geological Survey Open-File Report 88-18, Tucson.

Nials, Fred

2010 Archaic Planting Beds at the Las Capas Site. Report submitted to Desert Archaeology, Tucson, Arizona.

2008 Geomorphology and Stratigraphy. In *Las Capas: Early Irrigation and Sedentism in a Southwestern Floodplain,* edited by J. Mabry, pp. 35-54. Anthropological Paper No. 28. Center for Desert Archaeology, Tucson, Arizona.

Sternberg, Ben K., and James W. McGill

1995 Archaeology Studies in Southern Arizona using Ground Penetrating Radar. *Journal of Applied Geophysics* 33:209-225.

Waters, Michael, and John J. Field

1986 Geomorphic Analysis of Hohokam Settlement Patterns on Alluvial Fans along the Western Flank of the Tortolita Mountains, Arizona. *Geoarchaeology: An International Journal* 1:329-345.

REDISCOVERING MIDVALE'S PLATFORM MOUND AT LAS CANOPAS

Erik Steinbach

ABSTRACT

In 1931 Frank Midvale excavated two test pits in a large, well-preserved mound within the boundary of the Hohokam village site of Las Canopas in South Phoenix. Six years later, he returned to the site to discover that the mound had been leveled. Even though the mound itself is gone, knowledge of its location in relation to extant archaeological features preserved below the plow zone can contribute important data towards understanding economic, social, political and ideological dynamics at a major Hohokam Classic Period village site. However, the location of the platform mound remains unknown. In an attempt to relocate Midvale's mound, I review his field records and compare them to historic aerial photographs maintained by the Flood Control District of Maricopa County. I use a set of exceptionally high-quality aerial photographs taken in 1930, the year before Midvale's test excavation, to place Midvale's notes and sketch on the 1930s South Phoenix landscape. The photographic evidence confirms that a large, well preserved mound did exist at Las Canopas. Geographical Information Systems maps help to determine its exact location.

In the early 1930s, Frank Midvale recorded the presence of a large mound at the site of Las Canopas in south Phoenix. The mound is often called "Martin's Ruin", "Martin's Compound", or "Martin's Mound" after the owner of the property, Tom Martin; it has also been referred to as "Cottonwood Ruin." Sometime after 1935, though, Midvale reported that the same mound had been "plowed down". At present, there is only scattered information on the precise location of Martin's Mound.

The mound itself no longer exists. However, excavations within the Las Canopas site boundary have revealed hundreds of subsurface features preserved below the modern plow zone (Czarzasty and Rice, eds. 2009; Dobschuetz 2007, 2009; Hackbarth 1997a). The interpretation of these features is greatly influenced by their spatial relationship to the platform mound. Platform mounds served as a focal point of Hohokam ceremonialism during the Classic Period and were also the locus of activities such as feasting, craft production and food storage (Bostwick and Downum 1994).

HISTORIC DATA USED TO RELOCATE THE PLATFORM MOUND AT LAS CANOPAS

In this paper, I use geo-spatial techniques and tools to identify the position of the platform mound at Las Canopas based on two data sets. The first set of data comes from Frank Midvale's observations. Although Midvale's notes are brief, especially in comparison to modern excavation documentation, they provide a wealth of detail that can aid in locating the footprint of the mound. The second data set consists of historic aerial photographs of the feature and its immediate surroundings; the photographs can provide accurate visualizations of the landmarks described in Midvale's notes. I use the field notes in conjunction with geo-referenced aerial photographs that date to the 1930s (i.e., the time frame during which Midvale saw the mound) to locate the position of "Martin's Mound."

Frank Midvale's Sketch Map of Las Canopas and Notes on Martin's Mound

Frank Midvale made many contributions to Hohokam archaeology, including excavations at the site of La Ciudad in the 1920s. During the 1930s Midvale worked as a park ranger at South Mountain Park and would drive by the site of Las Canopas on his way to work. In his spare time, Frank Midvale also recorded the location of, write brief descriptions of, and often take photographs of Hohokam sites that were in the process of being destroyed by the expansion of agriculture that took place during the 1930s and 40s in the

Erik Steinbach / Rio Salado Archaeology LLC, Tempe, AZ / erik@riosaladoarchaeology.com

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 92-100

Phoenix Basin. Frank Midvale's correspondence, manuscripts, notes, photographs and maps are archived in two separate collections: in the Arizona Collection at the Hayden Library on the Arizona State University main campus in Tempe; and in the Archaeology Collections of the Arizona Museum of Natural History in Mesa. His notes for Las Canopas are recorded in a notebook entitled "Data Book III" archived at the Hayden Library.

Hackbarth (1997a) provided an excellent general archival review of the archaeological work completed at Las Canopas over the decades. In his synthetic overview of the site, he reproduced Midvale's sketch map of Las Canopas and Martin's Mound, his notes on the mound, and captions for two photographs. Foremost, I present two versions of Midvale's sketch map of Las Canopas, as originally published by Hackbarth (1997a:27, 1997b:3) (Figure 1a and 1b). The map clearly shows the compound and platform mound on the 1930's landscape with historic landmarks.

In addition to the map, I reproduce Midvale's notes in Data Book III on Las Canopas in their entirety (Midvale n.d.). The detail contained in these descriptions is critical to my spatial analysis of Las Canopas. Midvale describes the Las Canopas mound as follows:

> When I first saw this compound mound about 1929 it was undisturbed and in good condition. This was probably due to its location back in remote farmlands along a canal bank road which made it hard to reach. The unreclaimed half acre also contained small marginal parts of 2 trash mounds. The large mound was then called Martin's Ruin, after the owner. In 1931 I visited the site with Richard K. Meyer, an anthropology student. We got permission from Mr. Martin to dig 2 test pits to learn what type of mound it was. These were dug with 2 helpers near the south or higher part of the mound. In each test several floor levels were found and portions of rammed-earth walls 14" wide, the deepest floor level was 5 ½ ft below the surface. One test showed considerable ash and charcoal and many burned and broken stone tools. Mr. Martin gave his collection of stone axes, grinding tools and pottery and stone artifacts (about 80 specimens) to Richard Meyer. These were taken to Peoria, Illinois. The low and sloping nature of this mound and its location near a modern canal and large trees nearby as well as high cotton stubble in the field surrounding it made it difficult to photograph. In 1935 while working as a guide at the east end of South Mountain Park under C.M. Holbert, I tried an early A.M. photo but it proved too shady. Two years later I returned with James Simmons to retake the shot and found the ruin leveled and nothing left to photograph. In 1949 I found the old San Francisco canal empty and abandoned, the land fenced in and the canal road destroyed. This area in now lost and the land completely reclaimed.

Finally, captions on two photographs in Midvale's notes provide additional information on the size and location of the mound. The caption for Photograph 1 gives the dimensions of the mound:

> The only photo of Martin's compound. This was taken too soon after sunrise in December 1935, on my way to work at South Mountain. Flat top mound is 120 ft long; 70 ft wide and slopes

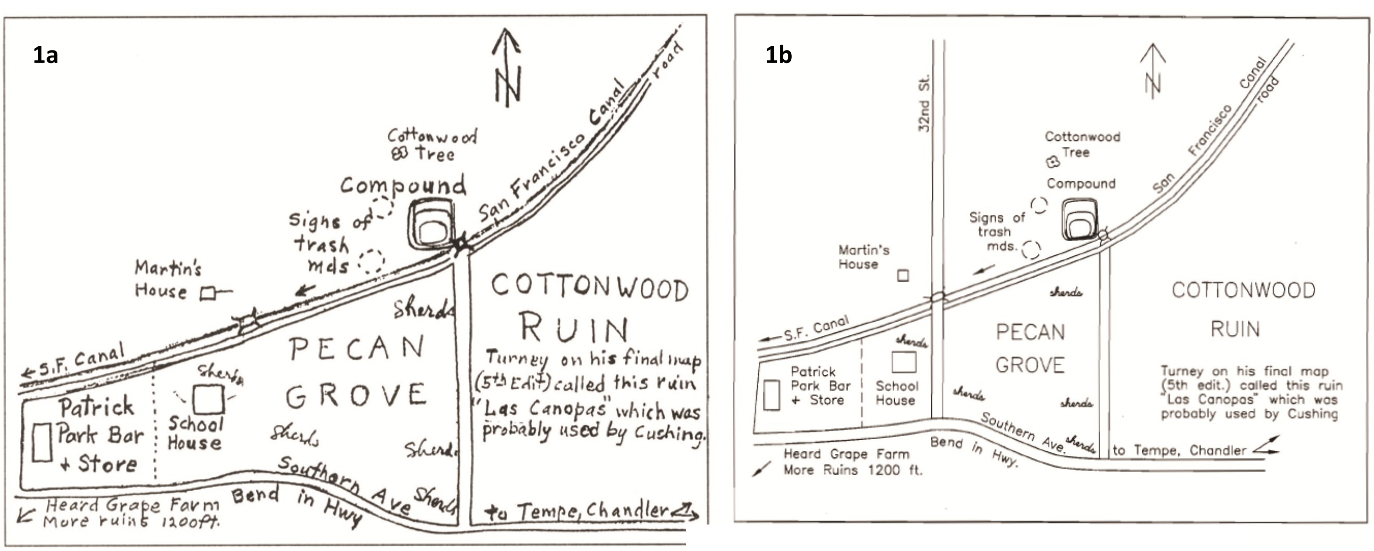


Figure 1a and 1b. Frank Midvale's sketch map of the "Compound" at Las Canopas (Hackbarth 1997b) on the left, and an edited version of Midvale's sketch map as published in Hackbarth (1997a: Figure 3.7) on the right.

> down south-to-north 7 ft to about 3 ½ at north. The long mound survived for many years after all of the others had been plowed down.

The caption for Photograph 2 confirms that the mound was destroyed in 1941 and indicates the spatial relationship of the mound to the San Francisco Canal:

> View of the site where earth-walled compound mound was plowed down and leveled in 1941. This was at one time called Martin's Mound after the owner who lived ¼ mile west near Patrick Park Store. It was only part of an extensive village ruin. Trees mark the bank of modern San Francisco Canal which crosses the photo but not in view. Car is parked on a canal bridge. James Simmons stands at right of car. This canal followed closely along prehistoric Canal Cottonwood.

Maricopa County Flood Control District Aerial Photographs

Historic aerial photographs of the Phoenix metropolitan area provide visualizations of the area immediately surrounding Martin's Mound during the time that Midvale was documenting the feature. These aerial photographs make it possible to compare Midvale's notes taken over a time period covering 1931 to 1949 with the actual conditions on the ground during those years.

Aerial photographs of large portions of Phoenix are archived, accessible online, and available for purchase at the Flood Control District (FCD) of Maricopa County website (http://www.fcd.maricopa.gov/GIS/maps.aspx). The earliest aerials date to 1930; the photographs were taken with excellent resolution and contrast for the time. The next available set of aerials dates to 1937. Compared to the 1930 aerials, these photos were taken at a much lower resolution and have a higher contrast value than the earlier set. However, this collection of aerials highlights areas of dense vegetation by displaying the foliage in a darker shade than surrounding fields. Aerial photographs were also taken in years 1949, 1959, 1969, 1979. These collections contain photos with high-quality resolution and contrast. After 1996, aerial photographs of the area were taken and archived on an annual basis.

I have selected from the Maricopa County FCD several aerial photographs that clearly display the area shown in Midvale's sketch map at different points in time (Figures 2-7). The photos are presented in reverse chronological order: Figure 2 dates to 2009, Figure 3 to 1969, Figure 4 to 1959, Figure 5 to 1949, Figure 6 to 1937, and Figure 7 to 1930. All of the aerial photographs were transformed to the same scale and were cropped to display the same patch of the earth's surface. The geographic information system (GIS) software on the Maricopa County FCD's website calculated the photos' scale as 1:3,441. Each photograph's horizontal axis displays a distance of 1,220 m (4,000 ft) on the ground; each photo's vertical axis covers a distance of 743 m (2,438 ft) on the ground.

