Las Capas Archaeological Project: Ground Stone and Maize Processing Experiments

Jenny L. Adams
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Contributions by

Mary F. Ownby

Technical Report No. 2014-02
Desert Archaeology, Inc.

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3975 North Tucson Boulevard, Tucson, Arizona 85716 ● April 2015

ABSTRACT

In this report, experimental ground stone and maize processing experiments are described. These experiments stem from archaeological investigations at the prehistoric site of Las Capas, AZ AA:12:111 (ASM), situated in the Tucson Basin of southern Arizona. Testing and data recovery excavations at Las Capas were conducted by Desert Archaeology, Inc., from August 2008 through September 2009, with smaller phases of fieldwork in 2012 and 2013, as part of Pima County's Regional Wastewater Reclamation Department Regional Optimization Master Plan (ROMP). This massive project involved major upgrades and expansion of wastewater facilities at the Tres Rios Wastewater Reclamation Facility (WRF). Funding was provided by Pima County, and the excavations were conducted under the supervision of their Office of Cultural Resources and Historic Preservation, which requires all projects to adhere to the Federal standards of Section 106 of the National Historic Preservation Act of 1966 (as amended).

Las Capas is located in the northern Tucson Basin, situated on the eastern bank of the Santa Cruz River, just downstream from the confluences of the river with Rillito Creek and Cañada del Oro Wash. This is the point in the Santa Cruz River Valley where all major tributaries in the surrounding watersheds converge because of the terrain and the gradient, making it an ideal location for agriculture due to high water table levels and predictable streamflow. The great majority of features recovered at Las Capas dated to the San Pedro phase (A.D. 1200-800 B.C.) of the Early Agricultural period (2100 B.C.-A.D. 50).

The archaeological excavations allowed the singular opportunity of investigating a large area of the site in detail and intensity, providing the most comprehensive look at a San Pedro phase farming community conducted, to date, in southern Arizona. Backhoe trenches were excavated over most of the wastewater facility area to document the extent of archaeological deposits. Following this effort, intensive excavations were conducted in loci where new plant facilities were to be constructed (identified as Loci A-E; Loci F-H were only treated during the exploratory phase of the project).

Data recovery resulted in the identification of more than 5,500 prehistoric features, of which 3,455 were excavated or tested. Investigated feature types included 53 pithouses, 8 possible pithouses, 22 extramural surfaces, 610 bell-shaped pits, 49 large pits, 2,099 small pits, 490 roasting pits, 40 pits of unknown or other function, 20 inhumations, 2 cremations, and 11 animal burials. The excavations resulted in the recovery of more than 113,000 artifacts and 7,300 samples of various kinds, representing the largest quantity of San Pedro phase material recovered yet from the Tucson Basin. A large agricultural field system was also discovered containing primary and lateral canals that delivered irrigation water from the Santa Cruz River to hundreds of small fields. This field system has now been well-documented, and its history of development and modification through time reconstructed in detail.

Primary research issues investigated at Las Capas include chronology, artifact analyses, irrigation technology, subsistence systems, and syntheses of Early Agricultural lifeways. In short, the excavations at Las Capas have provided an ideal opportunity to study an Early Agricultural irrigation community in detail from the "production" end—fields, canals, and their contexts—to the "consumption" end of domestic living.

The results of the Las Capas investigations are presented in a series of Anthropological Papers, Technical Reports, and a book published, variously, by Archaeology Southwest and Desert Archaeology. The two Anthropological Papers provide a broad overview and synthetic examination of the site, with a specific emphasis on the reconstruction of prehistoric life in the northern Tucson Basin during the Early Agricultural period San Pedro phase. One volume (Anthropological Papers No. 50) provides the environmental and cultural context of the Las Capas project area. The environmental setting is discussed in detail, as it is the "stage" on which all cultural behavior is enacted. The complex mix of environment and culture defines the "Anthropogenic Landscape," the overarching research theme of the Las Capas Archaeological Project. The other volume (Anthropological Papers No. 51) explores the cultural and behavioral components of the San Pedro phase Las Capas occupation and the Early Agricultural period occupation of the Tucson Basin in general.

The five Technical Reports focus on more specific research issues, providing data that may be of interest to a more limited or specialized audience. The Technical Reports include discussions of the field methods, feature descriptions and descriptions of the mortuary assemblage, and an experimental analysis examining Early Agricultural period agriculture and ground stone tool production. A map packet is also

included as a Technical Report, with areal maps showing the project area and feature location by individual locus. Finally, the book is available that presents the first comprehensive study of Early Agricultural period projectile points in the greater Southwest United States, including both typological and behavioral interpretations.

The Las Capas-related publications are as follows:

Anthropological Papers

Vint, James M. (editor)
2015 *Implements of Change: Tools, Subsistence, and the Built Environment of Las Capas, an Early Agricultural Irrigation Community in Southern Arizona*. Anthropological Papers No. 51. Archaeology Southwest, Tucson.

Vint, James M., and Fred L. Nials (editors)
2015 *The Anthropogenic Landscape of Las Capas, an Early Agricultural Irrigation Community in Southern Arizona*. Anthropological Papers No. 50. Archaeology Southwest, Tucson.

Technical Reports

Adams, Jenny L., Joyce Skeldon Rychener, and Allen J. Denoyer
2015 *Las Capas Archaeological Project: Ground Stone and Maize Processing Experiments*. Technical Report No. 2014-02. Desert Archaeology, Inc., Tucson.

Price-Steinbrecher, Barry, George L. Tinseth, J. Homer Thiel, John R. McLelland, Rachel M. Byrd, and James T. Watson
2015 *Las Capas Archaeological Project: The Burial Assemblage*. Technical Report No. 2014-09. Desert Archaeology, Inc., Tucson.

Sinensky, Robert J., Jessica M. South, Barry Price-Steinbrecher, and George L. Tinseth
2015 *Las Capas Archaeological Project: House and Extramural Surface Descriptions*. Technical Report No. 2014-08. Desert Archaeology, Inc., Tucson.

Theriot, Tyler S., and Catherine B. Gilman
2015 *Las Capas Archaeological Project: Map Packet*. Technical Report No. 2014-10. Desert Archaeology, Inc., Tucson.

Whitney, Gregory J., Robert L. Sinensky, George L. Tinseth, Barry Price-Steinbrecher, and Jessica M. South
2015 *Las Capas Archaeological Project: Field Methods, the Retention Basin, and Extramural Feature Descriptions*. Technical Report No. 2014-01. Desert Archaeology, Inc., Tucson.

Book

Sliva, R. Jane
2015 *Early Agricultural Period Projectile Points: Typology, Migration, and Social Dynamics from the Sonoran Desert to the Colorado Plateau*. Archaeology Southwest, Tucson.

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ACKNOWLEDGMENTS

The opportunity to conduct experiments as part of a cultural resource management project is unique, and I thank Bill Doelle and Jim Vint for providing the support and encouragement to conduct this research. Participants in the experiments at various times included Mario Arechederra, Katie Brower, Allen Denoyer, Mary Ownby, Stacy Ryan, Joyce Rychener, and Jim Vint. Most of the staff at Desert Archaeology visited either the parching or grinding experiments and tasted the product or provided their opinions; I particularly thank Mike Diehl and Val Hintze. Val, Joyce, Allen, and I took photographs that were used in this report. Rob Ciaccio produced several line drawings. Katie was instrumental in measuring product and organizing the database for the figures. As always, the support and extra efforts of the production department, Emilee Mead and Susan Hall, are greatly appreciated.

CHAPTER 1

AN EXPERIMENTAL APPROACH TO ANSWERING THE QUESTION – HOW DID THEY DO THAT?

Jenny L. Adams
Desert Archaeology, Inc.

It is unusual for a cultural resource management project to accommodate experimental research. Excavations conducted by Desert Archaeology, Inc., personnel in 2008 and 2009 at the Las Capas site, AZ AA:12:111 (ASM), uncovered portions of an unusually significant settlement in an area now covered by the Ina Road Regional Wastewater Reclamation Facility. Due to its early occupation dates, ranging primarily from 1200 B.C.-A.D. 50 (the Early Agricultural period), its irrigated fields, and its importance to the archeological record not only in the Tucson Basin but also to the borderlands of the U.S. Southwest and Mexico, a broad research program was developed to learn as much as possible about the people who lived there.

In this report, an experimental study conducted in concert with the analysis of ground stone artifacts recovered from Las Capas is described. The experiments were designed specifically for exploring issues important to ground stone research, and they follow guidelines about designing scientific experiments in general and archaeological experiments specifically (Adams 2010, 2014a:67-75; Amick and Mauldin 1989; Diamond 1989; Mathieu 2002; Miller 2007: 34-35; Robinson 2000; Semenov 1964; Vaughan 1985). For more than 70 years, replication studies and exploratory and confirmatory experiments have been providing archaeologists the opportunity to work with the types of tools they study. Replication studies are designed to reproduce techniques for achieving an outcome similar to what is in the archaeological record and are most commonly conducted for projectile points and pottery. The Las Capas experimental study replicates possible planting and harvesting techniques, as well as the manufacture of the stone and fired-clay pipes. Replications help identify which independent variables to manipulate and the dependent variables from which to create hypotheses for testing with experiments.

Exploratory experiments, such as the maize processing tasks described here, are designed to select an independent variable, operate a particular task, and create baseline data against which the results of other experiments can be compared. They show that conceptualized hypotheses about how tools generate product cannot substitute for seeing tools in action, and, perhaps most importantly, they identify issues that have yet to be conceptualized. Additional but differently designed exploratory experiments, as well as confirmatory experiments that test if the same results are accomplished every time, have yet to be conducted for the Las Capas experimental study. The potential for such research is discussed in the concluding chapter of this report.

A programmatic approach to experimentation is foundational for modeling past manufacturing and use behaviors, especially in archaeological contexts where there is no direct documentation through ethnography or personal accounts. However, descriptions of activities and tools recorded in the ethnographic literature provide data with which a range of models can be designed for experimentation. For the Las Capas study, models generated from the ethnographic literature of the borderlands are combined with the results from replication and exploratory experiments to create workable correlates for evaluating the association of Early Agricultural period features and tools with food production and pipe manufacture.

The excavations at Las Capas uncovered significant new information about the fields and crops of early agriculturalists living along the Santa Cruz River in the Tucson Basin (Vint and Nials 2015). Some of the maize phytoliths recovered from feature and refuse deposits at Las Capas were identified as closer to Chapalote and Reventador than any other modern maize variety. Other maize phytoliths were from possible hybrids with teosinte, *Zea diploperennis, Zea perennis,* and *Zea mays* (Cummings et al. 2013:12; Diehl 2015). Not only are the species identifications important, but it is also exciting to learn there were a variety of maize crops grown at Las Capas. Based on the experiments and ethnographically based models, we can explore the reasons why different maize varieties might have been grown by early agriculturalists, as well as the possible techniques for incorporating different maize varieties into their diets given the types of tools they used.

Fields were planted at Steam Pump Ranch to grow, harvest, and process three varieties of maize, Chapalote, Reventador, and Tohono O'odham 60-day (Chapter 2, this volume). Chapalote and Reventador are popcorns, and Tohono O'odham 60-day is a variety of flour maize included to serve as a control for comparisons during all maize processing experiments. Chapalote and Reventador are most commonly considered the oldest maize varieties in northwest Mexico (Pennington 1963:40, 1980:126-127) and in the U.S. Southwest during the San Pedro phase (1200-800 B.C.) (Adams 1994:276; Matson 1991:209-216, 250; Nabhan 2013; Wills 1988:38). Floury varieties of maize are scarce in the archaeological record of the borderlands until about A.D. 500 (Adams 1994:286, Tables 16.3-16.9; Adams et al. 1999:484). The types of tools used by early agriculturalists for food processing included manos and metates and mortars and pestles. A few possible food-processing mortars and pestles were recovered from Las Capas, although the experiments were designed to focus on the basin and flat/concave manos and metates (Chapter 3, this volume) (Figure 1.1).