On each aerial photograph, I have marked four possible locations, labeled A, B, C, and D, for the position of Martin's Ruin to facilitate discussion of the spatial analysis. The potential locations are outlined with a dashed box that represents the likely footprint of the platform mound. The dimensions of the box, 37 m (120 ft) long from north-to-south and 21 m (70 ft) wide from east-to-west, are based on measurements that Midvale reported in the caption of Photograph 1. I have also labeled recognizable landmarks that appear on Midvale's sketch map. These landmarks are critical to identifying the accurate location of the platform mound from among the four potential positions.

RECONCILING MIDVALE'S SKETCH MAP WITH LANDMARKS IN SOUTH PHOENIX: IDENTIFYING PROBLEMS AND POTENTIAL RESOLUTIONS

The first step in locating the position of Martin's Mound at Las Canopas is to attempt to identify the landmarks on Midvale's sketch map and then to geo-reference them to the modern landscape. At a cursory examination, the landmarks depicted on Midvale's sketch seem rather easy to recognize. The San Francisco Canal and Southern Avenue, which are two easily identified landmarks on the modern landscape, are clearly displayed and labeled. Moreover, when the layout of the sketch is compared to a modern aerial view of the area (compare Figures 1a,b and 2), the sketch appears to depict fairly well the bend in Southern Avenue at the intersection of 32nd Street and Southern Avenue in south Phoenix fairly well.

However, problems arise when geo-referencing the other landmarks to the modern landscape. In particular, it is difficult to identify the unnamed north-south street east of the pecan grove on Midvale's map (see Figure 1a). The start of the "Bend in Hwy", the dog leg in Southern Avenue immediately west of the unnamed street, suggests that the road is 32nd Street. The identification of the street as 32nd is consistent with the arrangement of roadways both in the modern day aerial photograph (see Figure 2) and in the 1930 aerial photo (see Figure 7). However, this determination directly contradicts the reported location of the mound in relation to other recognizable landmarks. If the unnamed road is identified as 32nd street, then the platform mound would be located northwest of the intersection of 32nd Street and the San Francisco

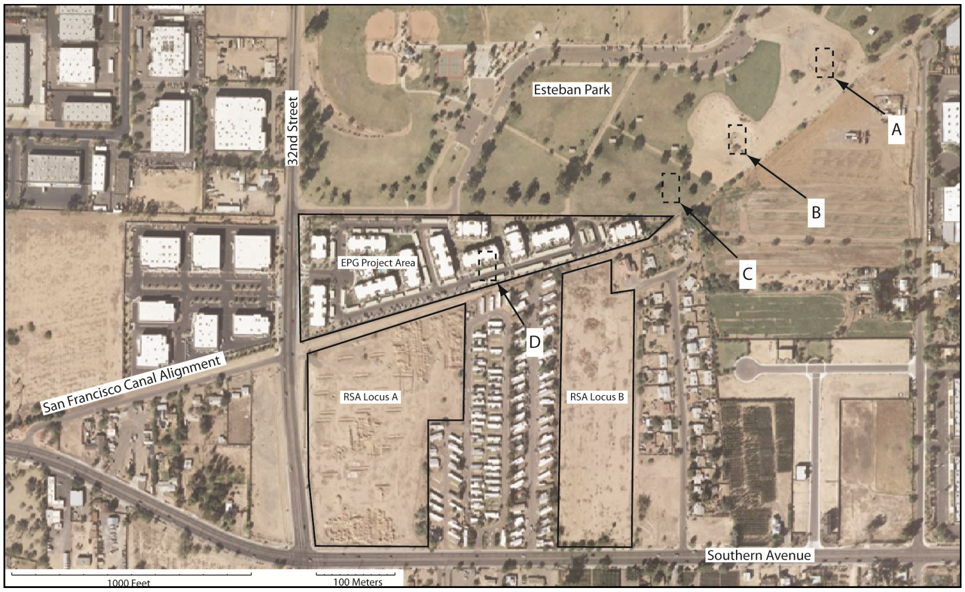


Figure 2. Maricopa County Flood Control District aerial photograph dated 2009.

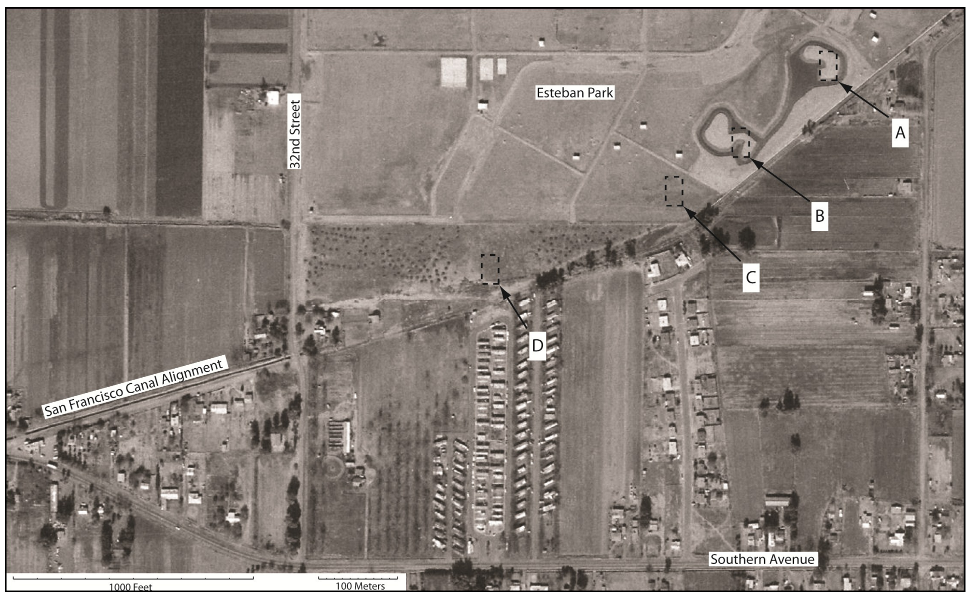


Figure 3. Maricopa County Flood Control District aerial photograph dated 1969.

Figure 4. Maricopa County Flood Control District aerial photograph dated 1959.

Figure 5. Maricopa County Flood Control District aerial photograph dated 1949.

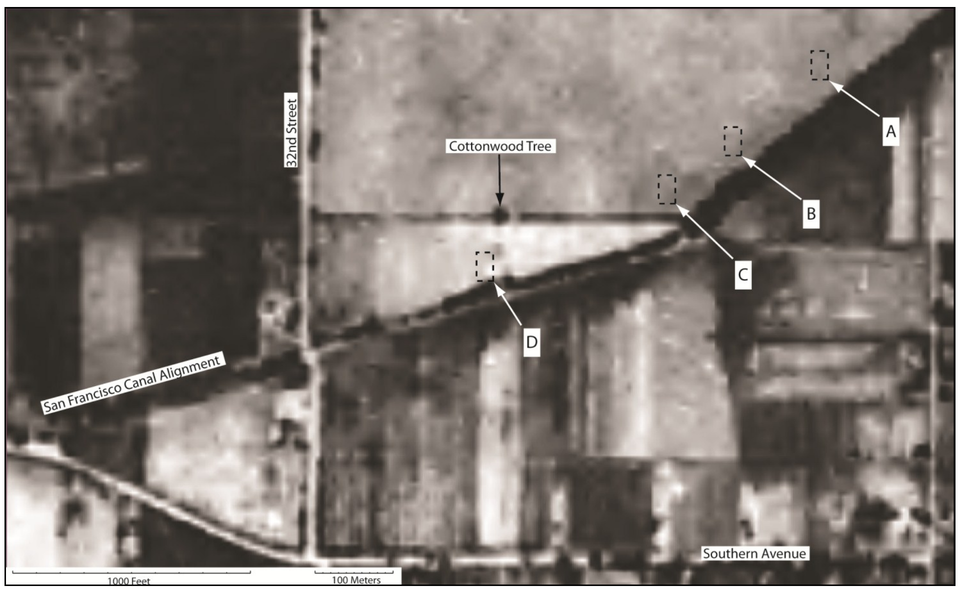


Figure 6. Maricopa County Flood Control District aerial photograph dated 1937.

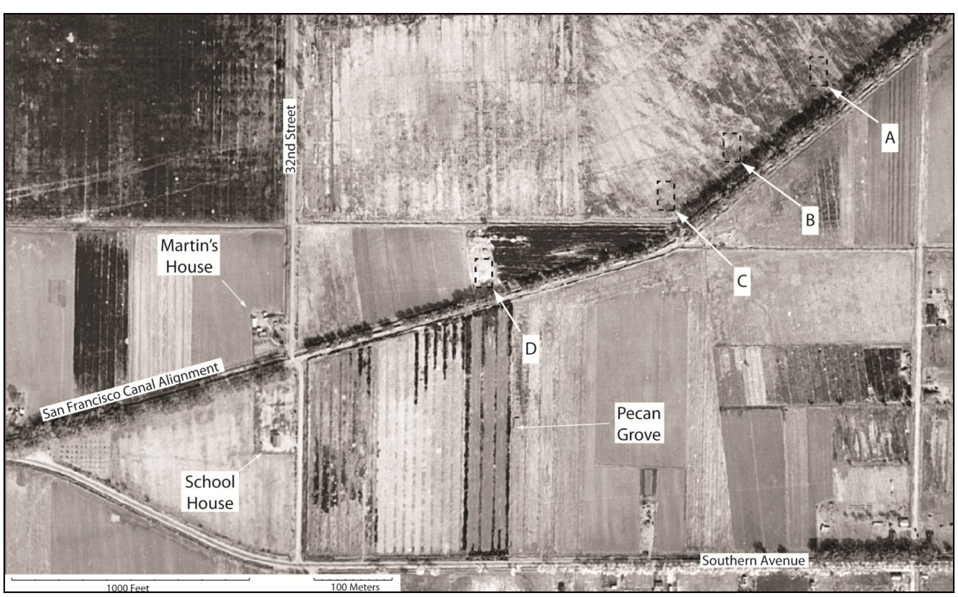


Figure 7. Maricopa County Flood Control District aerial photograph dated 1930.

Canal. This location would place Martin's Mound at the very edge of the known site boundary for Las Canopas and in the middle of a modern residence composed of a cluster of buildings visible in the 1930 aerial (see Figure 7: "Martin's House"). This arrangement does not leave any room for "Martin's house," the "School House," and "Patrick's Park Bar & Store" between 32nd Street and the intersection of the San Francisco Canal and Southern Avenue. It also places the pecan grove on the wrong side of 32nd Street.

Hackbarth recognized the problem with Midvale's sketch. He compensated for this error by adding 32nd Street to the map that he published as Figure 3.7 in *Archaeological and Archival Investigations of Las Canopas: The Esteban Park Project* (Hackbarth 1997a:27) (see Figure 1b). The addition of 32nd Street places Mr. Martin's house in the correct spot, immediately west of 32nd and north of the San Francisco Canal. It also situates the pecan grove in the correct place on the east side of 32nd. However, the addition of 32nd Street to the sketch map puts the bend in Southern Avenue on the wrong side of the street.

Appending 32nd to the map also leaves the unnamed north-south road as an unidentified roadway. One candidate for the unknown road is 36th Street, which appears on the 1930 aerial along the very eastern edge of the image (Figure 7). The position of 36th street in the 1930 aerial does match the arrangement in Midvale's sketch; the street does stop at the San Francisco Canal. A second candidate for the unnamed road is 34th Place. However, this street does not appear in the aerial images until 1969. It is then visible as the T-shaped street in the aerial photographs. A third possibility is that the thoroughfare is a route (possibly a dirt track) that runs from Southern Avenue to the mound along the eastern boundary of the pecan grove. Without a scale or any indication that the sketch was drawn to scale, it is not possible to select the correct choice from among the listed options.

REEVALUATION OF MIDVALE'S NOTES, PHOTOGRAPH CAPTIONS AND SKETCH

Attempts to identify and geo-reference landmarks on Midvale's sketch map illustrate that it is difficult to use the roads marked on the map to locate the Las Canopas platform. Thus, the second step in accurately locating the place of Martin's Mound is to evaluate the details in Midvale's notes and photograph captions. I treat the written descriptions and the remaining information on the sketch map as pieces of a jig-saw puzzle. I attempt to fit the pieces together to construct a spatial arrangement of the landmarks that best matches the arrangement in the 1930s aerial photograph, which is the best available picture of the mound and its vicinity at the time that Midvale documented the mound.