Pipes recovered from Las Capas were made from both stone and fired clay (Adams 2015). These are the earliest pipes and the earliest evidence for their local manufacture in the Tucson Basin (Chapter 4, this volume) (Adams 2005, 2014). Pipes have not previously been associated with contexts that date later than the Cienega phase (800 B.C.-A.D. 50). It should be noted, however, that stone pipes recently

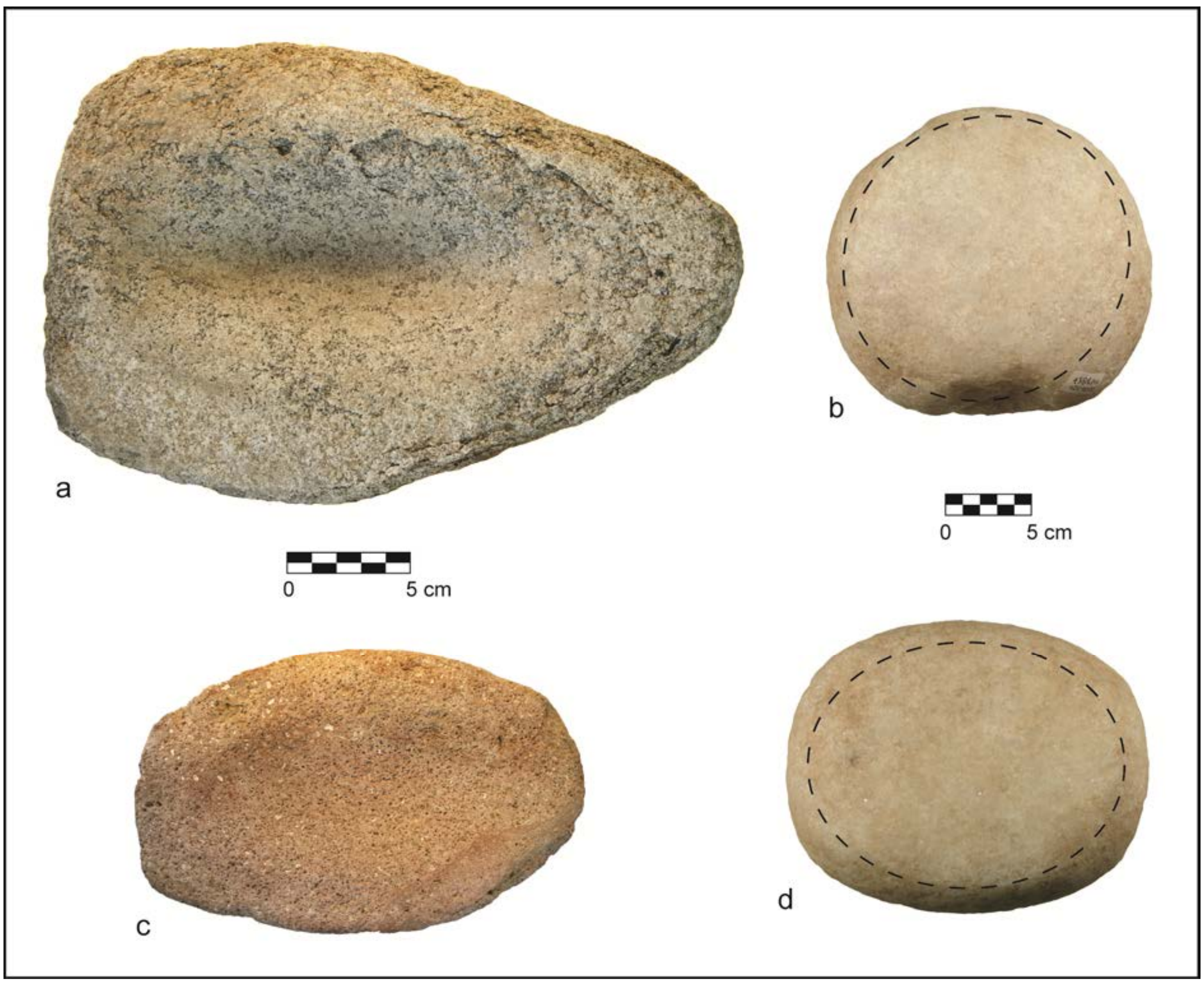

Figure 1.1. Mano and metate types recovered from Las Capas, AZ AA:12:111 (ASM): (a) basin metate [Feature No. 7403, FN 13089, Catalog No. 2008-329-473]; (b) basin mano [Feature No. 9302, FN 13857, Catalog No. 2008-329-474] (Adams 2015:Figure 3.3c); (c) flat/concave metate [Feature No. 7632, FN 13689, Catalog No. 2008-329-475]; (d) flat/concave mano [Feature No. 8835, FN 13682, Catalog No. 2008-329-476].

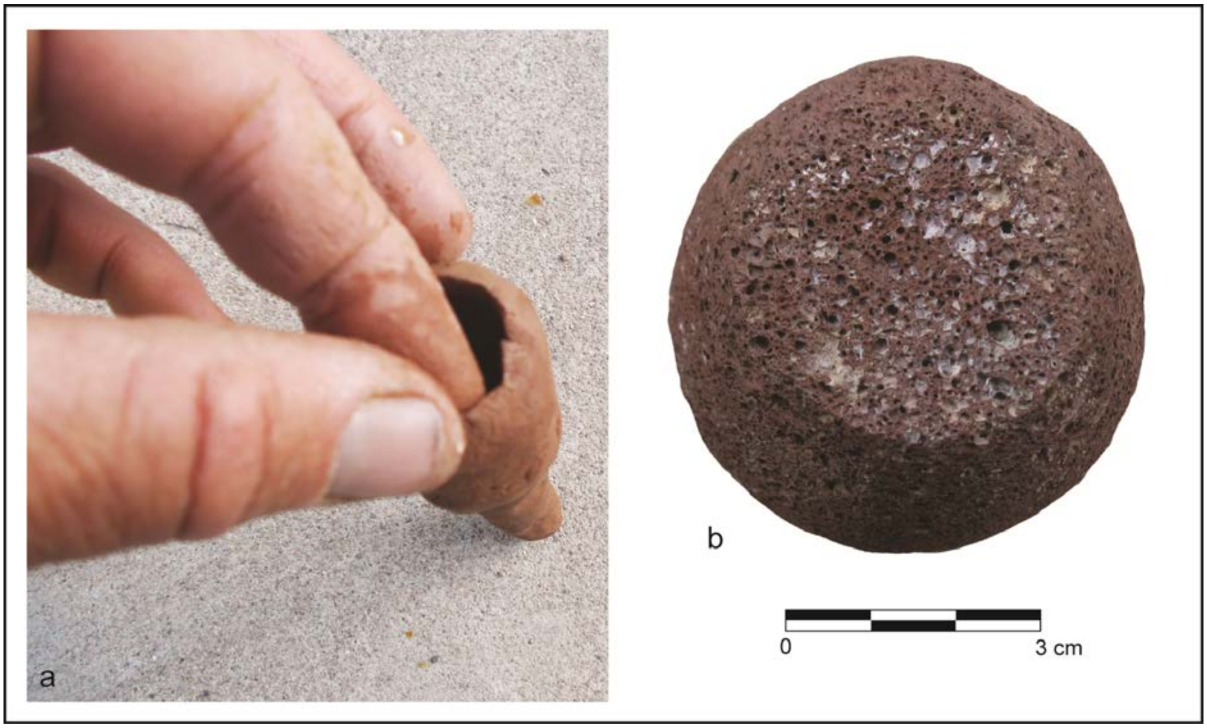

Figure 1.2. Pipe manufacturing experiments: (a) finishing the rim of a clay pipe before firing; (b) vesicular basalt pipe before the bore was drilled.

found at the Ironwood site, AZ AA:12:226 (ASM), were possibly in Hohokam contexts (Doug Mitchell, personal communication 2014). Russell (1975:112, 229, 260, 278) provides no description of Pimans smoking pipes, but he describes the Pima using pipe-like tubes for sucking illness out of patients, blowing cigarette smoke to identify illness, and he wrote down the words to songs that make references to pipes. In the northern U.S. Southwest, Puebloan pipe smoking has been described as both social and ritual (Adams 2014a:213; Stephen 1936:683). The experiments described in Chapter 4 replicate the manufacture of both stone and fired-clay pipes (Figure 1.2), but how they were used for smoking is left for future experiments.

BUILDING THE MODELS

Ethnographic sources provide behavioral and material culture examples that can be modeled for both experimentation and for comparison with the archaeological record. Nutritional studies and ethnographic sources provide examples of why certain foods are beneficial and how foods are chosen for consumption (Beadle 1939, 1972; Beaglehole 1937; Beck 2001; Bennett and Zingg 1976; Brenton 2003; Cushing 1920; Doolittle 1992; Ellwood et al. 2013; Hernàndez Xolocotzi 1985; Holden 1936; Katz et al. 1974; Keene 1985; Mangelsdorf 1974; Pennington 1963, 1969, 1980; Pilcher 1998; Rea 1997; Russell 1975; Smalley and Blake 2003; Spier 1933; Whiting 1939). For example, information collected in the late nineteenth and early twentieth centuries describes how different maize varieties are planted for specific uses by the Tarahumara and Tepehuan, and those processing tasks include juicing and parching (Pennington 1963:75-76, 1969:99) Nutritional studies describe how consuming immature maize is more beneficial and takes less effort than consuming dried maize.

Additional ethnographic and archaeological sources contributing to the Las Capas research include O'odham groups (previously known as Pima and Papago), Zuni, Pai, Hopi, and other Native Americans living in the broader U.S. Southwest (Bartlett 1933; Euler and Dobyns 1983; Hough 1915; Parsons 1939; Spier 1933:127; Stephen 1936; Underhill 1979). There are few details in ethnographic descriptions about food-processing tools and no information comparing the use of different tool types. Therefore, without using replicated tools to work the product, assumptions about their use and efficiency are primarily conjectures. The challenge for the Las Capas project, and what makes early agriculturalists distinctive from ethnographic groups, is that they did not use clay pots for storing or cooking their foods.

Similarly, nothing in the ethnographic literature of the Southwest describes the manufacture of stone and clay pipes. Kidder (1932:84, Figure 60) illustrates the archaeological evidence for different stages of tubular pipe manufacture recovered from Pecos Pueblo in New Mexico, but this information does not apply to most of the pipes found at Las Capas. Even though neither stone nor clay pipes were typical of Hohokam smoking technology, they were used elsewhere in the broader Southwest during the same time period and again in the borderlands during protohistoric and historic times (Di Peso 1956:426-430; Ferg 1998:595-606; Haury 1957:19; Roney and Hard 2002:164; Wheat 1955; Woodbury 1954:175). Replication studies were designed to demonstrate at least two methods that could have been used at Las Capas for pipe manufacture based on evidence found there (see Chapter 4).

THE EXPERIMENTS

Exploratory experiments are designed to deliberately vary independent variables to determine what happens and to identify the dependent variables that indicate process (Adams 2010:143; Robinson 2000:30). In the field, the independent variables are the maize varieties, while the harvested products are the dependent variables. The nature of the harvest is dependent on human reactions to environmental factors, including: (1) crop maintenance, such as improving soil development with fertilizer and supplementing the moisture derived from rain with irrigation water; and, (2) harvest schedule, such as picking produce when immature or mature (see Chapter 2). The products harvested from the field are immature and mature maize ears and stalks. Among the processing experiments, mano and metate types and maize variety are the independent variables. Basin and flat/concave mano and metate types are used in the experiments to process three types of maize harvested at different stages of development (Figure 1.3). The dependent variables that demonstrate process are grindability, efficiency, product texture, and taste (see Chapter 3).

Location, Location, Location

Scientific experiments are typically thought of as clinically clean, controlled in every detail, and tediously recorded. Experiments conducted for archaeological purposes are sometimes set up in the laboratory in an attempt to standardize observations and to consistently control some variables and systematically vary others. Other times, experiments designed to answer archaeologically derived questions are conducted in an environment similar to where tools were used in the past. Replication of

Figure 1.3. Two processing tasks comparing grindability of immature and mature dried kernels: (a) immature ear and kernels rubbed across the surface of a metate without a mano; (b) partially ground dried mature kernels.

planting and harvesting techniques in the natural environment means that some variables cannot be controlled, such as the weather and predators. The Las Capas farming experiments attempted some control by planting the seeds of each maize variety in separate sections to avoid cross-pollination (see Chapter 2). Records were kept to retain planting, watering, and harvesting data, and photographs were taken of the various stages in the growth and maturation of the maize plants.

Parching and pipe manufacturing replications were also conducted outside. Maize ears and kernels could have been parched in a laboratory using an oven with controls for temperature and length of time; however, an outdoor setting was chosen because the strategy was to explore traditional maize parching in pits without the use of pots (Figure 1.4). An ash and charcoal filled pit similar to those used to parch maize ears was used to fire the replicated clay pipes. Clay for making the pipes was gathered from the Las Capas area, and the sticks used to make molds for the fired-clay pipes and stone for the stone pipe bowls were from the Santa Cruz River. Bones for the pipe stems were recovered from modern trash contexts.

Some of the Las Capas grinding experiments were conducted in the laboratory to control for time and to standardize measurements of product (Figure 1.5). The independent variables of metate type, maize variety, and maize condition (immature, mature, fresh, dried, or parched) were varied to compare processing efficiency of manos and metates measured by texture of the product after 30 minutes of grinding. Time was held constant, and the ground product was measured in standardized increments using graduated sieves. The measured results are easily compared in graph form (see Chapter 3).

ASSESSING THE EXPERIMENTS

The experiments conducted for Las Capas established an ideal baseline for the continuation and expansion of experimental studies related to ground stone research. The models formulated from the ethnographic and nutritional literature include using basin and flat/concave manos and metates for processing immature and mature varieties of maize by juicing stalks and by grinding fresh, dried, and parched kernels. The documentation of use-wear on the manos and metates created under known circumstances provides additional data from these experiments. Impact fractures and abrasions on the surfaces of experimental tools are similar to those observed on the tools recovered from Las Capas. The unused and used surfaces of replicated food-processing tools were photographed microscopically and macroscopically (Figure 1.6). Patterns that have been replicated experimentally allow distinctions to be made between damage caused by manufacturing or use and damage caused by post-use situations, such as burial, trampling, excavation, and curation.

The planting and harvesting replications were successful in growing an abundance of ears and stalks for the processing experiments. Sequential planting and harvesting enabled us to compare the product from mature and immature plants and to demonstrate that it is possible to prolong field productivity.

Figure 1.4. Outside context of parching experiments: (a) setup of pits use for parching whole ears of maize; (b) kernelling of parched kernels.

Figure 1.5. Laboratory experiments: (a) kernels measured and bagged for controlled experiments; (b) beginning of controlled experiments comparing the grinding of parched Chapalote with basin and flat/concave manos and metates.

The processing experiments further demonstrate that early agriculturalists at Las Capas had the plants, tools, and features necessary to create a variety of recipes. They had the potential to control the taste and texture of the product by choosing to juice stalks, to harvest immature or mature ears, and to select fresh, dry, or parched kernels for processing. The parching experiments compared two techniques for parching maize in pits without the use of ceramic pots and determined that ears of maize are easier to parch than kernels. Fortunately, the pits used during the parching experiments illustrate the effects of thermal events in two different types of pits, using open flames in one type and charcoal-sustained heat in another (see Chapter 3).

The whole and broken pipes recovered from Las Capas provide clues about how they were made. A successful strategy was developed for replicating their manufacture, with flaked stone tools used to drill the bores and shape the tobacco chambers. As happened with the experimental manos, the additional advantage is the documentation of use-wear created under known circumstances on the bifaces (see Chapter 4).The replication of fired-clay pipes was successful in making the same types of impressions in the tobacco chamber seen in the fired-clay pipes at Las Capas. The use of a mold has not been identified in other ceramic traditions of the U.S. Southwest. The replications of both stone and fire-clay pipes, therefore, provide testable hypothesis for more controlled experiments to determine if the results achieved in this pipe-making study are replicable.

Each of these replication studies and exploratory experiments is now a model for future studies by creating a database consisting of independent and dependent variables. More exploratory experiments will broaden the database, which is one goal for future research, although confirmatory experiments will be conducted to determine if the results are consistently replicated.

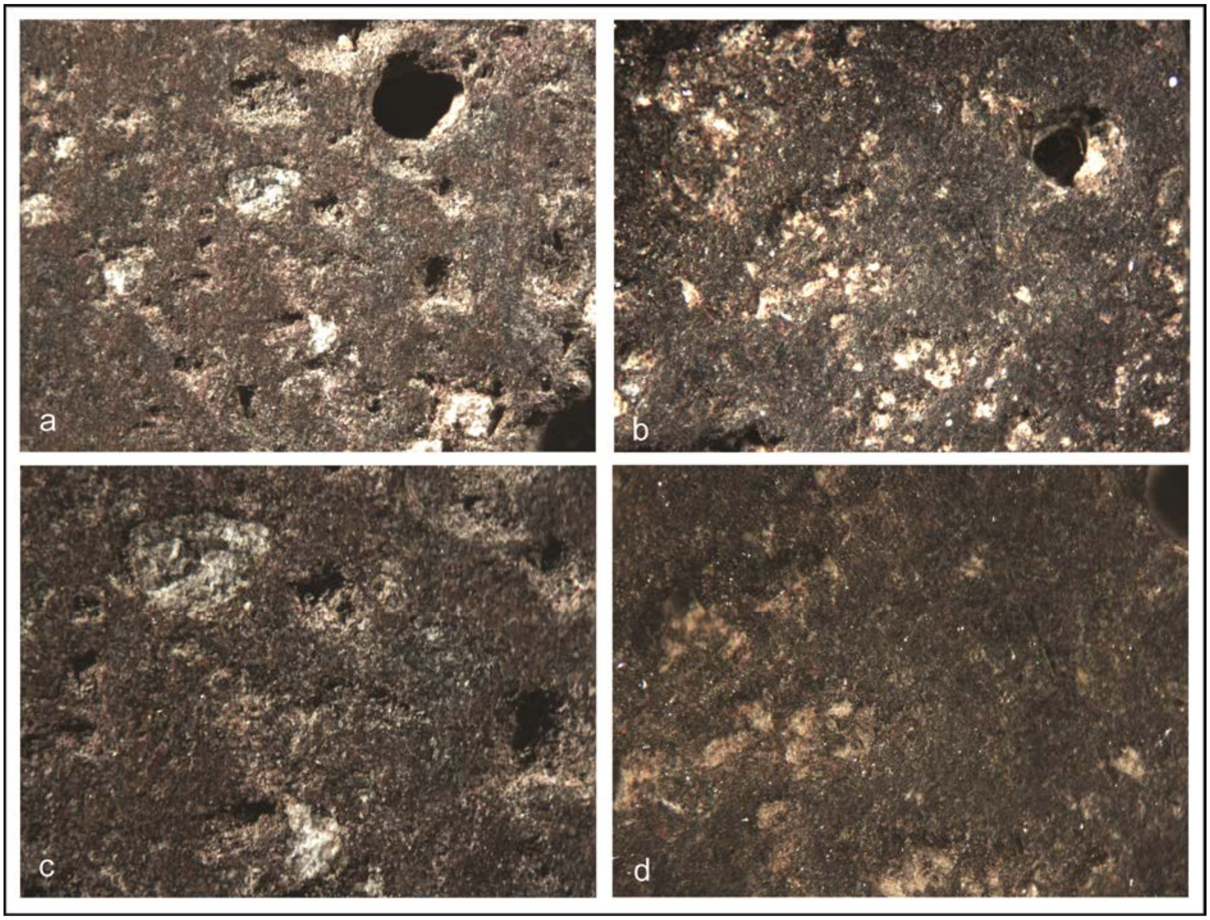

Figure 1.6. Photomicrographs of an experimental flat/concave mano: (a) unused surface at 20x; some of the margins between the vesicles were flattened during manufacture; (b) unused surface at 40x; (c) used surface at 20x; the surface is more uniformly flattened after more than 10 hours of use; (d) used surface at 40x.

CHAPTER 2

GROWING TRADITIONAL CROPS IN THE SONORAN DESERT NATIVE AMERICAN HERITAGE GARDEN: A PERSONAL PERSPECTIVE

Joyce Skeldon Rychener
Steam Pump Ranch

The Native American Heritage Garden of Steam Pump Ranch is located north of Tucson, Arizona, at the foothills of the Catalina Mountains next to Cañada del Oro Wash (Figure 2.1). My purpose at the garden is to grow traditional varieties of crops that have been grown in this region for thousands of years and to contribute to ongoing archaeological studies by growing varieties that are most similar to excavated specimens. I learned to garden when I was young, from a master gardener in Mendocino, California, on the ridge above the Navarro River. It came easily to me, as I have always loved the natural world and felt a special connection to plants. The soil in Mendocino was acidic and extremely fertile. We grew just about everything in a huge garden, big healthy cabbages and heads of lettuce, sweet peas, carrots, onions, sunflowers, and more.

Most of what I learned from that region had to be translated into different practices when I moved to the Sonoran Desert. I initially found it a harsh and difficult growing environment, but after years of trial and error, and learning from others, I began to understand how to grow plants in this soil and climate. My teachers included Apache and Tohono O'odham native gardeners, as well as wonderful books like Wilson (1987) and Caduto and Bruchac (1996). Most recently, I have enjoyed reading Underhill (1938), which captures the spirit of desert gardeners and their reverence for maize.

One of my many plantings was of Tohono O'odham 60-day maize at our ranch in Aravaipa Canyon, near the Aravaipa Creek in central Arizona. The area had been a traditional corn and squash farming site of the Arivaipa Band of Apaches until their removal to the San Carlos Apache Reservation (Seth Pilsk, personal communication 2011). The soil is sandy silt deposited by numerous overbank floods from Aravaipa Creek, and I did nothing to improve it. The crop was, however, watered by an automatic drip system when needed. As with past crops, the ears were small, 3-4 inches long, with incomplete kernel development (Figure 2.2). Following that harvest, I planted several different varieties of maize in my Aravaipa Garden to determine if the crop would improve with the addition of manure to the soil prior to planting. I also manually assisted the pollination process. The results were significantly longer ears with more numerous and fully developed kernels.

I began planting the Heritage Garden at Steam Pump Ranch in 2009. The first garden was planted with Tohono O'odham 60-day seeds. Jenny Adams, of Desert Archaeology, Inc., heard about my ancient maize growing project at Steam Pump Ranch from Henry Wallace, also an archaeologist with Desert Archaeology. I attended many presentations and tours conducted by Henry of Honey Bee Village, AZ BB:9:88 (ASM), during its excavation. Jenny asked me to grow specific traditional crops for her and work with her on grinding experiments. I grew three varieties of maize for three years, and helped with grinding and parching maize kernels and juicing maize stalks (Chapter 3, this volume).

THE STEAM PUMP RANCH NATIVE AMERICAN HERITAGE GARDEN

The garden is located on the southeastern floodplain of the Cañada del Oro Wash. I hoped to find the highest spot on this relatively level and vegetation-free plot of land and situate the garden below that point to take advantage of gravity flow and rainwater that would run into the garden (Figure 2.3a). When the summer rainstorms came, I watched where the water made gullies and knew that these gullies would take the precious topsoil and seeds away. To harness any runoff, I built raised earthen berms around the sunken planting beds and plastered the berm walls with wet clay (Figure 2.3b). I built small canals to direct rainwater and irrigation water into the garden (Figure 2.3c), such that one sunken bed would fill with water and the overflow would be directed into the next sunken bed. The fields excavated at Las Capas were the inspiration for this system even though the water delivery system was different at the site.

Figure 2.1. Native American Heritage Garden, Steam Pump Ranch, Oro Valley, Arizona; Chapalote maize in the foreground and Catalina Mountains in the background.

Figure 2.2. Underdeveloped ear of Tohono O'odham 60-day maize with incomplete fertilization of kernels.

Figure 2.3. The Native American Heritage Garden: (a) layout of the garden on the flat, vegetation-free landscape; (b) sunken planting beds with raised berms; (c) rainwater basin with ditch (bottom of the photograph) to the garden (top of the photograph); (d) first Chapalote seedlings in a mound.

The Soil

It all begins with the soil. In 2009, when I began preparing ground for the garden, the soil was so hard I could not get my shovel to penetrate it. Cattle and horses lived on this land for decades, which resulted in very compacted soil. Native plants were few, and strong winds had blown away much of the topsoil. Most likely, pesticides had been applied for many years. The ground was hard, barren, and empty of any life, except the red ants.

Changes began slowly with the application of water. A lizard appeared as the first animal. He was curious and brave. I began to break through the compacted soil with forceful jets of water from my hose, which eventually broke through to gravelly, sandy soil about a foot below. I began to turn the soil over with my shovel and hoe and added soil sulphur and mulch—organic matter gathered from beneath the nearby mesquite trees. Years of livestock manure accumulation made the soil very nitrogen rich, so no fertilizer was added the first season. After the first season, I added cattle and horse manure from my ranch in Aravaipa Canyon, and more organic sulphur. I have noticed that if I prepare the soil correctly from the start, everything goes better all the way through the growing season.

The Water

I had seen photos and the dioramas at the Arizona Historical Society and Arizona State Museum depicting Hohokam systems of diverting water from washes and rivers using canals and weirs and tried to replicate those methods. Most of it is common sense using the natural contours of the land, the pattern of water movement and gravity flow, and laying out the fields in such a way as to capture the most runoff. Berms need constant upkeep, shaping and compacting and, on occasion, plastering with clay so they are solid and keep the water where it is supposed to be. A breech in the berm can cause serious water loss and erosion resulting in lost crops and unwanted gullies.

Average rainfall in the garden area is 12 inches per year. Because the stalks and ears of maize grown in this garden were needed for the experiments, the decision was made to supplement. Well water was brought to the garden through a hose, and each sunken bed was flooded as if it were rain water, but only when rainfall was not sufficient. During pollination season, when the temperature exceeded 100°F and there were no monsoon rains, a central sprinkler cooled the air above the plants.