I have re-examined the details of Midvale's description and elements of his sketch map. From this re-examination, I have identified four possible locations for the mound platform. Each of the potential locations is mapped in Figures 2-7; they are labeled A, B, C, and D. I selected each of the possible locations for the platform mound through the careful consideration of several variables: current conditions on the ground, relative spatial orientation to the three candidates for the un-named road described in the previous section, and proposed locations mapped by previous investigators (Hackbarth 1997a:45).

In addition, I have distilled from Midvale's notes a list of spatial criteria that I use to evaluate the accuracy of the four potential positions for Martin's Mound at Las Canopas (positions A, B, C, and D on Figures 2-7). The six criteria, which serve as test expectations for the placement of the mound, are as follows:

1. In 1930, the mound was located within an "un-reclaimed" parcel, one-half acre in size and surrounded by cotton fields.
2. In 1930, the mound was a visible surface feature. In 1937, the mound was plowed under the surface. By 1949, the land was "reclaimed."
3. The mound was 37 m (120 ft) long from north-to-south and 21 m (70 ft) wide from east-to-west.
4. The mound was located immediately north of the San Francisco Canal and obscured by large trees that grew along its bank. It was this growth of trees that hindered Midvale's ability to photograph the entire mound.
5. A single cottonwood tree grew north of the mound.
6. The mound was located across the canal from the northeast corner of a pecan grove.

In constructing these criteria/test expectations, I relied predominantly on Frank Midvale's sketch and notes. In addition, I assumed that his sketch and notes were, overall, an accurate representation of the local landscape. My reliance on the accuracy of Midvale's notes is an attempt to use his first-hand observations to their fullest degree to help identify the location of Martin's Ruin.

Locations A and B

Locations A and B were identified as possible positions of the Las Canopas platform mound for similar reasons. 1) They are in the correct general area, 2) their ground surfaces appear as slightly raised mounds in Esteban Park, and 3) prehistoric artifacts are observable on and around these mounds (author's personal observation).

However, Locations A and B do not match some of Midvale's descriptions. After returning to the site in 1937 to get a better photograph of the compound, Midvale stated that he "found the ruin leveled and nothing left to photograph". At present, though, the ground surface in this area is raised above the surrounding sport fields. The 1969, 1959, and 1949 aerial photographs (Figure 3) may explain this inconsistency. The 1969 image shows two artificially raised and contoured areas, which were likely constructed during the early years of the park, in the exact placement of Location A and Location B. In the 1959 (Figure 4) and 1949 (Figure 5) aerial photographs this parcel was an agricultural field. These images show parallel berms that cross both Locations A and B in order to channel irrigation water evenly throughout the field. The presence of these berms indicates that the parcel's ground surface was level in the 1940's and 1950's when the photographs were taken.

Locations A and B initially remain candidates for the position of Martin's Mound, because both areas in 1949 would have matched Midvale's description of being both level and irrigated. Midvale stated, "In 1949 I found the old San Francisco canal empty and abandoned, the land fenced in and the canal road destroyed. This area is now lost and the land completely reclaimed". I assume that Midvale uses the word "reclaimed" to convey that this parcel of land was reclaimed from nature and put into agricultural production. It may be a simple coincidence that artificial mounds were constructed in the 1960s near the former location of the platform mound.

However, Locations A and B can be firmly eliminated as candidates for the position of Martin's Mound, because the characteristics of these locations do not match many of the other test expectations/criteria for the placement of the mound. Neither location is consistent with criterion 1 in the list of test expectations. The 1930 aerial photograph (Figure 7) of this parcel shows that the land was in use for agricultural production; it was not "un-reclaimed." Moreover, neither Location A nor Location B is consistent with criteria 5 and 6. There is no indication of a lone cottonwood tree north of these locations in 1930, and the pecan grove appears to have been more than 300 m (1000 ft) to the southwest of both locations.

Thus, I conclude that neither Location A nor Location B represents the placement of Martin's Mound.

Location C

Location C is the place that is most often identified as the probable location of Midvale's mound (Hackbarth 1997a:45). It is near a kink in the San Francisco Canal, where the direction of the canal changes from southwest to west-southwest. This location, in the vicinity of the canal bend, matches Midvale's sketch, which also shows a curve in the canal's channel.

However, Location C can be eliminated as a candidate for the placement of the mound because the characteristics of this area do not match the criteria previously outlined (particularly criteria 1, 2, 5, and 6). The 1930 aerial photograph of the area containing Location C indicates that it is not within an un-reclaimed ½ acre parcel. Similar to Locations A and B, Location C was in an area used for agricultural production in 1930. Moreover, the photograph shows no cottonwood tree north of this location. Although Location C is closer to the pecan grove than Location A, it is still more than 240 m (800 ft) away. Thus, I conclude that Location C is not the correct placement of Martin's Mound.

Location D

Location D is the most likely candidate for the placement of the Martin's Mound at Las Canopas. I initially selected this location because it is consistent with criteria 6; it is situated immediately across the San Francisco Canal from the northeast corner of the pecan grove. I eventually determined that Location D matched all of the other outlined criteria as well. Figure 8, which provides a close up view of Location D in the 1930 aerial photograph, demonstrates that the characteristics of Location D are consistent with each of the criteria/test expectations.

1. In 1930, Location D was an un-reclaimed parcel approximately ½ acres in size.
2. In 1930, there could have been a mound on the parcel, but not in 1949. The 1949 aerial (Figure 5) shows a plowed field on that location.
3. Although the resolution of the 1930 image is not high enough to depict a platform mound clearly, it is high enough to indicate that there was sufficient room to fit a 37 m by 21 m (120 ft by 70 ft) mound within the parcel. Moreover, the image appears to show sloped sides of a raised area to the south.
4. The location is situated immediately north of the San Francisco Canal, and is also screened by tall trees that grow along the canal bank.
5. A lone cottonwood tree grows north of the mound. Its shadow can barely be discerned in the 1930 aerial photograph (see Figure 8). However, a dark round shape in the area north of Location D is clearly visible in the 1937 aerial (Figure 6).
6. Location D is across the San Francisco Canal from the northeast corner of a pecan grove.

Location D is the most suitable candidate for the location of Midvale's Martin Ruin. The sketch map that Midvale drew (Figure 1) likely shows an un-named

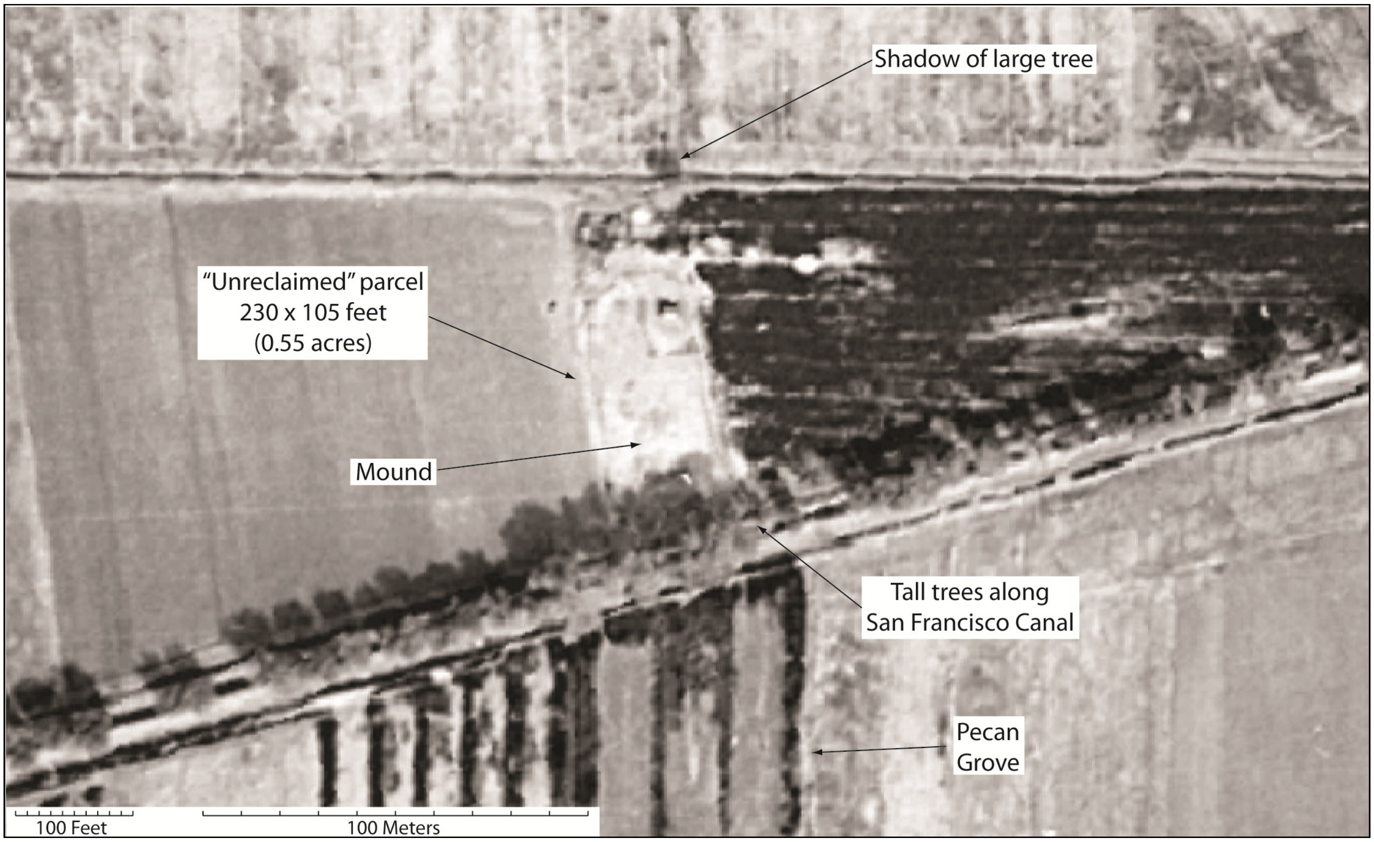


Figure 8. Close up of the 1930 Maricopa County Flood Control District aerial photograph at Location D.

road that served as Midvale's primary access to the mound. He would have exited Southern Avenue onto a dirt road that ran along the eastern boundary of the pecan grove; he would then cross a canal bridge, which he depicted on the map as a circle with four "appendages" southeast of the mound. He described the canal bridge in the caption for Photograph 2. Apparently, Midvale did not regard 32nd Street as an important landmark. He did draw another canal bridge southeast of Martin's house, which presumably was the crossing for 32nd Street (Note that Hackbarth depicted this bridge in his corrected version of the map, see Figure 1). In the end, Midvale's inclusion of a lone cottonwood tree on his map sealed the identification of Location D as the most likely candidate for the mound. No other tree stood by itself north of the San Francisco Canal and east of 32nd Street.

THE LAS CANOPAS PLATFORM MOUND IN CONTEXT

Where is the Las Canopas platform mound located in relation to other known prehistoric cultural features? Figure 2 maps Location D on the most recent aerial image (2009). The figure places this location within the Esteban Park Apartments complex. These apartments were built in 2007 after a data recovery project conducted by Environmental Planning Group (EPG) mitigated the adverse effects of the construction (Dobschuetz 2007, 2009). EPG's work documented over 600 archaeological features and resulted in the repatriation of over 300 human remains. Concurrently, Rio Salado Archaeology LLC conducted a data recovery project on two parcels of land immediately south of the San Francisco Canal, on either side of a mobile home park (Czarzasty and Rice, eds. 2009). Rio Salado's excavations recorded eight residential loci and six cemeteries containing 622 burials (repatriated in 2006).