The Seeds and Planting

For three seasons, 2011-2013, I grew three types of maize for the experiments. Two are popcorn varieties, Reventador and Chapalote, and one is flour maize, Tohono O'odham 60-day (Figure 2.4). Reventador was grown in 2011 and 2013, Chapalote and Tohono O'odham 60-day were grown in all three seasons. Reventador and Tohono O'odham 60-day seeds were purchased from the Native Seeds/SEARCH

Figure 2.4. Three varieties of corn planted in the Native American Heritage Garden at Steam Pump Ranch: (a) Chapalote, considered a popcorn; (b) Reventador, considered a popcorn; (c) Tohono O'odham 60-day, considered a flour corn.

Figure 2.5. First row of Chapalote planted in July 2012.

store. The first Chapalote seeds were given to me by ethnobotanist Martha Burgess, who acquired them from Barney Burns, both of Native Seed/SEARCH. Seeds saved from my first and second planting seasons were mixed with Native Seeds/SEARCH seeds to provide greater biodiversity.

The planting strategy was the same for all three years, only the dates changed depending on the timing of the second monsoon rain. For example, I planted the first Chapalote seeds on 5 July 2012. In four days, 9 July, the seedlings emerged. They were a good, healthy green color but showed some grasshopper damage on 11 July. On 16 July, I planted more Chapalote seeds from a Native Seeds/SEARCH packet and continued to plant at intervals until the last of the first planting on 24 July. I expected to harvest mature ears from these first plantings around 24 October, since Chapalote has approximately a 90-day growing cycle (Figure 2.5).

Second sequential plantings were on 4 August and 11 August 2012. These were done for several reasons: (1) to maintain a longer growing season for the garden as a whole; (2) the garden was too big to plant all at once; (3) we wanted to have the maize available in different stages of growth for the experiments; and, (4) so everything did not need harvesting at the same time. First sprouts appeared four days after planting, and they grew about 1 inch per day (Figure 2.6a). I found this to be a typical emergence rate during the summer rains, although it can take up to 10 days for first sprouts to emerge when planted earlier or during cooler seasons. I expected to harvest ripe ears from the second planting around 10 November 2012. On 1 September, female florets had formed (Figure 2.6b), and the male tassels started to shed some pollen (Figure 2.6c).

Four mounds with depressed centers were made in each sunken bed divided by earthen berms (see Figure 2.3b). Four or five seeds were planted in each depression, 4 inches apart and 1 inch deep. Maize likes to be planted in clumps, blocks, or in large clusters rather than one lone, long row so pollination can

Figure 2.6. Chapalote plants: (a) first maize sprout; (b) arrow points to the first Chapalote floret (female part of plant), which appeared on 29 August 2012; (c) first Chapalote tassels (male part of plant), which appeared on 26 August 2012; (d) pollen moving down the plant into the base of a leaf (at arrows).

readily occur. Seedlings emerge on average in four days during the warm and rainy season, and grow almost 1 inch per day (see Figure 2.3d).

Maize was planted first, followed by beans, and then squash. The beans fix the nitrogen in the soil, making it available to the maize, which is a heavy nitrogen feeder. The maize, in turn, provides support for the growing bean runners. The squash spreads out among the maize stalks and acts as natural mulch, cooling off the soil around the maize and bean plants. The prickly squash stems also deter some pests. Many other factors greatly influence the success of the harvest and the size and formation of the ears. The pollination and fertilization period is the most critical stage of development for the maize crop, and severe heat or drought stress during this period can greatly diminish the successful formation of maize kernels.

Harvesting

The gardens planted during the summers of 2011-2013 were sequentially and partially harvested when the plants were immature, mature, and dried in the field. The experiments for which the produce would be used focused on how maize could have been incorporated into the diet of the inhabitants of Las Capas, AZ AA:12:111 (ASM). The choices to plant and harvest were guided by discussions in the ethnographic and nutritional literature (see Chapter 3; also Adams 2014b, 2015). One choice was to pick ears and stalks for processing while they were immature for comparison with ears and stalks that were allowed to mature.

Upon the advice of ethnobotanist Dr. Karen Adams, a taste test was conducted to evaluate the degradation of sweetness of harvested immature ears. An immature Reventador ear was tested at 11:15 am on 28 August 2011. When poked with a thumbnail, the pliable kernels produced a milky liquid; the same happened at 11:23 am when a kernel was tasted. The taste was surprisingly sweet. Kernels on the same ear were poked again at 12:35 pm and 1:52 pm, but at 3:17 pm, when poked, the kernel was drier and the liquid was thicker. Poked again at 7:13 pm, the liquid was even thicker and continued to thicken past 9:37 pm and 7:52 am the next morning. That morning the poked kernel was noticeably less sweet. By 5:13 pm of the day after picking, the kernel was pasty, and by 7:01 am the second day, 30 August, after picking, no liquid came out when poked. The taste at this time was still sweet but also a little starchy. The same was noted for a taste test on 31 August at 9:15 pm. By 2 September, the taste was only slightly sweet, and the kernels were resilient, but not hard. The sweetness diminished over a two-day period, although even when starchy and mature, the Reventador kernels retained some sweetness.

Fresh, immature ears of Reventador and Tohono O'odham were picked in 2011 on 2 September, and on 3 September, the kernels were scraped off and packaged for grinding. Some ears were left to dry, and the immature kernels were easily removed from the cob. The pericarp floated off and was easily winnowed away. Both in the immature, fresh stage and the mature, dried stage, the Tohono O'odham kernels were much easier to remove from the cob and to grind into a useful product than the Reventador kernels.

Harvesting for immature Chapalote ears began on 26 September 2012. The kernels tasted as sweet as remembered for the Reventador. This time, however, Jim Vint tested the sugar content of each ear with a refractometer. They averaged 16 on the Brix scale, as sweet as modern sweet corn. The stalks measured 5.0 on the Brix scale, as sweet as asparagus. The refractometer is the kind used by beer brewers and wine masters to determine the amount of sugars in a solution by measuring refracted light passing through the suspension. The Brix scale standardizes the measurement of suspended solids, and if there are solids other than sugar in the solution, the measurement is only an approximation. On the Brix scale, 4.5 is a poor level of sweetness for modern corn. Based on the sweetness taste test described for immature popcorn kernels, it is assumed that as the kernels mature, starch more than sugar is responsible for refracting the light.

The ears were harvested by pulling downward on the ear and giving it a final twist to detach it from the stalk. I laid the stalks on a table inside my house to dry to prevent rodents from eating the ears. Sometimes, we left the husks on the ears, and at other times, we experimented with husking the ears first and then letting them dry. The kernels dried and hardened more quickly after the ears were husked. The husks were left on and the silks were pulled off a few ears that were going to be parched.

Stalks for juicing were harvested at three different times. The first Reventador stalks were cut 17 June 2013, before ears were formed on the stalks. The second harvest of stalks was when the ears were immature, and the third was when the ears were mature. The stalks were cut with metal tools, and the leaves were stripped in preparation for immediate juicing.

Processing

Although I had grown traditional maize crops for many years, I had no access to the traditional tools needed to process what was harvested. I loved being able to view and work on ancient or accurate replicas of basin metates. Something about the process of simultaneously grinding maize with others seemed very familiar to me. I had to adjust my natural behavior significantly while grinding the maize for the experiments, as each session was precisely timed and the results analyzed. Normally, I do not track time, and like to talk, laugh, and gesture with my hands, which all interfere with accurate measuring of grinding times. Also, I am attuned to the beauty of maize, and it was hard for me not to just stop and view the ears through the eyes of an artist setting up a painting. Growing crops requires very keen observation; there is the necessity to closely watch each plant as it goes through its life cycle, and I can spend hours doing so without noting the passage of time. The scientific experience was different in the sense that I had to pay attention to the time and try to be consistent in my grinding methods. I worked hard at focusing only on the task at hand.

Parching ears and juicing stalks were also new experiences for me. It is easy to burn the kernels, and we learned how to use a tool for handling the hot coals and ears necessary to avoid seriously burned hands. The parching process was very smoky. I was also impressed by how much juice was easily squeezed from the young stalks as opposed to the more mature stalks. The sweetness of the juice surprised me, and I will continue to view the stalks as a food source. I would like to experiment with allowing the juice to evaporate and leave sweet crystals of maize sugar.

Observations

I try to closely observe as much as possible as often as possible. Roadrunners, cactus wrens, and other birds and animals can easily consume the tender maize seedlings when they emerge, so I always replant what has been destroyed. Once my plants make it through this series of onslaughts, the leaves become tougher and growth is fast. Moths lay eggs inside the whorls, and these turn into larva, also called corn worms. I try to minimize grasshopper damage with constant vigilance, picking off the grasshoppers by hand (Figure 2.7a).

Rock squirrels (*Spermophilus variegatus*) (Figure 2.7b) and Botta's pocket gophers (*Thomomys bottae catalinae*) are both harmful to the maize plants. Squirrels eat the stalks, tassels, and especially the ears of maize as soon as they are ripe. Gophers eat at the roots from below and pull the whole plant down through their holes into their tunnels (Figure 2.7c). The negative impacts of the gophers and the squirrels are numerous, and include the possibility of destroying or severely damaging an entire crop. They are very difficult to control, and because I use no poisons in my garden, the most effective way to manage them is with traps. I have also poured into or stuffed gopher holes with hot chili peppers, onions, garlic, datura, and sulphur with some success.

The positive impacts of the gophers are that they significantly aerate and fertilize the soil, providing food for microorganisms that are necessary for productive soil. Interestingly, I have observed that maize sprouts will spontaneously emerge far from the original gardens. Occasionally, an entire ear of Chapalote will germinate in the compost pile. Because the gophers and squirrels have buried kernels and ears in their tunnels and dens, these too will germinate and sprout. I wonder how much these spontaneous events contribute to cross-pollination, and I can see that sometimes, maize grows without human intentions.

When I first started gardening at this site in 2009, four Harris hawks lived on the property and were constantly vigilant sitting on the electrical lines over my field. After several years, these hawks left, perhaps because big-horned owls moved in, but I started having real trouble with the gophers after the Harris hawks left. Also, for the sake of safety, rattlesnakes were constantly being removed from the Steam Pump Ranch property; as a result, I believe the pocket gophers increased dramatically. I recently noticed a rattlesnake had taken up residence in one of the squirrel tunnels near the garden (Figure 2.7d), and I believe this will help with rodent control.

CONCLUSION

I am intrigued by the entire process of growing traditional maize from start to finish. Every stage has unique features to observe, but a highlight is the pollination stage. After the pollen grains form on the tassel, they fall down the stalk onto the silks that are emerging from the ear. The pollen grains penetrate the silk and grow down to the embryo where the kernels form. What happens in the environment during the pollination period determines the yield and vigor of the harvest. If the ambient temperature rises to 100˚F or more, the pollen will die. If the tassels dry out too soon or there

Figure 2.7. Interlopers: (a) grasshopper feeding on a corn leaf; (b) rock squirrel caught in a live trap; (c) gopher damage to a corn plant; (d) rattlesnake in a gopher hole.

are strong winds, the pollen does not reach the silks, the kernels are not pollinated, and the ears form fewer kernels (see Figure 2.2). Cornstalk design is perfect for moving pollen down and through the plants, into the ears (see Figure 2.6d). Pollen pouring like liquid gold from the base of a leaf to the base of the next leaf is deposited onto the silks facilitated by tiny hairs. One of my favorite things to do in the morning is to "help" the maize with pollination by gently shaking the tassels onto the silks. This spreads pollen everywhere, including all over me, and I get my blessing for the day. I often eat the pollen for breakfast and feel very energized by it, as it tastes very fresh and alive.

By growing these ancient crops, I have developed an enormous respect for those who survived in this harsh environment for thousands of years before us. Having a successful maize crop is fraught with challenges, and it requires determination and ingenuity. Successful strategies are learned primarily through trial and error and experience. This teaches us to respect and work with natural forces, such as temperature, rainfall, winds, animals, and soil conditions.

The opportunity to work on replicas of prehistoric ground stone tools with Jenny Adams opened up a new chapter for me. Being able to further the knowledge by experimenting with maize processing procedures completes a cycle. Now that I have figured out how to grow it, how do I use it? Grinding the maize I had grown was very rewarding, as I could now experiment with ways to process it. I learned much from comparing the rates of seed emergence, flowering, tasseling, and ear maturation among the different maize varieties. The Reventador and Chapalote proved much more difficult to grind, and they produce much less flour, although both had more flavor than the Tohono O'odham 60-day variety. The Tohono O'odham 60-day produced finer flour, but had less "maize" flavor.