The layout of platform mound sites and their built environments in the Hohokam core area was patterned. Ballcourts were predominately located to the northeast of platform mounds (Gregory 1987:198). The reported ballcourt at Las Canopas was located near 36th Street and Roeser Road (Hackbarth 1997a:46), approximately 750 m due northeast of Midvale's mound. In addition, enclosing walls typically surrounded platform mound complexes. Platform mounds were generally located either in the west central or north central part of the enclosed compounds (Gregory 1987:194). Mounds were most commonly placed in the west central section of these enclosed spaces; the platform mounds at Pueblo Grande, Mesa Grande, Adamsville, and Casa Grande, among others, were situated in the west central portion of a compound (Gregory 1987:195). At Las Canopas, a compound wall may have encompassed the structures and burials that EPG recorded to the east of Location D. Therefore, these features should be re-evaluated in light of their proximity to the ceremonial center of the Las Canopas community (Bostwick and Downum 1994). The second most common placement of mounds was in the north central section of a walled compound. The platform mounds at Casa Blanca, La Ciudad, and Las Muertos are all located in the north central portion of a walled space. If the platform mound at Las Canopas was located in the north central portion of an enclosing compound wall, then the area immediately south of the mound is within the ceremonial center of the Las Canopas community. Thus, this area should be treated with particular care if development occurs on the property now occupied by the Green Valley Trailer Park (see Figure 2).

CONCLUSION

The 1930's era aerial photographs maintained by the Maricopa County Flood Control District show a platform mound at the site of Las Canopas in the location indicated by Frank Midvale's notes. He excavated two test pits into the mound and recorded multiple floor levels and rammed earth walls. The mound was leveled in 1941. However, knowledge of its location can aid in the interpretation of Hohokam cultural materials excavated by EPG and Rio Salado Archaeology in the surrounding area and inform future excavations conducted in the vicinity of Esteban Park.

Over the last decade, historic aerial photographs have become more readily available to the public through government and corporate websites. Many of these websites incorporate Geographical Information Systems (GIS) in the form of web applications that present the data in geo-referenced format that is easily accessible to a non-expert. Incorporating information from historic maps and aerial photographs will allow researchers to view archaeological sites within a larger cultural landscape. Modern development in the Phoenix metropolitan area has obscured the relationship between features within an archaeological site and the relation of a site to its natural surroundings. The advent of historic geo-spatial data will go a long ways toward revealing this contextual data.

Acknowledgements. I am grateful to the partners at Rio Salado Archaeology for providing me with the opportunity and time to work on this project. I also thank Mr. Don Barkdoll, Mr. Cortland Silver, Mrs. Kim Silver and especially the late Mrs. Helen Smith for their generous support of the RSA excavations at Las Canopas; Todd Bostwick for encouraging me to dig deeper into the Frank Midvale collection; Mark Hackbarth, whose Archaeological and Archival Investigations of Las Canopas provided an example of what can be accomplished with archival material; and Shelly Dudley, the Salt River Project archivist, who was generous with her time in showing me the Salt River Project aerial photograph collection. The 1934 Fairchild aerial photographs are located in the Salt River Project Research Archives in Phoenix, Arizona. Additional resources include the Maricopa Flood Control District website (http://www.fcd.maricopa.gov/GIS/maps.aspx) and the Frank Midvale collections at the Arizona Museum of Natural History and Arizona State University.

REFERENCES CITED

Bostwick, Todd W. and Christian E. Downum
1994 Site Structure and Ceremony at Pueblo Grande. In *Archaeology of the Pueblo Grande Platform Mound and Surrounding Features, Volume 2; Features in the Central Precinct of the Pueblo Grande Community,* edited by Todd W. Bostwick and Christian E. Downum, pp. 297-386. Pueblo Grande Museum Anthropological Papers No. 1, Phoenix, Arizona.

Czarzasty, John L. and Glen E. Rice, editors
2009 *Excavations at Las Canopas: A Hohokam Village in the Phoenix Basin.* Pueblo Grande Museum Anthropological Papers No. 17, Todd W. Bostwick, general editor. Phoenix.

Dobschuetz, Kris
2007 *Report of Remains for the Esteban Park Apartments Testing and Data Recovery Project, Las Canopas, Phoenix, Arizona*. EPG Cultural Resource Research Report No 2006-3.
2009 *Las Canopas: Archaeological Investigations at the Esteban Park Apartments Project, Phoenix, Arizona*. EPG Cultural Resource Research Report No 2009-1.

Gregory, David A.
1987 The Morphology of Platform Mounds and the Structure of Classic Period Hohokam Sites. In *The Hohokam Village: Site Structure and Organization*, edited by David E. Doyel, pp. 183-210. AAAS Publication 87-15. Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science, Glenwood Springs, Colorado.

Hackbarth, Mark R.
1997a *Archaeological and Archival Investigations of Las Canopas: The Esteban Park Project*. Pueblo Grande Museum Anthropological Papers No. 6. City of Phoenix Parks, Recreation and Library Department, Pueblo Grande Museum.
1997b Archaeology Above and Below Ground at Las Canopas. Archaeology in Tucson, *Newsletter of the Center for Desert Archaeology* 11(1): 2-3.

Midvale, Frank
n.d. Data Book III. Midvale Collection, Arizona Room, Hayden Library, Arizona State University, Tempe, Arizona.

ARCHITECTURE AND THE AFTERLIFE: A SPATIAL ANALYSIS OF MORTUARY BEHAVIOR AT UNIVERSITY INDIAN RUIN

Rachael M. Byrd
James T. Watson
Suzanne K. Fish
Paul R. Fish

ABSTRACT

Architectural construction underwent a significant transformation from the Hohokam Pre-Classic (A.D. 700-1150) to Classic period (A.D. 1150-1450); from ball courts and pit house groups to platform mounds and adobe-walled compounds. These changes reflect the partitioning of social, political, and religious space to facilitate differential access within sites. At University Indian Ruin (AZ BB: 9:33), a Classic period platform mound site in the Tucson Basin, mortuary features were commonly located within rooms or along walls outside of rooms, and often in discrete clusters. We therefore hypothesize that there is a direct association between interments and architectural units at University Indian Ruin (UIR)—a pattern that legitimized inheritance among house members inhabiting partitioned space. Results of a chi-square analysis indicate that the frequency of mortuary features associated with architecture (66.1%) is greater than expected. Further analysis of characteristics of these mortuary features (Spearman correlation) identify significant relationships between 1) burial type and site locus, 2) burial type and grouping of individuals, 3) burial type and artifact (ceramic) type, and 4) site locus and artifact (ceramic) type. Overall, our results demonstrate a significant association between architecture and mortuary features at UIR, and we suggest that decisions made by the living when burying the dead reinforced social distinctions and corporate inheritance within Hohokam sites.

The Pre-Classic to Classic period transition (circa A.D. 1100) is recognized as a time of considerable change among Hohokam groups in central and southern Arizona. It is characterized by population aggregation, a change in public architecture, and elaboration of domestic architecture and partitioned space (Abbott 2003; Bayman 2001; Doyel 1977; Fish and Fish 2000; Haury 1976). Pre-Classic period (AD 700-1100) communal ball courts and wattle and daub pit structures were replaced by platform mounds and above ground adobe rooms in the Classic period (AD 1100-1450) (Fish et al. 1992). The open arrangement of courtyard groups in the Pre-Classic period was replaced by the enclosed spaces of contiguous adobe walled compounds in the Classic period (Crown 1990; Doyel 2007; Elson 2000, 2007). Moreover, substantial changes in mortuary behavior also occurred across the Pre-Classic to Classic transition (Doyel and Fish 2000). These transformations have been interpreted as the product of changing social dynamics, codified by the redefinition of spatial relationships within and among Hohokam communities.

McGuire (1992) and Mitchell and Brunson-Hadley (2001) suggested that the living increasingly placed burials in and around architectural compounds in the Salt River valley during the Classic period. Recent research at the Hohokam Classic period site of University Indian Ruin (AZ: BB: 9:33), in the eastern Tucson Basin (Figure 1), revealed a prevalence of mortuary features located near or within architectural units. In this pa-

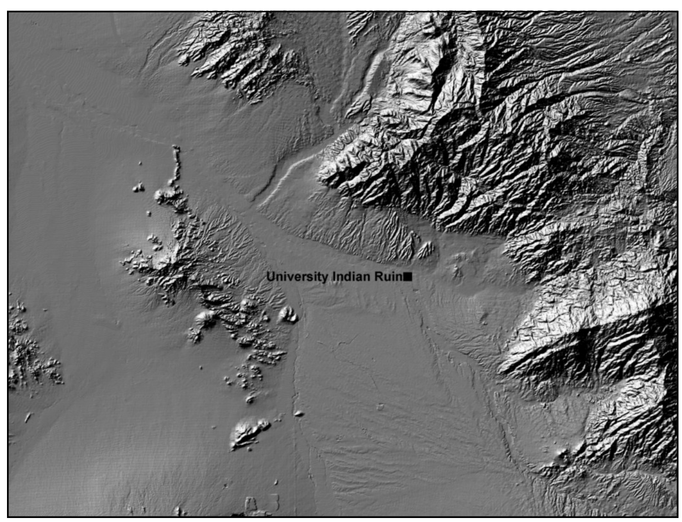


Figure 1. Location of University Indian Ruin (AZ BB: 9:33).

Rachael M. Byrd / School of Anthropology, University of Arizona, Tucson / rmbyrd@email.arizona.edu
James T. Watson / Arizona State Museum, University of Arizona, Tucson / watsonjt@email.arizona.edu
Suzanne K. Fish / Arizona State Museum, University of Arizona, Tucson / sfish@email.arizona.edu
Paul R. Fish / Arizona State Museum, University of Arizona, Tucson / pfish@email.arizona.edu

Journal of Arizona Archaeology 2012, Volume 2, Number 1: 101-111

per, we test the hypothesis that mortuary features are more frequently associated with architecture at University Indian Ruin (UIR). We also test for correlations among some characteristics of these mortuary features, including burial type, site locus, grouping, and artifact (ceramic) type/style. By examining the relationships between mortuary features and architectural space at UIR, we hope to provide insight into how Hohokam communities reinforced social distinctions through corporate inheritance by connecting the deceased to architectural units and their living residents.

CLASSIC PERIOD MORTUARY PRACTICES

In order to interpret mortuary behaviors during the Hohokam Classic period, it is critical to understand the general pattern and elements of the larger social transformation from the Pre-Classic to the Classic period. For example, the spatial distribution of mortuary features changed between the two time periods (Brunson 1989; Crown 2007; Mitchell et al. 1989, 1994; Mitchell and Brunson-Hadley 2001, Cerezo-Roman and McClelland 2008). During the Pre-Classic, pit house courtyard groups shared external cooking ovens, refuse middens, and burial areas (Bayman 2001). However, during the Classic period, residents of Hohokam communities built grouped adobe rooms, sometimes with compound walls, and shifted placement of burials to within and around rooms and even within platform mounds at some sites (McGuire 1992; Mitchell and Brunson-Hadley 2001). This reallocation of both architecturally-bound space and placement of burials within this space likely reflects changing social dynamics.

Cremation and inhumation burial types are prevalent across southern Arizona during the Classic period. Cremated human remains were buried in both primary and secondary contexts, whereas inhumed remains were often buried as primary interments. Primary inhumations were often placed in an extended, supine position, with the head and body oriented east-west in a similarly oriented burial pit (Brunson 1989; Cerezo-Roman and McClelland 2008; Crown 2007; Mitchell et al. 1989, 1994; Mitchell and Brunson-Hadley 2001). Both cremation and inhumation burial features are generally associated with diverse artifact types. Common grave accompaniments for Pre-Classic period bur-

Figure 2. Distributions of burial types at Classic period Hohokam sites from in the Phoenix and Tucson Basins.

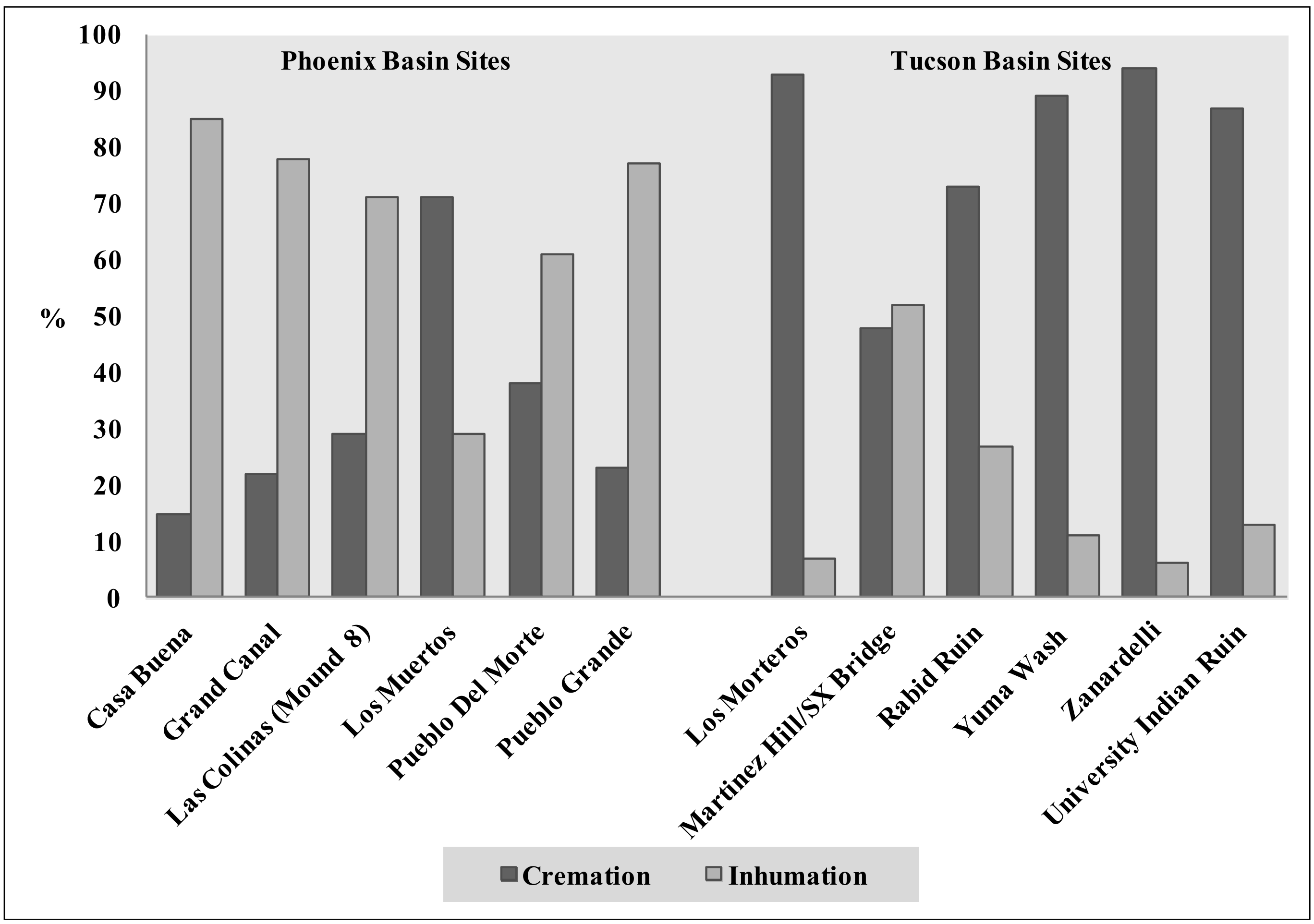


Table 1. Distribution of burial type at Classic period Hohokam sites. Adapted from Mitchell and Brunson-Hadley 2001: Table 4.1

	Site Name	Platform Mound	*N*	% Cremations	% Inhumations	Reference
Phoenix Basin	**Casa Buena**	**Y**	61	15	85	Effland 1988
	Grand Canal	N	101	22	78	Anderson 1983
	Las Colinas (Mound 8)	**Y**	21	29	71	Hammack and Sullivan 1968
	Los Muertos	**Y**	522	71	29	Brunson 1989
	Pueblo Del Morte	**Y**	26	38	61	Weaver 1973
	Pueblo Grande	**Y**	809	23	77	Mitchell and Brunson-Hadley 2001
Tucson Basin	**Los Morteros**	N	75	93	7	Wallace 1995
	Martinez Hill/SX Bridge	N	40	48	52	Saul 1987
	Rabid Ruin	N	44	73	27	Hammack and Sullivan 1968
	Yuma Wash	N	37	89	11	Cerezo-Roman and McClelland 2008
	Zanardelli	N	19	94	6	Ruble 2009
	University Indian Ruin	**Y**	77	87	13	Hayden 1954; Haury 1938; Cummings 1935

ials included censers, ceramic figurines, stone palettes, and projectile points (Haury 1976). During the Classic period typical accompaniments were decorated and plain ceramics, shell ornaments, bone artifacts, and projectile points (Crown 2007).

The relative proportions of cremation and inhumation burials vary considerably among Hohokam sites through time (through the Pre-Classic and Classic periods) and across space (across the Tucson and Phoenix basins). Cremation was the predominant burial type during the Pre-Classic period, although inhumations also occurred. Barnes (1988) noted that inhumation burials increased in the Pre-Classic Sedentary period, whereas Haury (1976) felt that they were practiced infrequently until the beginning of the Classic period. During the Classic period in the Salt River valley, residents of Hohokam villages practiced inhumation burial more frequently than secondary cremation burial (Table 1; Figure 2). Inhumation represented between 55 and 85 percent of the burial populations at well-documented Classic period sites in the Salt River valley; cremation represented only between 15 and 45 percent of these populations. However, in the Tucson Basin, residents in Hohokam communities practiced cremation burial more frequently than inhumation. During the Classic period, cremation burial constituted between 48 and 94 percent of the burial populations at well-documented sites in the Tucson Basin, while inhumation accounted for only 6 to 52 percent (see Table 1; Figure 2). Although the frequency of inhumation burials increased from the Pre-Classic to the Classic period in both the Salt River valley and the Tucson Basin, the relative proportions of inhumations and cremations in community burial populations vary between these two major population centers. This difference in preferred burial type may represent a divergence in ritual performance and possibly ideology.

Mortuary researchers have proposed several mechanisms to explain the practice of both inhumation and cremation throughout the Hohokam cultural sequence. Cushing (1890) believed that differences in mortuary treatment reflected social status. He proposed that a high-status segment of Hohokam society performed inhumation burial and that the remaining population cremated their dead. Other researchers have suggested that diversity in burial type expresses differences among multiple social groups in their ideological beliefs and death ceremonies (Brunson 1989; Doyel 1991; Gladwin et al. 1937; Haury 1945). Doyel (1991), however, dismissed the connection between mortuary behaviors and migration, and envisioned various segments of Hohokam society practicing multiple ideologies, which were unrelated to social status and resource control. Interpreting this observed diversity even more broadly, Doelle and Wallace (1991) proposed that Hohokam populations in the Tucson basin followed the same general system as people in the Phoenix basin, yet they were a distinctive group of people from inhabitants of the Gila and Salt River valleys.

At the Classic period site of Pueblo Grande in the Phoenix Basin, the residents of compounds likely maintained discrete cemetery clusters (Mitchell 1994: 116-126, 128). Cremated individuals were often buried

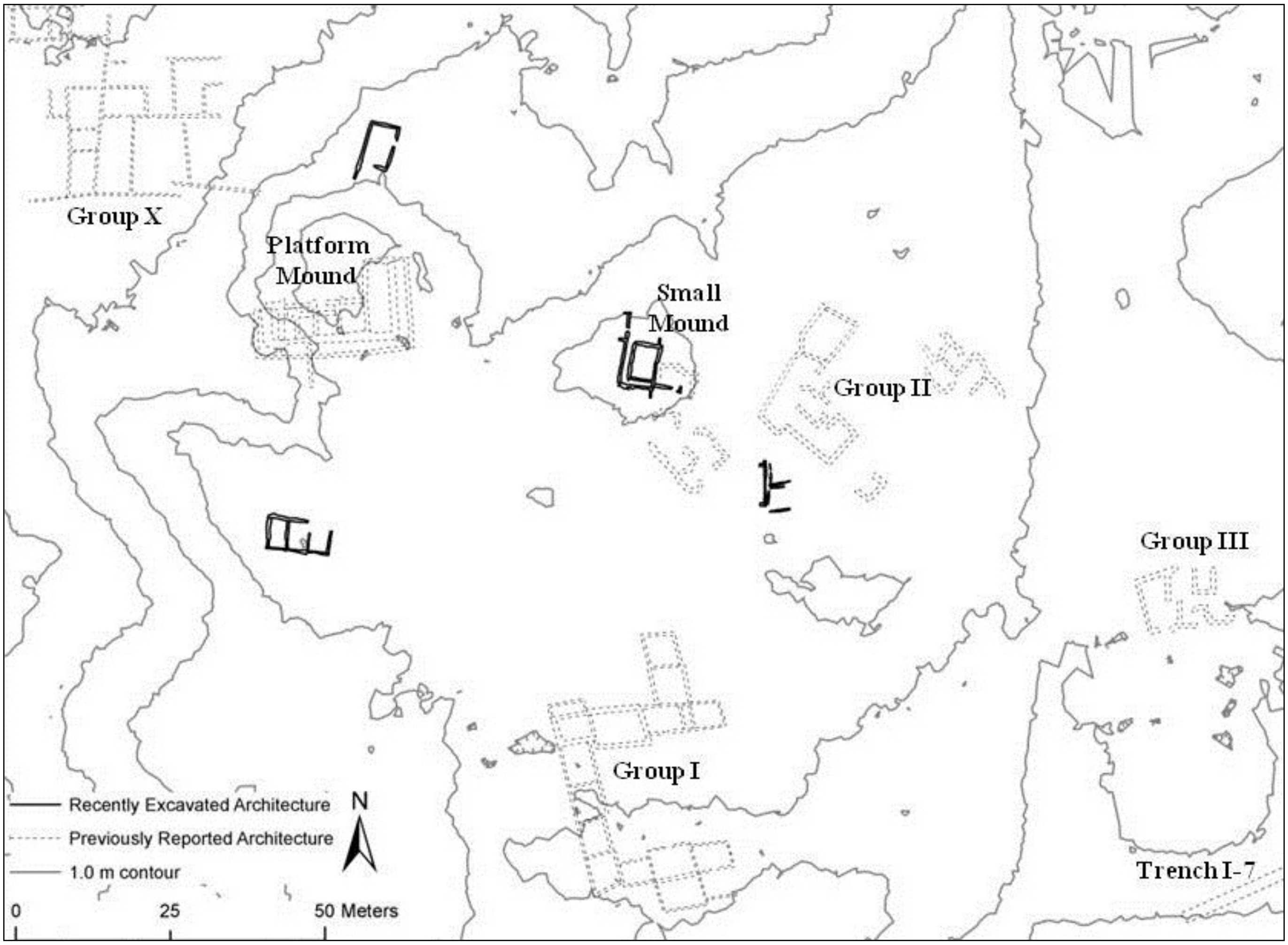


Figure 3. Site map of University Indian Ruin illustrating recent and previously excavated architecture.

within cemeteries, while inhumed individuals were buried inside compound walls (although they were sometimes also buried in cemeteries) (Mitchell 1992; Mitchell and Brunson-Hadley 2001: 52). In a recent analysis of Hohokam Classic period cemetery organization, Hackbarth (2012) demonstrated that the vast majority of burials (86 percent) were placed in parallel rows. He further noted that the majority of secondary cremation burials did not intrude on each other; this preservation of burial features suggests that the living knew the location of individual graves (Mitchell 1994: 127; McGuire 1992: 31; 59 - 60).

Hohokam social and political organization is still relatively poorly understood, yet most agree that some level of status and power inequality existed (Crown and Fish 1996, Elson 1998, Bayman 2001). Several researchers have argued that mortuary feature spatial relationships are related to kin-group membership (Anderson 1986; Effland 1988; Mitchell et al. 1989; see Howell and Kintigh 1996 for a similar argument at the Zuni settlement of Hawikku), while others have suggested they were related to the control of resources and/or religious knowledge/leadership (Doyle 2007; Fish and Fish 2000).