By comparing the growing habits of the different varieties, I can see how the Tohono O'odham 60-day is a more dependable variety to grow in the Sonoran Desert. The short time from planting seed to harvesting mature ears is well adapted to a 3-month rainy season. The shorter Tohono O'odham 60-day stalks are less likely to be blown over by the hot dry winds and dust devils that invariably blow through the garden area knocking over the taller Chapalote and Reventador stalks.

Successfully cultivating traditional crops in the desert for thousands of years is valuable and life-saving knowledge with relevance for generations to come, and is knowledge that needs to be preserved. It seems that these growing methods are being lost. My intention is to continue to learn how to grow food in an arid environment, such as the Sonoran Desert, and to pass this information on to the next generation. Working with ancient grinding tools and experimenting with different food-processing methods adds another piece to the puzzle. It is through interdisciplinary partnerships such as these that the most learning occurs. My next venture will be exploring the problem of storage; that is, protecting these products from rodents, insects, mold, moisture, and decay.

Acknowledgments

First and foremost, I want to thank Jenny Adams for including me in her research project. She appreciated my many years of experience in growing ancient maize and understood the importance of using varieties that are as close as possible to what is known from the archaeological record. Few others have had the willingness to risk the uncertainties of growing maize in this environment. I appreciated her showing me and letting me work on replicas of prehistoric grinding tools and sharing her ideas throughout the process. Her brilliant mind and kind spirit have been most appreciated by me. I have learned so much and have been able to more clearly explain to others my purpose for growing ancient maize.

I cannot name all the people who have helped me in the garden over the years, but these people have stuck with me the longest: Dee Carter, Fred Roof, and Margaret Parnell.

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Finally, my deepest gratitude goes to my husband David, and son and daughter James and Sophia for their patience with my deep interest in growing maize.

To all the youth who have visited the garden throughout the years, thanks for your appreciation.

CHAPTER 3

BUILDING MODELS FOR UNDERSTANDING HOW MAIZE WAS INCORPORATED INTO THE DIET OF EARLY AGRICULTURALISTS

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The fields, canals, and ditches uncovered at Las Capas, AZ AA:12:111 (ASM), give us unique insight into the farming techniques of the early agriculturalists along the Santa Cruz River. The 2008-2009 excavations at the site (Vint 2014) exposed a series of small, rectangular fields bordered by ditches that brought water to the plots from canals along the Santa Cruz River (Figure 3.1a). Analysis of maize samples submitted to PaleoResearch Institute (Cummings et al. 2013:12) led to the discovery that more than one maize variety was grown in the Las Capas fields (Figure 3.1b). Some varieties were more closely related to Reventador and Chapalote than others. The others had traits more consistent with hybrids between teosinte, *Zea diploperennis, Zea perennis,* and *Zea mays.*

Chapalote and Reventador are the maize varieties most commonly considered the oldest in the borderlands of northwest Mexico and the U.S. Southwest (Mangelsdorf and Lister 1956:172; Pennington 1963:40, 1980:126-127). Based on similarity in color and shape of the cobs, Mangelsdorf (1974:151) thought the maize remains recovered from Bat Cave, New Mexico, were related to modern Chapalote. An early hybridization between Chapalote and teosinte is considered the origin of Reventador, but Pennington (1963:40, 1980:127) proposed that Reventador entered northern Mexico via a different route and remained more restricted in its distribution than Chapalote. More than Reventador, the earliest iteration of Chapalote diversified into multiple landraces by adapting to differing ecological conditions (Sundberg et al. 2008:903; Wills 1988:38). Proto-Sonoran-Uto-Aztecan groups are thought to have spread Chapalote into the Sonoran Desert and into locations north of the border in Arizona and New Mexico (Adams 1994:276; Carpenter et al. 2002, 2005:31-32; Matson 1991:209-216, 250; Nabhan 2013; Wills 1988:38). Chapalote is generally considered the oldest maize grown in the borderlands during the San Pedro phase (1200-800 B.C.) (Adams 1994:276; Matson 1991:209-216, 250; Nabhan 2013; Wills 1988:38), which is the time of the earliest occupation of Las Capas.

In northwestern Mexico, twentieth century farmers selectively planted maize kernels to take advantage of local contexts (Hernàndez-Xolocotzi 1985). Certain soil conditions and some ecological zones allow for a greater variety of maize than other soil conditions and zones. Decisions about where and when to plant and how the maize is used are guided by kernel color or ear morphology (Bellon and Brush 1994:48; Bohrer 1994:483; Hernàndez-Xolocotzi 1985:425; Webster 2011:86). Other cultural requirements, such as taste and ease of grinding, or “grindability,” are important and may also have been catalogued and tracked for propagation by color.

It is apparent from the identifications reported by Cummings et al. (2013) that early agriculturalists at Las Capas grew multiple varieties of maize. Well after the main occupation of Las Capas, more floury varieties of Pima/Papago maize, such as Maize Blando, became available for planting in the borderlands—sometime prior to A.D. 500 (Adams 1994: 286, Tables 16.3-16.9; Adams et al. 1999:484). Although the varieties of maize grown at Las Capas were more variable than previously considered by borderlands archaeologists, the varieties grown in the area today are far more derived, meaning they are genetically and phenotypically further away from the teosinte hybrids that were grown 3,000 years ago (Adams 1994:294-295; Adams et al. 2006; L. Huckell 2006:105; Pennington 1963:41, 1969:53). The Chapalote and Reventador kernels used in the Las Capas experimental studies are not exact replicas of what were probably much smaller ears and kernels grown by the early agriculturalists, but they serve, for now, as proxies in the experiments.

Figure 3.1. Agricultural features: (a) aerial view of Las Capas, AZ AA:12:111 (ASM), gardens outlined in white that were irrigated by water delivered through canals off the Santa Cruz River, Cañada del Oro Wash, or the Rillito Wash (photograph by Henry Wallace); (b) Native American Heritage Garden at Steam Pump Ranch where maize plants were grown for the experiments (photograph by Joyce Rychener).

As a food source, the maize plant offers more than an ear full of kernels, and an ear of kernels can be exploited at any point during its growth (Webster 2011:81). Ethnographic descriptions note that before the ears are formed, sweet, clear juice can be extracted from maize stalks (Bennett and Zingg 1976:47; Bruman 2000:58; Pennington 1963:150, 1969:103; Smalley and Blake 2003:680-681, citing Pennington 1963:150). The stalks are pounded until limp between handstones and netherstones or on a rock with a "sizeable depression" and then twisted and squeezed to extract the juice. Juice was removed from the depression with a gourd dipper and could have been used in multiple ways. The Tarahumara cooked it and fermented it into a beverage called "tesguino," with an alcohol content of 3-5 percent. Tesguino is processed today using similar techniques, but often with the juice from a variety of plants.

Maize stalks are sweetest before the sugars move from the stalks into the kernels (Smalley and Blake 2003:679). The sweetness of immature ears originates with the fertilization of each kernel as the sugars from the stalk fill each kernel (Smalley and Blake 2003:679). Immature kernels are characterized as being in a milky state, but as the ears mature, enzymes convert the sugar to starch, and the kernels become doughy and tough (Brenton 2003:23; Smalley and Blake 2003:679). As kernels mature on the stalk, they pass through the stages of milky, doughy, denting, and maturity as the ratio of sugar to starch decreases, a process that takes approximately 30 days.

One advantage to eating immature maize kernels is that no cooking or grinding is required. They are soft, milky, and easily digested. The disadvantage is that fresh, immature kernels spoil quickly and cannot be stored for later use without some type of processing (Smalley and Blake 2003:679). Just before the sugar turns completely to starch, the nearly mature-sized ears can be prepared by boiling or roasting, or dried for parching or grinding. Heat destroys the enzymes that convert sugar to starch, fixes the sugar content, and destroys other enzymes that cause kernel deterioration during drying (Brenton 2003:23). The resulting product is relatively sweet. Other advantages to eating immature maize are: (1) better protein value; (2) more available nitrogen, potassium, and other essential minerals; and, (3) roasting immature maize converts niacin to nicotinamide, which is easily digested (Brenton 2003:23).

With each stage, from milk to maturity, the niacin becomes increasingly bound and less easily digested. Once kernels have matured, niacin and other vitamins and minerals are bound in a way that hinders their digestion. The lack of bioavailable niacin in mature kernels is blamed for pellagra, a niacin-deficiency disease in many maize-dependent populations (Brenton 2003:23; Katz et al. 1974:766). Digestibility can be improved by grinding or by various cooking methods, including roasting, parching, popping, and boiling, particularly in an alkaline solution, a process known as nixtamalization, which is not discussed further here, because there is no evidence in the archaeological record at Las Capas for this process. The advantage to eating dried mature maize ears is their durability for storage; however, their storage time also has limits due to spoilage from excess heat, moisture, and mold, in addition to scavenging by animals and insects (Keene 1985:171).

Relatively simplistic characterizations of maize kernels are needed to understand their unique performance characteristics during processing. All maize kernels have a tough outer layer, or pericarp, that covers the relatively soft insides, the endosperm (Adams 1999; Adams et al. 2006; Weatherwax 1954). The kernels of pop, flint, dent, and some flour varieties have both a hard, flint endosperm and a soft, flour endosperm arranged in different configurations depending on the landrace (Adams et al. 2006:Figures 5-6). At one extreme, popcorn varieties have mostly flint endosperm with little flour endosperm, and on the other extreme, flour maize varieties have primarily flour endosperm with little flint endosperm. Mature kernels are not all the same shape, even from the same ear. Some are small and round, and others are larger with flatter sides. At the start of grinding, small, round kernels were more challenging to grind than flat kernels. Round kernels roll out from under the mano and scatter off the metate surface, especially on the flattest surfaces. Once the pericarp is broken and the endosperm is released, however, grinding is easier on any metate surface.

Basin and flat/concave manos and metates were used to process food at Las Capas, but the flat/concave tools are far more numerous in the Las Capas assemblage for reasons discussed elsewhere (Adams 2015). Basin metates (Figure 3.2a-b) have a manufactured basin designed to confine the product as it is worked with a mano that is moved in both circular and reciprocal strokes within the basin. Flat/concave metates start with a flat surface, although the use of circular and reciprocal strokes with a mano that is shorter than the width of the metate eventually wears a depression in the metate surface that can become indistinguishable from a basin metate (Figure 3.2c-d). These two tool designs continued to be used in southern Arizona well into the twentieth century, with only the addition of an open-trough metate design that began around A.D. 450. The trough design has a rectangular grinding surface with borders on both long sides to confine the product as it is worked with a reciprocal stroke and a mano that is as long as the trough is wide (see Adams 2014a for more complete descriptions of the different mano and metate types and their distributions through time and across space.) Because trough manos and metates occur later than the Las Capas occupation, they were not included in the experiments described here.

THE EXPERIMENTS: PLANTING, HARVESTING, PROCESSING TASKS

Experimental fields were planted among the Heritage Garden at Steam Pump Ranch in Oro Valley, Arizona (see Figure 3.1b), and the processing tasks were coordinated with three consecutive planting seasons, 2011-2013 (Chapter 2, this volume). Kernels of popcorn varieties, Reventador and Chapalote, and for comparative purposes, kernels of a flour corn variety, Tohono O'odham 60-day, were purchased from Native Seeds/SEARCH, a heritage seed bank in Tucson, Arizona. The fields were designed, planted, managed, and harvested by Joyce Rychener, an experienced Sonoran Desert gardener, with the aid of many valued volunteers (see Chapter 2).

Fields at Steam Pump Ranch were loosely modeled after those at Las Capas, as small plots outlined with berms. The fields were planted after the first soaking monsoon rains that typically begin in July of each year. The strategy during each of the three seasons was to prolong the use-life of the field by planting sections a week or so apart. This staged the growth sequence of tasseling, new ears, maturation, and drying (see Chapter 2).

Maize stalks were monitored and irrigated by hose only when the monsoon rains did not provide enough water for the growth required for the experiments. Invaders were discouraged from the crops by trapping rodents and picking off worms and grasshoppers. Ears and stalks were harvested according to how they would be used in various experimental tasks. Immature ears and stalks were harvested as required, but most ears were left on their stalks until they were mature. Some ears were then harvested fresh, and others were left to dry on the stalks or picked and dried in a location protected from predators.