We propose that, in part, some aspects of Classic period Hohokam mortuary behavior reinforced subdivided spatial relationships via the placement of the dead. Foremost, we evaluate a potential association between burial placement and architecture at University Indian Ruin in the Tucson Basin. Then, we suggest that Levi-Strauss's (1982, 1987) *sociétés à maisons* concept (i.e., the Levi-Straussian "house") and Gillespie's (2000a, b, c) discussion of ancestral connections to property rights may help to explain patterns of intramural burial in the Hohokam Classic period (see Craig 2007, 2010 for discussions of Levi-Straussian "houses" and estates in Hohokam communities).

UNIVERSITY INDIAN RUIN

University Indian Ruin (AZ BB: 9:33 [ASM]) is a Hohokam Classic period platform mound site (Figure 3) located in the eastern Tucson basin, at the confluence of Tanque Verde Wash and the Rillito River (Figure 1). Non-cutting tree-ring dates (A.D. 1371-1375) indicate

Table 2. Burials documented at UIR by excavation projects.

Directed Excavations (Years)	Cremations	Inhumations	*n*
Hayden (1940-1941)	3	4	7
Haury (1938-1939)	15	5	20
Cummings (1930-1937)	47	1	48
Fish and Fish (2010-2012)	2	0	2
Total Documented (%)	67 (87%)	10 (13%)	77

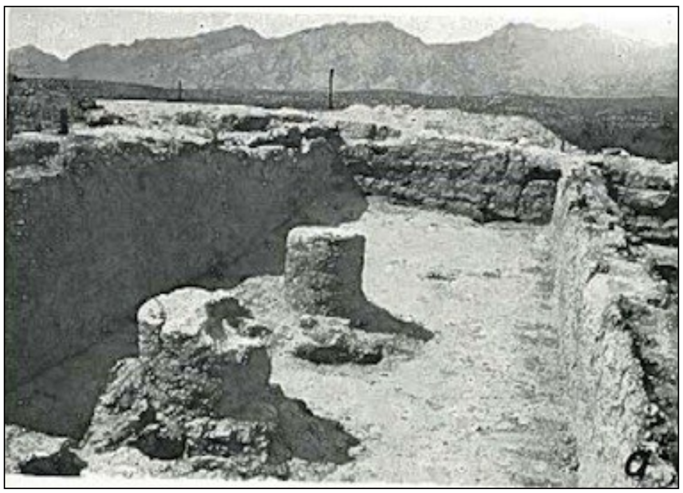


Figure 4. Photo of excavated room (D4: Room 2) in platform mound at UIR with two cylindrical caliche piers in the center (Hayden 1954:87).

that UIR was among the last platform mound sites still occupied in the Tucson basin at the end of the Classic period (J. Dean, personal communication). Four major excavation programs have taken place at UIR; the projects were directed by Byron Cummings (1930-37), Emil C. Haury (1938-39), Julian Hayden (1940-41), and currently by Paul Fish and Suzanne Fish (2010-12). These excavations revealed complex adobe room block structures, a trash midden, and mortuary features that appear to fit within the larger pattern expected for Classic period sites in the Tucson basin.

If some adobe room complexes and associated mortuary features are representative of Levi-Straussian "houses," then identifying significant relationships between mortuary features and architecture may help us to understand how Hohokam populations legitimized property rights and established house-level social identities at UIR. Here, we focus on previously excavated adobe architecture and mortuary features to test our hypotheses that mortuary features are frequently associated with architecture at UIR.

ANALYTICAL METHODS

Materials

We collected data for 77 mortuary features previously excavated from UIR from archived field notes and reports in the Arizona State Museum (ASM) collections catalog for 77 mortuary features previously excavated from UIR (Table 2). Overall, the mortuary feature sample includes 10 primary inhumations and 67 secondary cremations. Variables related to burial type, site locus, architecture association, grouping (singular feature vs. clustered features), and ceramic type (both form and style) were recorded for each of the burial features to test for significant correlations. Sixty-two features provided data regarding positioning related to architecture. Differences in research designs, excavation techniques, data reporting, and artifact conservation have left incomplete records, especially from Cummings' and Haury's excavations.

Group I, an adobe room block at UIR (see Figure 3), was initially excavated in the 1930's by Byron Cummings. He later excavated Groups II-IV, east of the platform mound (Jones 2006; Kelly 1936). Thirty-three cremations in jars and pitchers, which were placed along the outside of occupied rooms or inside abandoned rooms, were excavated in Group I (Kelly 1936). Haury encountered several burials in a test trench (Trench I-7) dug through the edge of a trash mound and possibly into several rooms in a residential compound east of the platform mound (Eaton 1939; Mitalsky 1939; Shaeffer 1939).

Hayden (1954) was the first to publish his work at UIR formally; he detailed excavation of the platform mound and a compound northwest of the mound. His work exposed four inhumations and three cremations. Two individuals recovered from the mound included inhumations of a small child and another of indeterminate age (Hayden 1954). During Hayden's (1954) excavation of one of the rooms at the center of the platform mound at UIR (Figure 4), he found several large burned animal bones, horns of elk, mountain sheep, and deer, as well as a metate with a hole in the bottom and a mano placed over it. In 2010, two additional cremations (one in a small jar and with an associated quartz crystal) were recovered adjacent to room walls in test trenches east of the platform mound. Four test trenches were also placed in areas without visible surface signs of architecture to the west and north of the platform mound. These excavations did not uncover any burials. Current field schools are no longer focused on locating and excavating burials at UIR.

Most individuals at UIR were cremated (86.6 percent) and placed inside a variety of ceramic types and styles. Decorated ceramic styles associated with burials include Gila and Tucson Polychrome, Tanque Verde Red-on-Buff, Gila Black-on-Red, San Carlos, and Sells Red Ware (Hagberg 1939). One cremation was found

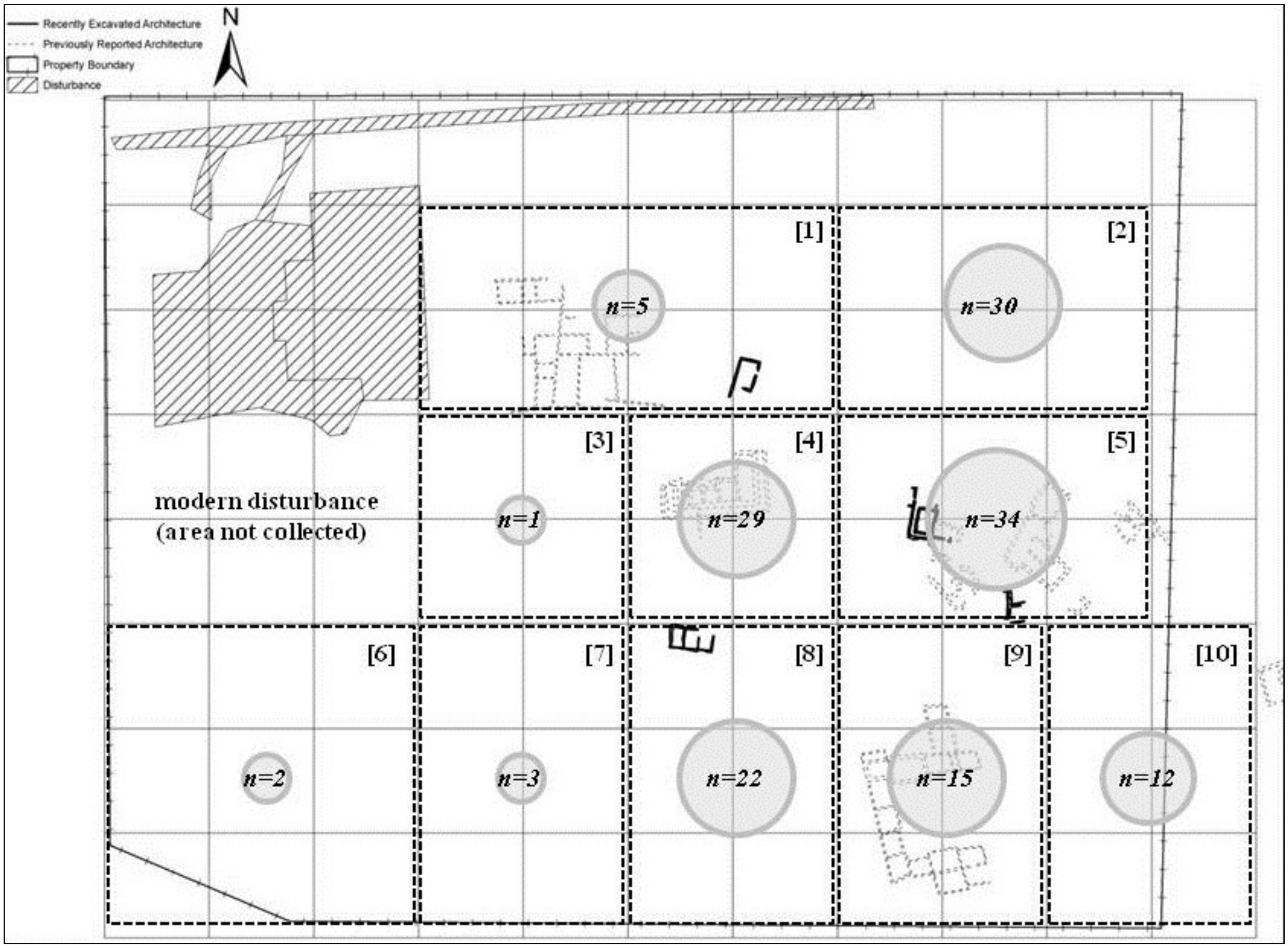


Figure 5. Surface density map of human bone at University Indian Ruin. Previously excavated architectural units are highlighted by gray dashed lines. Modified polygons are superimposed and densities recorded on the surface are noted in circles.

in a duck-shaped jar (Cummings 1935). Limited types of other artifacts were associated with burials at UIR. One adult male inhumation was reported to have been buried with an associated selenite pendent, pottery spindle whorl, three fragments of unworked selenite, and five pieces of quartz crystal (Eaton 1939). This individual was not associated with architecture but rather with a trash mound. These types of artifacts (minerals, jewelry, etc.) were very limited in UIR burials and for this reason were excluded from this study.

Evaluating Sampling Bias

Before testing the hypothesis that burial placement at UIR was differentially associated with architecture, it is important to demonstrate that excavation did not result in the collection of a biased burial feature sample (i.e., that preferential excavation in architectural units did not result in the identification of a higher proportion of intramural burials than the population contains). Thus, we assessed the likelihood that the mean number of bone fragments found on the surface in unexcavated areas is approximately the same as the mean number of bone fragments found in areas with previously excavated architecture. We used an independent samples t-test to evaluate a hypothesis that the mean number of bone fragments in each of the two areas is from the same population.

To perform the test, we first tallied the number of human bone fragments recorded during the 2010 field school surface survey within gridded 25 m surface units. We then created a density map of the distribution of surface bone (Figure 5). We used a modified polygon approach (constrained by the grid-based data) to identify ten different sections of the site that either 1) lacked previously excavated architectural units or 2) were associated with excavated architecture (see Figure 5). Next, we calculated the mean number of bone fragments found in those sections that lacked previously excavated architecture and the mean number of fragments in those that contained excavated architecture. Note that the surface density map shows a great deal of variability in the mean number of bones identified on the surface within the polygons, regardless of association with previously excavated architecture.

Finally, we performed an independent samples t-test to evaluate a null hypothesis that the mean number of fragments in sections without previously excavated architecture is from the same population as the mean number of fragments in sections with excavated architecture. The t-test did not reject this null hypothesis (t = 0.914; df = 8, p = 0.387). Thus, it is likely that the two means are from the same population.

We therefore infer that sampling bias from past excavations is not a significant confounding factor to the association of mortuary features with architectural units at UIR. Other formation processes and larger social phenomena likely contributed to the distribution of cremated human bone on the site surface. Most importantly, however, these results indicate that we can proceed with testing the central hypothesis regarding a socially-determined association between mortuary features and architecture.

Testing the Association between Burial Placement and Architecture

The majority of burials (n = 42, 66.1 percent) recovered at University Indian Ruin over the past 80 years were directly associated with architectural units. These burial features were placed in rooms, along outer walls, adjacent to architectural groups, and within the platform mound. Summary statistics suggest that there is an association between burial and architecture at UIR.

A chi-square analysis was conducted to test a hypothesis that the observed frequency of UIR burials associated with architecture is significantly higher than expected if burial placement and architecture are independent. Results of the test reveal that the frequency of burials associated with architecture at UIR is higher than anticipated ($\chi 2 = 6.3516$, df = 1, n = 62, $p >$ 0.01). These results support our central hypothesis that mortuary features are frequently associated with architecture at UIR.

Table 3. Spearman correlation analysis of mortuary variables at UIR.

		Locus	Arch. Assoc.	Grouping	Artifact Type	Artifact Style
Burial Type	*r*	0.316	-0.149	0.439	-0.341	0.021
	p	**0.013**	0.246	**0.000**	**0.003**	0.861
	n	61	62	62	75	69
Locus/ Area	*r*		0.167	0.089	-0.304	0.062
	p		0.197	0.494	**0.017**	0.655
	n		61	61	61	55
Arch. Assoc.	*r*			0.193	0.105	0.214
	p			0.133	0.415	0.114
	n			62	62	56
Grouping	*r*				-0.122	-0.054
	p				0.387	0.691
	n				62	56
Artifact Type	*r*					0.066
	p					0.592
	n					69

Shaded: Significant at the 0.05 level

Analysis of Mortuary Features

Finally, we attempted to identify relationships within and among a number of different attributes of the burial features uncovered at UIR. More specifically, we explored relationships among the following variables: burial type, site locus, grouping (singular feature vs. clustered features), ceramic type and ceramic decoration style. We used a Spearman nonparametric correlation analysis to test for statistically significant correlations among variables. With this correlation analysis, we were able to distinguish additional relationships between mortuary practices and architecture at UIR.

The Spearman correlation analysis identified statistically significant correlations among the following pairs of variables: 1) burial type and locus, 2) burial grouping (singular vs. clustered) and artifact type, and 3) locus and artifact type (Table 3). The relationship between burial type and site locus ($r = 0.316$, $p < 0.05$) indicates that cremations were more widespread across the site than inhumations. The relationship between burial type and grouping, one of the strongest identified correlations, ($r = 0.439$, $p < 0.001$) reveals that inhumations were always singular mortuary features, while the majority of cremations were placed in groups or clusters. A significant relationship between burial type and artifact (ceramic) type ($r = -.341$, $p <$ 0.05) demonstrates that cremations at UIR are associated with a greater diversity of ceramic types; such as ollas, urns, jars, and pitchers; than inhumations, which are most often associated with bowls. Burials associated with site loci containing architectural compounds contain similar ceramic types ($r = -0.304$, $p < 0.05$).

DISCUSSION

Results support our hypothesis that there is an association between burial features and architecture at UIR. These features likely functioned to reinforce partitioned space among corporate groups, some of which may represent "houses." Several authors hypothesize that Hohokam political structure contained a strong kinship component in which power and economic control was differentially distributed among houses (Craig et al. 1998; Doyel and Fish 2000). We suggest that decisions regarding burial location worked to legitimize social groups and inheritance practices during the Classic period at UIR (In addition, notions of burial spacing [grouping] and the inclusion of certain ceramic types in burial features may have also contributed to group identities). Concepts of social differentiation and limited access are reflected through the construction of walled compounds, yet interpretations of social organization based on architecture alone are inadequate (Crown and Fish 1996). Incorporating data involving mortuary behaviors and artifact assemblages provides a more detailed understanding of social organization at such sites.

We propose that Craig's (2010) application of the Lévi-Straussian "house" to Hohokam communities may help to explain, in part, burial in and around architecture at some Classic period Hohokam sites (see also Craig 2007). Recently, Craig (2010) used Lévi-Strauss' (1987) concept of a "house" (maison) to examine the persistence of Hohokam courtyard groups and the potential maintenance of an estate tied to property holdings. Lévi-Strauss (1987) defined the "house" as, "a corporate body holding an estate made up of both material and immaterial wealth, which perpetuates itself through the transmission of its name, its goods, and its titles down a real or imaginary line, (it is) considered legitimate as long as this continuity can express itself in the language of kinship or of affinity, and most often, of both" (see Beck 2007; Joyce and Gillespie 2000; and Gillespie 2000c for applications of the "house" to the archaeological record). In his application of this idea, Craig (2010: 72-75) identified the courtyard group as the cultural and architectural foundation for Lévi-Straussian "houses" in Hohokam communities (Wilcox 1981 et al). He observed that successful, aristocratic "houses" were those that persisted over time, and thus demonstrated some resilience. In addition, he stated that "[m]ulti-household residential compounds should be considered candidates for aristocratic houses", because they displayed residential continuity, potential intra-generational transfer of valuable property (i.e., control of resources), and association with burial features (Craig 2010: 73). Thus, it is reasonable to view adobe compounds at UIR as potential "houses."

We suggest that the physical act of interring a member of the lineage within or around the architectural unit, as opposed to an external cemetery shared by multiple lineages, may connect claims of a "house's" legitimacy to the past (Craig 2010: 72-73; see also Adams and King 2011, Helms 1998; Gillespie 2000a,b; Joyce 2000). This can be done more effectively via 'direct contact' between the deceased and the living within living/domestic spaces in growing communities (Craig 2010: 73; Gillespie 2000a:19). The privatization of burials interred within, or adjacent to, rooms demonstrates a connection between the tangible remains of past inhabitants and the socio-metaphysical metaphor of the Lévi-Straussian "house."

Several researchers have suggested that ancestor veneration can serve as a focus of group identity in a traditional house society, and ancestral figures can symbolize the origins of a "house" (e.g., Beck 2007; Gillespie 2000a; and Helms 1998). Moreover, ritual practices associated with ancestor veneration in the "house" may provide a mechanism of group authority, and a means to control access to property rights, especially to land (Craig 2010; Gillespie 2000b; Joyce 2000). Applying Levi-Strauss's (1982, 1987) concepts of the "house" to inhabitants of adobe complexes, we suggest that compound residents likely cooperated as corporate entities with their own identities and responsibilities. "House" residents likely maintained both material and immaterial property over many generations through both descent and marriage ties (Levi-Strauss 1982, 1987). In addition, in order for the "house" to perpetuate, "house" members often make use of real or fictive kinship, in terms of alliance and adoption (Levi-Strauss 1987). Thus, house members and their property holdings are anchored to a specific locale first inhabited by "house" ancestors, whom are often buried there (Helms 1998, Gillespie 2000a). Member rights are legitimized through these forms of direct connection to the past.

Although both inhumations and cremations at UIR appear to be equally associated with architecture, the results of our analyses illustrate further distinctions between the two burial types. Cremation was the dominate practice at UIR and corresponds to patterns found at other Classic period sites in the Tucson basin, such as Zanardelli, Yuma Wash, Rabid Ruin, and Los Morteros (Ruble et al. 2009; Cerezo-Roman-McClelland 2008; D. Schwartz, personal communication; Hammack and Sullivan 1968; Hammack and Huckell 1969; Wallace 1995). Our results also demonstrate a significant relationship between burial type and grouping; cremations were often interred in clusters around architectural units at UIR, whereas inhumations were singular features. At Classic period sites in the Phoenix basin such as Grand Canal Ruins, Los Muertos, and Pueblo Grande, cremation burials were located in discrete clusters as well (Mitchell et al. 1989; Mitchell et al. 1994; Fink 1989 Mitchell and Brunson-Hadley 2001). Similar patterns in mortuary behavior were observed at Rabid Ruin in the Tucson Basin, where secondary cremations were buried in separate areas from inhumation burial features (Huckell 1969).

Binford (1971) suggests that the form and structure of mortuary practices in any society are conditioned by the form and complexity of social organization. Tainter (1978) and Carr (1995) both suggest that burial accompaniments can symbolize aspects of personal identity and gender, while Carr (1995) also demonstrates that these items can symbolize particular beliefs about the afterlife. We propose that the relationship at UIR between burial type (cremation or inhumation) and particular ceramic types may represent a social marker that distinguishes among "houses" at UIR. Cremations are associated with a greater diversity of ceramic types and styles, and secondary cremations were placed within ollas, urns, and sometimes pitchers and often covered with bowls. Irregular ceramic types were found rarely with only cremations and included an unusual elongated shape that appears to have been mended, a crude duck form, and a vase. Inhumations were most often associated with bowls or without ceramics. Cremations located in clusters often contained similar ceramic types. Many variables (e.g., sex, age, death circumstances, status, various social identities) can contribute to what the living decide to inter with the dead. This relationship between burial type and ceramic type may represent a variety of aspects regarding social identity and organization.

CONCLUSION

The Classic period is recognized as a time of exceptional change and many of these forces of change—migration, population aggregation and co-residence, increasing competition for resources, and the differential partitioning of both public and ritual space—likely contributed to the diversity and complexity of mortuary practices during this time. We suggest that some aspects of Hohokam Classic period mortuary behavior functioned to reinforce subdivided spatial relationships via the placement of the dead within sites.

The primary goal of this analysis was to examine mortuary features at the Hohokam Classic period site of University Indian Ruin (AZ: BB: 9:33) in order to test relationships between aspects of mortuary features and architectural complexes. The majority of mortuary features at the site are directly associated with architecture, with significantly more features found within or near room walls. Cremations were mostly placed in clusters whereas inhumations were singular features. Secondary cremations have the greatest ceramic diversity, and spatial clusters of cremation features often contain similar ceramic types. Burial type (cremation or inhumation), burial clustering (clustered or singular), and the style of ceramic accompaniments are likely distinguishing characteristics of "house" identity at UIR.

Ultimately, we identified that mortuary behaviors at UIR fit within a larger Classic period. We and propose that they served to legitimize inheritance among "house" members (possibly via ancestor veneration) by associating mortuary features with partitioned architectural space.

Acknowledgements. We would like to thank Matt Pailes for producing the maps, which were the result of his work in the field. We would also like to thank the reviewers and the editors for their insightful comments and suggestions, which contributed to a much improved paper.

REFERENCES CITED

Abbott, David R.
2003 *Centuries of Decline during the Hohokam Classic Period at Pueblo Grande*. University of Arizona Press, Tucson.

Adams, Ron L. and Stacie M. King (editors)
2011 *Residential Burial: A Multiregional Exploration*. Archaeological Papers of the American Anthropological Association 20. Blackwell Publishing Inc., Boston.

Anderson, Keith M.
1986 Hohokam Cemeteries as Elements of Settlement Structure and Change. In *Anthropology of the Desert West, Essays in Honor of Jesse D. Jennings*, edited by Carol S. Condie and Don D. Fowler, pp. 179-202. Anthropological Papers No. 110. University of Utah Press, Salt Lake City.

Bayman, James M.
2001 The Hohokam of Southwest North America. *Journal of World Prehistory* 15(3):257-311.

Barnes, Ethne
1988 Inhumations Recovered from Casa Buena: Skeletal Analysis. In *Excavations at Casa Buena: Changing Hohokam Land Use along the Squaw Peak Parkway*, edited by Jerry B. Howard, pp. 619-691. Soil Systems Publications in Archaeology No. 11, Phoenix.

Beck, Robin A., Jr. (editor)
2007 *The Durable House: House Society Models in Archaeology*. Center for Archaeological Investigations Occasional Papers No. 35. Southern Illinois University, Carbondale.

Binford, Lewis R.
1971 Mortuary Practices: Their Study and Their Potential. *Memoirs of the Society for American Archaeology* 25:6-29.

Brunson, Judy, L.
1989 The Social Organization of the Los Muertos Hohokam: A Reanalysis of Cushing's Hemenway Expedition Data. Unpublished Ph.D. dissertation, Department of Anthropology, Arizona State University, Tempe.

Carr, Christopher
1995 Mortuary Practices: Their Social, Philosophical-Religious, Circumstantial, and Physical Determinants. *Journal of Archaeological Methods and Theory* 2(2):105-200.