Multiple processing techniques were explored, including grinding dried kernels, which is the technique most often considered by archaeologists. Other techniques included: (1) processing immature and mature ears while fresh; (2) drying and then grinding the kernels from immature and mature ears; (3) drying, parching, and then grinding the kernels from immature and mature ears; and, (4) juicing the stalks. All of these techniques have been described, some with more detail than others, in the ethnographic literature about Native Americans in the U.S. Southwest/Mexico borderlands (Bartlett

1933; Bennett and Zingg 1976:47; Bruman 2000:58; Euler and Dobyns 1983; Hough 1915; Parsons 1939; Pennington 1963:150, 1969:103; Spier 1933:127; Stephen 1936; Underhill 1979). The ethnographic record provides multiple useful models for food-processing behavior, but not for behaviors that occurred prior to the manufacture of fired-clay cooking pots, or before the evolution of modern maize varieties. Because the agriculturalists living at Las Capas grew maize varieties with tough flinty kernels and did not make cooking or storage pots, techniques described in the ethnographic literature are not completely pertinent.

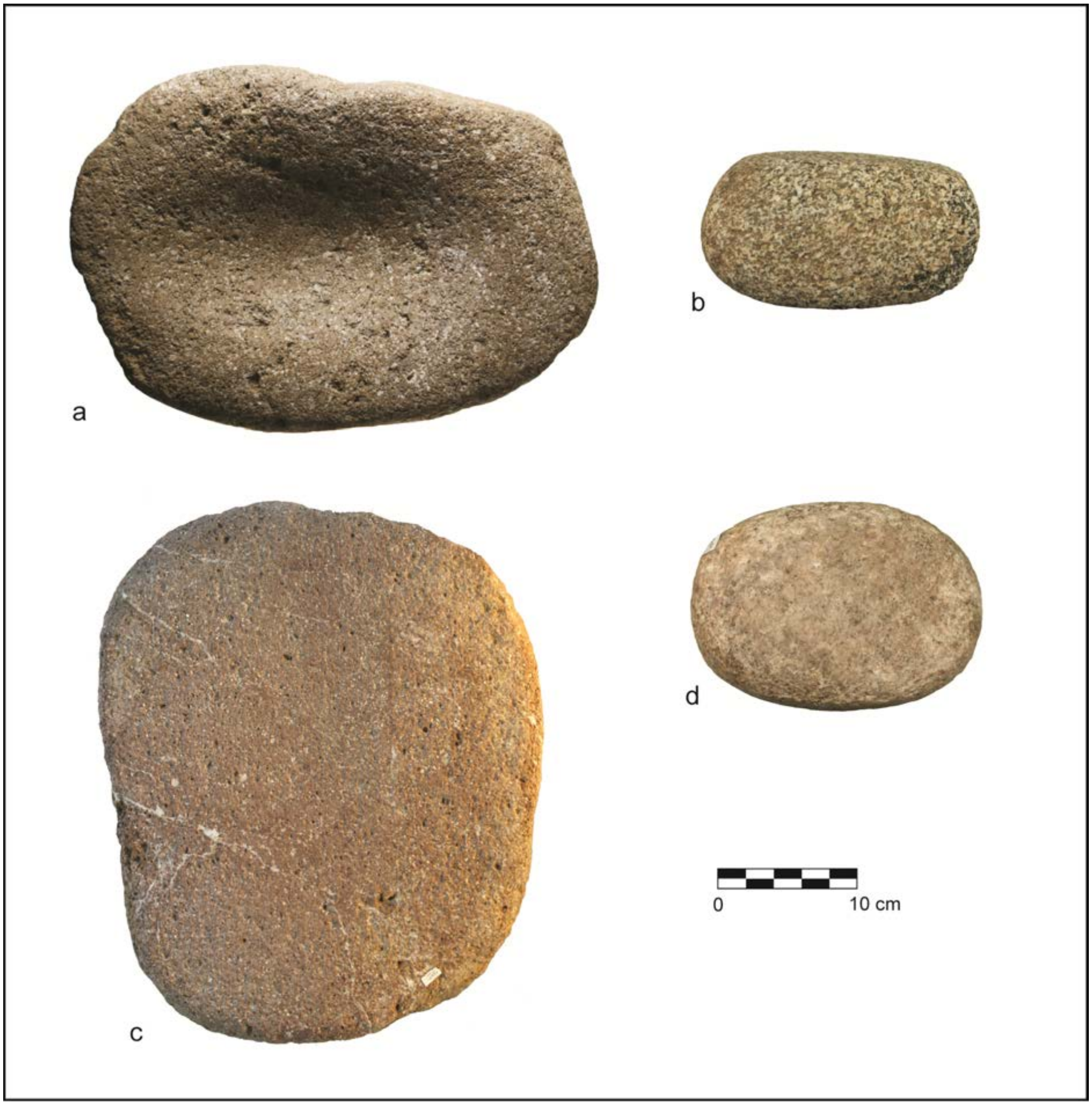

Figure 3.2. Mano and metate types recovered from Las Capas, AZ AA:12:111 (ASM): (a) basin metate (photograph by Rob Ciaccio) (Adams 2015:Figure 3.5a); (b) basin mano compatible with the basin metate in (a); (c) flat/concave metate (photograph by Rob Ciaccio) (Adams 2015:Figure 3.4a); (d) flat/concave mano compatible with the flat/concave metate in (c); note that even though the manos and metates fit well together, there is no way to be certain they were actually used together, and multiple manos are compatible with these metates.

Maize Parching Tasks

Most ethnographic accounts of parching describe dried and shelled kernels in sand-filled pots placed over charcoals (see, for example, Pennington 1963:76). Two parching tasks were designed to explore potless parching methods. In 2011, two pits were dug less than 10 feet apart. Pit A was smaller in diameter but deeper, and it began as the parching pit (Figure 3.3a). The dirt removed for its construction was placed elsewhere. Pit B, the larger, more shallow pit, was for keeping a fire going to make hot charcoals and ashes to add to the parching pit as needed (Figure 3.4). The dirt removed for its construction rimmed the pit.

A pyrometer was used to measure the temperature in the parching pit using Schurr et al. (2001) as a guide to the appropriate temperatures (Figure 3.3b). Schurr et al. (2001) studied the effects of temperature and cooking times on the integrity of kernels. At temperatures greater than 350°C, kernels quickly carbonize, while between 150° and 300°C kernels cook for up to 120 minutes before carbonizing (Schurr et al. 2001:411). One goal of the parching tasks was to parch 12 cups of dried Reventador kernels, and perhaps even pop them without scorching.

The charcoals in pit A reached 400°C, but after a thin layer of sand was added, temperatures dropped to 300°C for about 30 minutes, and 200-300°C for another 30 minutes. A handful of test kernels tossed into the sand quickly charred with direct contact with the charcoals. More sand was added until the temperature dropped to 150°C. The extra sand also provided more cushioning between the charcoals and the kernels. Fifteen minutes later, the kernels were added to the thicker layer of sand, where they cooked for 20-25 minutes. A basket scoop was used to remove the kernels but also snagged charcoals and sand. The sand was sifted away through a flat "sifter basket," but enough charcoals remained to quickly burn the kernels and the basket (Figure 3.3c). Kernel removal was tedious, and after 30 minutes, the search for kernels in the sand was stopped. Another 8 hours was spent removing small charcoal pieces and burned kernels from 10¾ cups of kernels. A little more than 10 percent of the product was lost to the process, but the time spent separating kernels from charcoals made this an inefficient method, which was probably not used at Las Capas.

The second parching task was conducted in 2012, with dried ears of Chapalote and Tohono O'odham 60-day. The parching and charcoaling pits from the previous year were cleaned out, photographed, and mapped (see Figure 3.4). Pit A was more oxidized and closer to its original shape despite being deeper than pit B. The sloping sides and backdirt from pit B had weathered so that the opening was smaller than the original pit dimension. Charcoal left from the previous year's firing, as well as sand and dirt used to put out the fires, were removed from both pits. The deep, straight-sided pit A, with no encircling backdirt, needed less maintenance than pit B to return it to service after a year of sitting idle. The sides of pit B were loose and the same color as the substrate, with no evidence that an open fire had burned in this pit for almost 3 hours. The deeper pit A was clearly oxidized on the bottom and partway up the sides. This pit had open flame long enough to make a layer of charcoal, after which it was filled with charcoal and warm sand for about 3 hours. Apparently, the low, uniform heat in pit A did more to oxidize the pit than the high temperatures of an open flame in pit B.

For the second season of parching, both pits were established with an open fire to create charcoals. The pyrometer was at pit A, and when the temperature at the edge of the charcoals was just over 200°C and the middle was just over 300°C, the parching began. The ears included immature and mature Chapalote that had been dried and husked, as well as dried mature ears with the husks attached but the silks removed (Figure 3.3d). These were divided equally between the pits, but in pit A the ears were placed directly on the charcoals, and in pit B, they were placed on large rocks, keeping the ears above the charcoals. Husks on the first test ears in both pits caught fire and began to char the kernels (Figure 3.3e). The husks on the rest of the ears were soaked in water for about 10 minutes. In pit B, the wet husks did not combust as easily and, after a few minutes, the sound of popping kernels could be heard (Figure 3.3f). In less than a minute in pit A, the husks caught fire, and the ears were quickly removed before they were thoroughly charred. Ears on the rocks in pit B did not combust as quickly, but otherwise, the rocks provided no advantage and were only in the way when the ears were rotated to prevent charring or when they were removed from the pit. Ears with no husks were added to both pits, and in each pit, they began to char in less than 45 seconds (Figure 3.3g).

Figure 3.3. Parching Parching tasks: (a) parching pit A with charcoal on the bottom; (b) pyrometer measuring the temperature of the sand with Reventador kernels; (c) kernels and charcoal removed from the pit and placed in a sifter basket; (d) immature Chapalote ears on the coals in pit B; (e) mature Chapalote ears with dried husks immediately charred in pit A; (f) mature Chapalote ears with soaked husks in pit B; (g) husked, mature Chapalote ears; (h) final product with husks removed and some kernels bagged and ready for processing (photographs by Val Hintze).

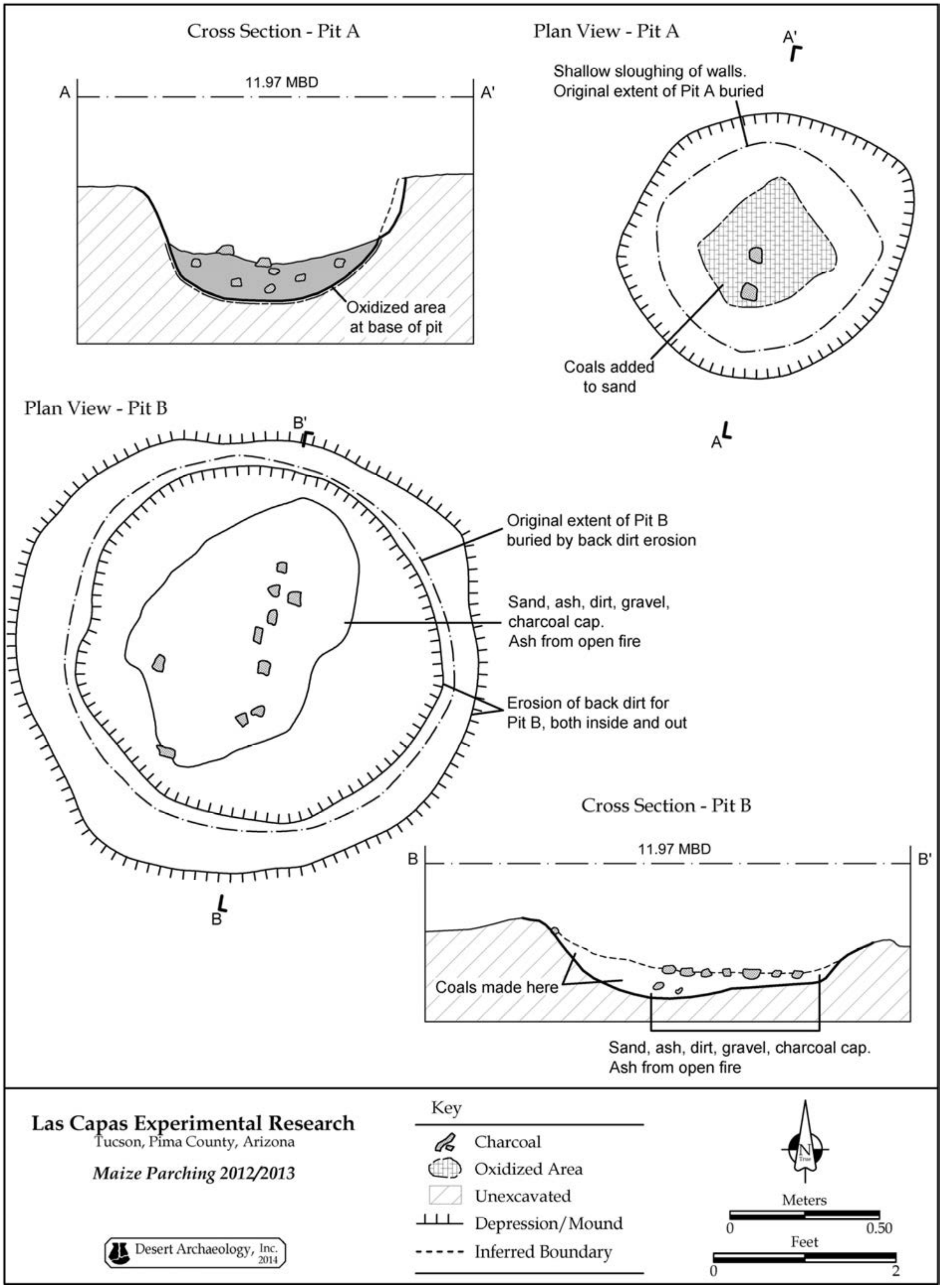

Figure 3.4. Illustration of parching pits A and B at the start of the second parching session, 2012.