Cerezo-Román, Jessica I., and John McClelland
2008 Mortuary Practices at Yuma Wash and the Hohokam Classic World. In *Archaeological Investigations at Five Sites West of the Santa Cruz River in Marana, Arizona: Yuma Wash and Silverbell-Ina Hohokam Sites AZ AA:12:311(ASM, AZ AA:12:314(ASM), and AZ AA:12:315 (ASM); & Bojórquez-Aguirre Ranch and Meador-Cañas Sites AZ AA:12:122(ASM) and AZ AA:12:313(ASM),* edited by Art C. MacWilliams and Allen Dart (draft), pp. 6.1-6.32. Old Pueblo Archaeology Center, Tucson.

Crown, Patricia L.
1990 The Hohokam of the American Southwest. *Jour-*

nal of World Prehistory 4(2):223-255.

2007 Growing Up Hohokam. In *The Hohokam Millennium,* edited by Suzanne K. Fish and Paul R. Fish, pp. 23-29. School for Advanced Research Press, Santa Fe.

Crown, Patricia L., and Suzanne K. Fish

1996 Gender and Status in the Hohokam Pre-Classic to Classic Transition. *American Anthropologist* 98:803-817.

Craig, Douglas B.

2010 Modeling Leadership Strategies in Hohokam Society. *Journal of Arizona Archaeology* 1(1):71-88.

Craig, Douglas B., and T. Kathleen Henderson

2007 Houses, Households, and Household Organization. In *The Hohokam Millennium*, edited by Suzanne K. Fish and Paul R. Fish, pp. 31-37. School for Advanced Research Press, Santa Fe.

Craig, Douglas B., James P. Holmlund, and Jeffery J. Clark

1998 Labor Investment and Organization in Platform Mound Construction: A Case Study from the Tonto Basin of Central Arizona. *Journal of Field Archaeology* 25:245-259.

Cushing, Frank H.

1890 *Preliminary Notes on the Origin, Working Hypothesis and Primary Researches of the Hemenway Southwestern Archaeological Expedition*. Congres International des Américanistes. Berlin.

Cummings, Byron

1935 Field notes from University Indian Ruins. ASM/UA Notebook No. 4. Manuscript on file, Arizona State Museum, Tucson

Doelle, William H., and Henry D. Wallace

1991 The Changing Role of the Tucson Basin in the Hohokam Regional System. In *Exploring the Hohokam: Prehistoric Desert Peoples of the American Southwest*, edited by George J. Gumerman, pp. 279-345. University of New Mexico Press, Albuquerque.

Doyel, David E.

1977 Classic Period Hohokam in the Escalante Ruin Group. Unpublished Ph.D. Dissertation, Department of Anthropology, University of Arizona, Tucson.

1991 Hohokam Cultural Evolution in the Phoenix Basin. In *Exploring the Hohokam: Prehistoric Desert Peoples of the American Southwest*, edited by George J. Gumerman, pp. 231-278. University of New Mexico Press, Albuquerque.

2007 Irrigation, Production, and Power in Phoenix Basin Hohokam Society. In *The Hohokam Millennium*, edited by Paul R. Fish and Suzanne K. Fish, pp. 82-89. School for Advanced Research Press, Santa Fe.

Doyel, David E., and Suzanne K. Fish

2000 Prehistoric Villages and Communities in the Arizona Desert. In *The Hohokam Village Revisited*, edited by David E. Doyel, Suzanne K. Fish, and Paul R. Fish, pp. 1-35. Southwestern and Rocky Mountain Division of the American Associate for the Advancement of Science, Fort Collins.

Eaton, Grace

1939 Field Notes from University Indian Ruin under Emil C. Haury. Manuscript on file, Arizona State Museum, Tucson.

Effland, Richard W.

1988 An Examination of Hohokam Mortuary Practices from Casa Buena. In *Excavations at Casa Buena. Changing Hohokam Land Use along the Squaw Peak Parkway Vol. 2*, edited by Jerry B. Howard, pp. 693-794. Soil Systems Publications in Archaeology, Phoenix.

Elson, Mark

1998 *Expanding the View of Hohokam Platform Mounds: An Ethnographic Perspective.* Anthropological Papers of the University of Arizona No. 63. University of Arizona Press, Tucson.

2000 Southwest Platform Mounds from an Ethnographic Perspective. In *The Hohokam Village Revisited*, edited by David E. Doyel, Suzanne K. Fish, and Paul R. Fish, pp. 345-372. Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science, Fort Collins, Colorado.

2007 Into the Earth and Up to the Sky: Hohokam Ritual Architecture. In *The Hohokam Millennium*, edited by Paul R. Fish and Suzanne K. Fish, pp. 49-55. School for Advanced Research Press, Santa Fe.

Fink, T. Michael

1989 The Human Skeletal Remains from the Grand Canal Ruins, AZ T:12:14 (ASU) and AZ T: 12:16 (ASU), In *Archaeological Investigations at the Grand Canal Ruins: A Classic Period Site in Phoenix, Arizona. Vol. 2*, edited by Douglas R. Mitchell, pp. 619-703. Soil Systems Publications in Archaeology No.12, Phoenix.

Fish, Suzanne K., and Paul R. Fish

2000 The Institutional Contexts of Hohokam Complexity. In *Alternative Leadership Strategies in the Prehispanic Southwest,* edited by Barbara J. Mills, pp. 154-167. University of Arizona Press, Tucson.

Fish, Suzanne K., Paul R. Fish, and John H. Madsen

1992 *The Marana Community in the Hohokam World*. Anthropological Papers of the University of Arizona No. 56. University of Arizona Press, Tucson.

Gillespie, Susan D.

2000a Beyond Kinship: An Introduction. In *Beyond Kinship: Social and Material Reproduction in House Societies*, edited by R. A. Joyce and S. D. Gillespie, pp. 1-21. University of Pennsylvania Press, Philadelphia.

2000b Lévi Strauss: Maison and Société à Maisons. In *Beyond Kinship: Social and Material Reproduction in House Societies*, edited by R. A. Joyce and S. D. Gillespie, pp. 22-52. University of Pennsylvania Press, Philadelphia.

2000c Rethinking Ancient Maya Social Organization: Replacing "Lineage" with "House". *American Anthropologist* 102(3):467-484.

Gladwin, Harold S., Emil W. Haury, E. B. Sayles, and Nora Gladwin

1937 *Excavations at Snaketown: Material Culture*. Medallion Papers No. 25. Gila Pueblo, Globe.

Hagberg, Elizabeth

1939 Field Notes from University Indian Ruin under Emil C. Haury. Manuscript on file, Arizona State Museum, Tucson.

Hackbarth, Mark R.

2012 Prehistoric Cemetery Spatial Organization in Southern Arizona. *Kiva* 77(3):313-357.

Hammack, Laurens C., and Alan P. Sullivan

1981 *The 1968 Excavations at Mound 8 Las Colinas Ruins*

Group, Phoenix, Arizona. State Museum Archaeological Series No. 154. University of Arizona, Tucson.

Hammack, Nancy S., and Lisa W. Huckell
1969 Rabid Ruin AZ AA:12:46, Manuscript on File, Arizona State Museum. Tucson.

Haury, Emil W.
1945 *The Excavation of Los Muertos and Neighboring Ruins in the Salt River Valley, Southern Arizona.* Peabody Museum of American Archaeology and Ethnology Vol. 24, No. 1. Harvard University, Cambridge.
1976 *The Hohokam Desert Farmers and Craftsmen Snaketown 1964-1965*. University of Arizona Press, Tucson.

Hayden, Julian
1957 *Excavations, 1940 at University Indian Ruin, Tucson, Arizona.* Southwestern Monuments Association, No. 5, Globe.

Helms, Mary W.
1998 *Access to Origins: Affines, Ancestors, and Aristocrats.* University of Texas Press, Austin.

Howell, Todd L., and Keith W. Kintigh
1996 Archaeological Identification of Kin Groups Using Mortuary and Biological Data: An Example from the American Southwest. *American Antiquity* 61:537-554.

Jones, Jeffery T.
2006 *Archaeological Monitoring, Testing, and Data Recovery Investigations Near the Northwest Periphery of University Indian Ruins, AZ BB:9:33 (ASM) in Pima County, Arizona.* Tierra Right of Way Services, Tucson.

Joyce, Rosemary A.
2000 Heirlooms and Houses: Materiality and Social Memory. In *Beyond Kinship: Social and Material Reproduction in House Societ*ies, edited by R. A. Joyce and S. D. Gillespie, pp. 189-212. University of Pennsylvania Press, Philadelphia.

Joyce, Rosemary A. and Susan D. Gillespie (editors)
2000 *Beyond Kinship: Social and Material Reproduction in House Societies*. University of Pennsylvania Press, Philadelphia.

Kelly, William H.
1936 University Ruin. *Kiva* 1:1-4.

Levi-Strauss, Claude
1982 *The Way of the Masks.* Translated by S. Modelski. University of Washington Press, Seattle.
1987 *Anthropology and Myth: Lectures, 1951-1982*. Translated by R. Willis. Blackwell, Oxford.

McGuire, Randall H.
1992 *Death, Society, and Ideology in a Hohokam Community*. Investigations in American Archaeology. Westview Press, Boulder.

Mitalsky, Frank
1939 Notes on Seminar Class Excavation Project under Emil C. Haury. Manuscript on File, Arizona State Museum, Tucson.

Mitchell, Douglas R.
1992 Burial Practices and Paleodemographic Reconstructions at Pueblo Grande. *Kiva* 58:91.

Mitchell, Douglas R., T. Michael Fink, and W. Allen
1989 Disposal of the Dead: Explorations of Mortuary Variability and Social Organization at the Grand Canal Ruins. In *Archaeological Investigations at the Grand Canal Ruins: A Classic Period Site in Phoenix*, edited by Douglas R. Mitchell, pp. 705-773. Soil Systems Publications in Archaeology No. 12, Phoenix.

Mitchell, Douglas R., Penny Dufoe Minturn, Deirdre J. Hungerford, and Michael S. Foster
1994 Burial Descriptions. In *The Pueblo Grande Project, Vol. 2: Feature Descriptions, Chronology, and Site Structure*, edited by Douglas R. Mitchell, pp. 107-156. Soil Systems Publications in Archaeology No. 20, Phoenix.

Mitchell, Douglas R., and Judy L. Brunson-Hadley
2001 An Evaluation of Classic Period Hohokam Burials and Society: Chiefs, Priests, or Acephalous Complexity? In *Ancient Burial Practices of the American Southwest*, edited by Douglas R. Mitchell and Judy L. Brunson-Hadley, pp. 45-67. University of New Mexico Press, Albuquerque.

Ruble, Ellen C. (editor)
2009 *Archaeological Excavations at the Zanardelli Site, AZ BB:13:1(ASM).* Technical Report No. 2004-01. Desert Archaeology Inc., Tucson.

Saul, Marilyn
1987 Osteological Analysis of Human Remains. In *The Archaeology of the San Xavier Bridge Site (AZ BB:13:14) Tucson Basin, Southern Arizona*, edited by John C. Ravesloot, pp. 467-47. Arizona State Museum Archaeological Series No. 171, Tucson.

Saxe, Arthur A.
1970 Social Dimensions of Mortuary Practices in a Mesolithic Population from Wadi Halfa, Sudan, Unpublished Ph.D. dissertation, Department of Anthropology, University of Michigan, Ann Arbor.

Shaffer, James
1939 Report on Excavation and Analysis in Block I-7, University Indian Ruins under Emil C. Haury. Manuscript on file, Arizona State Museum, Tucson.

Tainter, Joseph A.
1978 Mortuary Practices and the Study of Prehistoric Social Systems. *Advances in Archaeological Methods and Theory* 1:105-141.

Wallace, Henry D. (editor)
1995 *Archaeological Investigations at Los Morteros, a Prehistoric Settlement in the Northern Tucson Basin*. Anthropological Papers 17. Center for Desert Archaeology, Tucson.

Weaver Jr., Donald
1973 Excavations at Pueblo Del Monte and the Classic Period Hohokam Problem. *Kiva* 39:1.

Wilcox, David R.
1991 Hohokam Social Complexity. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by Patricia L. Crown and W. James Judge, pp. 253-276. School of American Research, Santa Fe.