About 30 minutes was spent parching 44 maize ears (Figure 3.3h). Sixteen of the 44 ears were not done enough to grind and four were charred beyond use. Most of the rest of the ears had some kernels that were either burned or under done. Approximately 8 cups of parched kernels were bagged for grinding. Interestingly, the ears that appeared completely charred and that were thought to be wasted turned out to have the most thoroughly parched and tastiest kernels. The tightly packed kernels protected most of the surface area so that only the tops of the kernels were burned. The most reliable place in the pit to parch the ears was around the edge of the charcoals, closest to the pit wall, although even there, the ears needed to be turned to prevent charring. Ears placed in the middle of the fire charred too quickly, leaving the kernels burned on top and uncooked toward the cob.

The parching experiments helped identify additional variables that, at some point, need to be explored further. Large rocks were probably not used in parching maize. Future parching experiments should include small rocks rather than sand or large rocks. The hypothesis is that the small rocks would quickly absorb heat from the charcoals but shield the ears from direct contact with small charcoals. Husks left on the ears, but with silks removed during parching, spent more time in the charcoal before they charred, especially if the husks were first soaked in water for a few minutes. The sound of multiple little pops indicated the ears were parching, and these popping sounds continued for a few seconds after the ears were removed from the charcoals. Parching in small batches around the edges of the pits makes it easier to attend the ears, turning them, and removing them to keep them from charring.

Grinding Tasks

Grinding tasks were designed to evaluate the productivity of basin and flat/concave manos and metates, and to document the performance characteristics of fresh, dried, and parched kernels of Chapalote, Reventador, and Tohono O'odham 60-day maize as they were ground. These experiments provided the opportunity for multiple observations, not only about qualitative traits, such as taste and grindability, but they also supplied quantitative data on product texture, measured with graduated sieves and a scale, and sweetness, measured with a refractometer and a Brix Scale (see Chapter 2, for a description of the refractometer and Brix scale).

Grinding experiments were conducted after three growing seasons, 2011-2013. Three varieties of maize were ground with a basin mano and metate and a flat/concave mano and metate. Both mano/metate sets were made from local vesicular basalt by Allen Denoyer (Figure 3.5a-b). After they were dried, or dried and then parched, 1 cup of kernels of each variety was ground with each grinding task lasting 30 minutes. Grinders worked in pairs on each mano and metate set, with one person grinding for 15 minutes while the other took notes and photographs (Figure 3.5c). The roles were switched for another 15 minutes to minimize the variation between individual grinders.

After 30 minutes of grinding, the product was poured through three graduated screens, resulting in four texture categories: (1) coarse meal; (2) fine meal; (3) coarse flour; and, (4) fine flour (Figure 3.6). Proportions of meal and flour are used here as proxy measures of efficiency. For a specific length of grinding time, the higher the ratio of flour to meal, the more efficient the grinding tool. Independent variables include mano/metate type, time, maize variety, and kernel condition (dried, parched, immature, or mature). The measureable dependent variables are product textures (Table 3.1; see Figure 3.6).

Comparisons were made between the products of two types of popcorn and one type of flour maize kernels ground with different types of manos and metates, at different stages of maturity, at different stages of freshness, and before and after parching. The hypotheses explored with the experiments are: (1) fresh, dried, immature, and mature kernels of Reventador, Chapalote, and Tohono O'odham 60-day kernels produce different textured products; (2) basin and flat/concave manos and metates are similarly efficient for grinding the finest flour; and, (3) parching changes grindability of Reventador, Chapalote, and Tohono O'odham 60-day kernels, as well as the texture and taste of the product. Grindability and taste are the most subjective variables.

The sensory perceptions considered here as taste are described as sweet, salty, sour, bitter, and savory. Experimenters added nutty and green to describe the flavor of parched and fresh product that did not fit the other taste descriptors. Flavor is not considered further here, however, because it is a more complex perception involving taste plus aroma, texture, juiciness, mouth feel, and color according to the Culinary Innovation Center (2014).

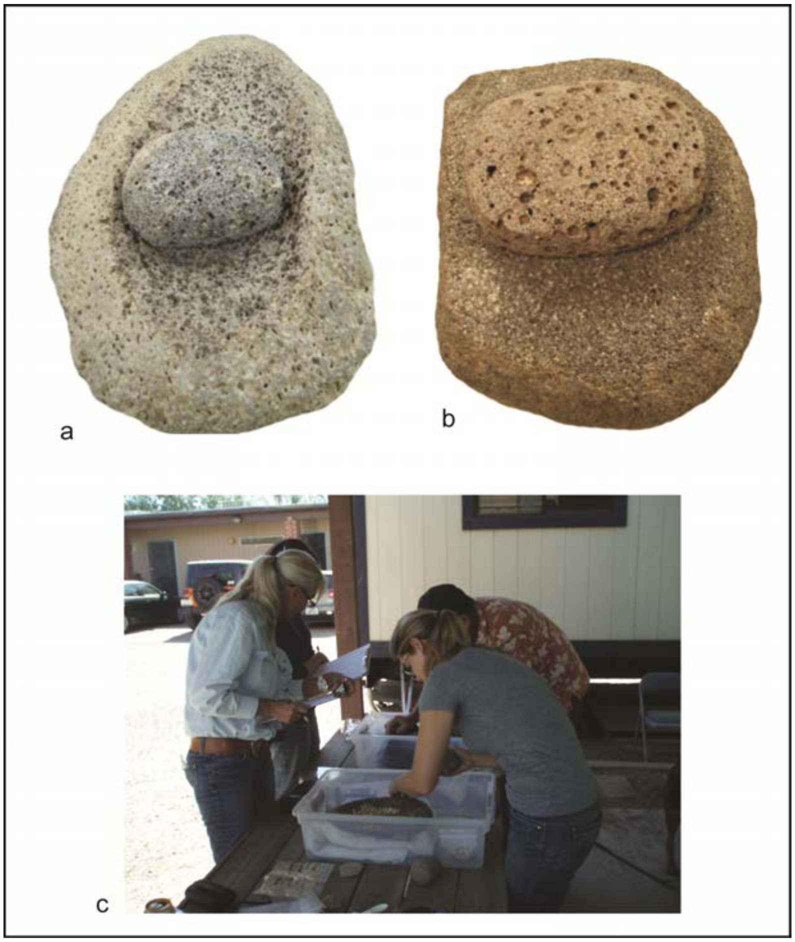

Figure 3.5. Setup of grinding experiments: (a) vesicular basalt basin mano and metate; (b) vesicular basalt, flat/concave mano and metate (both tool sets made by Allen Denoyer); and, (c) grinding stations with one person grinding and another person taking notes.

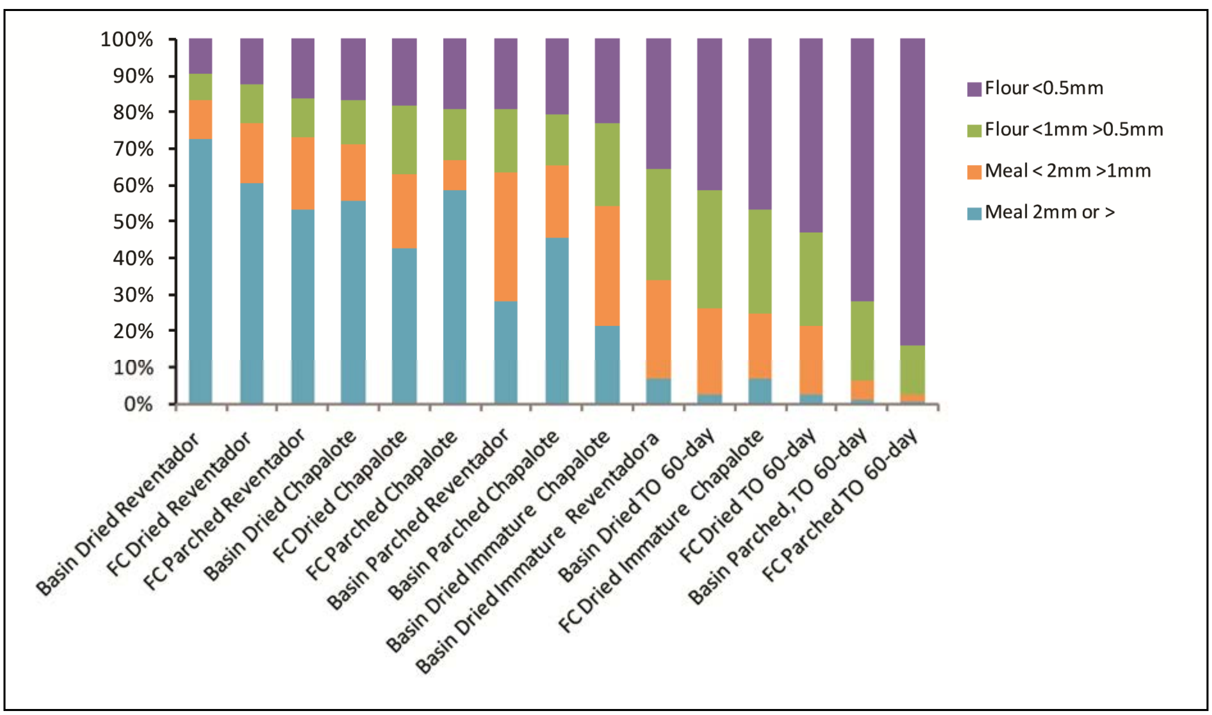

Figure 3.6. Chart with the rank order of grinding tasks, by proportions, of fine flour texture.

Table 3.1. Results from 15 grinding tasks conducted with two types of replicated manos and metates and three varieties of maize.

		Ground Weights (gm)				Total	Ground Proportion			
		Coarse Meal	Fine Meal	Coarse Flour	Fine Flour		Coarse Meal	Fine Meal	Coarse Flour	Fine Flour
Metate Type	Product	2 mm or >	< 2 mm > 1 mm	< 1 mm > 0.5 mm	< 0.5 mm	Weight (gm)	2 mm or >	< 2 mm >1 mm	<1 mm > 0.5 mm	< 0.5 mm
Basin	Reventador parched	43.0	54.0	27.0	29.5	153.5	28.0	35.2	17.6	19.2
Basin	Reventador dried	150.0	21.0	15.0	20.0	206.0	72.8	10.2	7.3	9.7
Flat/concave	Reventador parched	56.0	21.0	11.5	17.0	105.5	53.1	19.9	10.9	16.1
Flat/concave	Reventador dried	162.0	44.0	29.5	33.0	268.5	60.3	16.4	11.0	12.3
Basin	Reventador dried green[a]	4.5	18.0	20.0	23.5	66.0	6.8	27.3	30.3	35.6
Basin	Chapalote dried	97.0	27.0	21.5	29.0	174.5	55.6	15.5	12.3	16.6
Basin	Chapalote parched	76.0	33.0	23.5	34.5	167.0	45.5	19.8	14.1	20.7
Basin	Chapalote dried green	29.5	45.5	31.0	32.0	138.0	21.4	33.0	22.5	23.2
Flat/concave	Chapalote dried	72.0	34.0	32.0	30.5	168.5	42.7	20.2	19.0	18.1
Flat/concave	Chapalote parched	105.5	15.5	25.0	34.5	180.5	58.4	8.6	13.9	19.1
Flat/concave	Chapalote dried green	10.0	25.5	41.0	66.5	143.0	7.0	17.8	28.7	46.5
Flat/concave	Tohono O'odham 60-day dried	4.0	30.0	40.0	84.0	158.0	2.5	19.0	25.3	53.2
Flat/concave	Tohono O'odham 60-day parched	0.5	3.0	18.0	112.5	134.0	0.4	2.2	13.4	84.0
Basin	Tohono O'odham 60-day parched	1.5	7.0	30.0	97.5	136.0	1.1	5.1	22.1	71.7
Basin	Tohono O'odham 60-day dried	4.0	38.0	51.0	66.0	159.0	2.5	23.9	32.1	41.5

Notes: All tools were made from vesicular basalt and all tasks were conducted for 30 minutes; starting quantities are 1 cup, unless otherwise noted; product weighed in a 4 x 6 plasic bag; 4 gm subtracted for the weight of the bag.
[a]1/2 cup ground.

Grindability is a relative variable that describes how some kernels are easier to crack and reduce to fine flour during a specified period of time than others. Kernels that produced the highest proportion of finer-textured product were considered to have better grindability than kernels that produced the highest proportions of coarse-textured product. Fifteen grinding tasks used kernels that had been dried or parched and were more rigorously controlled than the explorations with processing fresh ears of maize. These grinding tasks were designed to complement the analysis of ground stone processing tools recovered during the Las Capas project (Adams 2014a) and to provide baseline information for designing more controlled experiments to be conducted over the next several years.

Because there is little ethnographic description of kernelling techniques, each participant was allowed to devise their own strategy for removing kernels from the cob. Bare hands were not useful for removing the kernels from fresh ears, so a thin sandstone fragment and a sharp flake were tested for usefulness. The sandstone fragment was useful for milking the immature ears, but the flake performed better in separating the kernels from the cob. The flake was universally chosen by those removing immature and mature fresh kernels from the cob (Figure 3.7a). The flake and the sandstone fragment were each satisfactory for dislodging the dried or parched kernels from the cob, row by row.

Several bare-handed techniques were used to separate kernels from dried and parched ears. One technique was to break the ear and push the kernels off the edge with a thumb (Figure 3.7b). During one timed task, this method produced 4 cups of kernels from 21 ears of Reventador in 99 minutes. Another technique was to rub together two ears of dried or parched kernels until all the kernels were knocked off (Figure 3.7c). Alternatively, an entire ear was gripped by one hand on top and the other on the bottom so that when each hand twisted in the opposite direction, the kernels were dislodged (Figure 3.7d).

Figure 3.7. Kernelling techniques devised by experiment participants: (a) flake used to scrape fresh, mature kernels from the cob; (b) parched ear broken and the kernels pushed off the cob with thumbs; (c) two parched ears rubbed together to dislodge kernels from both ears; and, (d) two-handed motion used to twist dried kernels off the cob (photographs by Val Hintze).

This technique required very strong hands, and was not effectively used by everyone on every type of maize ear. The consensus among the experimenters was that dried kernels were more difficult to remove from the cob than fresh and that dried popcorn kernels were more difficult to remove than dried flour kernels. Parched, mature kernels of any maize variety were easier to remove from the cob than dried, mature kernels.

Harvesting and Processing Immature Maize Ears

Plant growth was monitored so that ears and stalks could be harvested at appropriate stages of maturation. During the growing seasons of 2011 and 2012, the first harvests were of immature Reventador and Chapalote ears (Figure 3.8a). Immature ears of Reventador and Tohono O'odham 60-day were picked on2 September 2011, and immature ears of Chapalote were picked on 26 September 2012. The innermost husks of fresh immature ears were removed, and these proved to be tender and tasty enough to have been exploited as a food source. Immature ears are also surprisingly sweet, but that sweetness diminishes over a few days (see Chapter 2). Within a day of picking, the kernels were scraped off the cob producing less than 1 cup of milky masa from six ears of each variety of fresh, immature maize (Figure 3.8b). Subjectively, the immature kernels of Reventador and Chapalote tasted equally sweet compared to each other and much sweeter compared to the immature kernels of Tohono O'odham 60-day.

In 2012, a refractometer was used as a relative measure of sweetness. A refractometer measures concentrations of solids in solution. The assumption is that sugar is the solid blocking the passage of light through the meter, but as the maize matures, I think starch is probably the most abundant solid. For immature Chapalote kernels, the measurement was 5, which is "poor" sugar content for modern "corn" varieties according to the Refractometer Brix Scale accompanying the refractometer. Measurements were not taken for Tohono O'odham 60-day. Future experiments will use Benedict's reagent to more directly measure sugar content of all varieties.

The fresh but immature kernels of both Reventador and Chapalote contained much more liquid than the fresh, immature kernels of Tohono O'odham 60-day (Figure 3.8c-d). Nevertheless, all were workable into balls of masa on the metate surface. Except the many pieces of pericarp, the masa became relatively uniform in texture. The processing of 12 ears of immature popcorn, including husking, kernelling, and kneading the masa, was accomplished in 40 minutes, resulting in a handful of masa. After working masa with these manos and metates, it was decided that vesicular basalt was not a good surface for working sticky dough until all the holes were filled with dough.

Observations made during the explorations of fresh, immature Reventador, Chapalote, and Tohono O'odham 60-day maize kernels include: (1) immature, fresh, Tohono O'odham 60-day kernels are starchier and not as sweet as those of Reventador or Chapalote; (2) husks are not as tightly bound around the Tohono O'odham 60-day ear as they are around the Reventador and Chapalote ears; (3) the Tohono O'odham 60-day ears had more worms; (4) stone scraping tools used to kernel the fresh, immature ears broke the pericarp, allowing the soft insides to be scraped away onto the metate; and, (5) more work went into kernelling and less into working the product into masa.

Dried, immature kernels were so small and friable that the whole ear was rubbed without using a mano across the metate surface, grinding away the cob and making fine flour with tiny bits of pericarp. The kernels are easily fingered from the cob, however, and the pericarp was easily winnowed away before grinding (Figure 3.8e-g). As the ears matured, the kernels with more starchy content became more difficult to remove (see Figure 3.7a). The immature kernels of both popcorn varieties produced fine flours that came close to the fine flour texture achieved with the experimental grinding of Tohono O'odham 60-day kernels (see Figure 3.6).

Harvesting and Processing Mature Maize Ears

A dozen ears of fresh, mature Reventador maize were picked and worked on the basin and flat/concave metate surfaces (Figure 3.9a-b). Compared to the fresh, immature kernels, the fresh mature kernels were firm with very little liquid and were quickly worked into a thick masa with pieces of pericarp. Masa made from the mature kernels was a thicker consistency and held together better for making tortillas

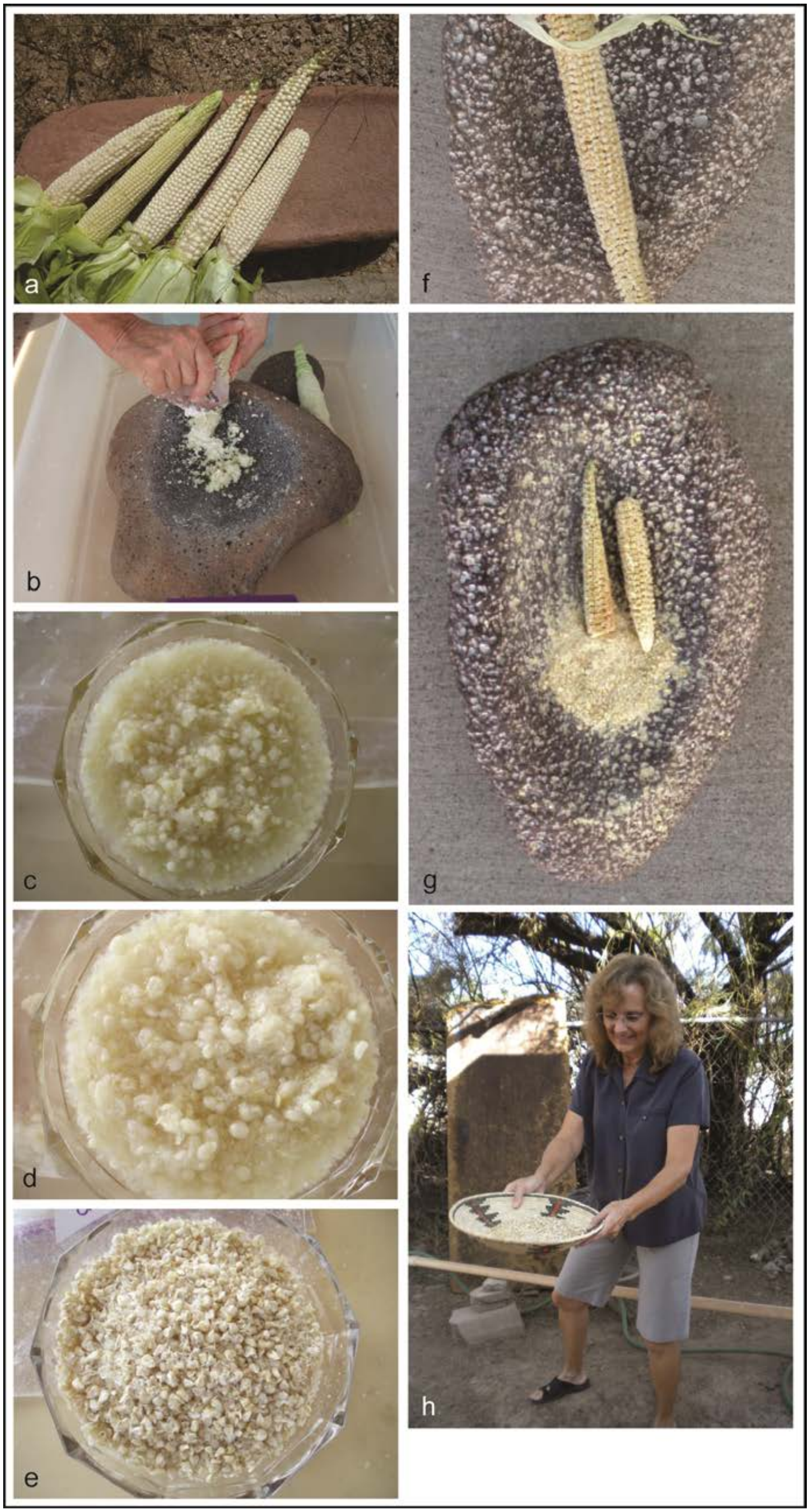

Figure 3.8. Immature maize: (a) fresh, immature Reventador ears progressing from left to right with very immature on the left and nearly mature on the right; note that kernels are plumper on the more mature ears (photograph by Joyce Rychener); (b) immature Tohono O'odham 60-day kernels scraped off the cob using a thin stone; the milky product can be worked into masa on the metate surface with little effort; (c) milky product from an immature Revendator ear of maize; (d) milky product from an immature Tohono O'odham 60-day ear of maize; (e) dried kernels from an immature Reventador ear of maize; (f) dried ear of immature Reventador maize; (g) dried immature Chapalote ears and meal created by rubbing the cobs against the metate; (h) winnowing away the pericarp from dried, immature Reventador kernels (photograph by Val Hintze).

Figure 3.9. Masa made from fresh, mature Reventador maize kernels: (a) worked on the surface of a basin metate; (b) worked on the surface of a flat/concave metate; (c) tortilla made from Reventador maize.

than masa from the immature kernels, due to the higher starch content of the mature kernels. Prolonged grinding dried the masa made with mature kernels, reduced the particle size of the pericarp pieces, and made flour fine enough for a thick tortilla (Figure 3.9c).

The dried mature kernels from either popcorn variety produced less flour than the dried immature kernels from any of the three maize varieties (see Figure 3.6). Between the two popcorn varieties, dried immature Reventador is the easiest to grind and has a sweet taste, but not as sweet as fresh, immature Reventador. This was a subjective assessment that was not measured with the refractometer.

The rest of the mature maize ears were left in the field to dry on their stalks until fear of predators caused us to harvest them and put them where they were better protected (Figure 3.10). Most of the ears were harvested in September and October, and experimental tasks were conducted on 9 December 2011, 1 November 1 2012, 7 December 2012, and 1 February 2013. Fifteen grinding tasks were performed (see Table 3.1).

During the 30-minute processing tasks, 1 cup of Reventador, Chapalote, or Tohono O'odham 60-day kernels was processed with either the replicated basin or flat/concave mano and metate set. At the start of each task, the kernels were processed with a combination of crushing and grinding strokes until enough meal was generated to more securely hold the kernels on the metate surface. Then, reciprocal and circular grinding strokes continued until the end of the 30 minutes. The strokes were similar in direction on both metate surfaces, but the larger, flat/concave grinding surface allowed for more variation in the strokes than did the basin surface.

The shallow basin surface confined the dried, mature kernels better than the flat/concave metate surface, but grinding was a messy task with either metate (Figure 3.11). Consensus among the grinders was that grinding kernels is easiest with the heavier flat/concave mano but most difficult with the flat/concave metate because the kernels were easily pushed off the surface. Even with time spent retrieving errant kernels, the flat/concave mano and metate set produced slightly more flour-textured product (1.4 percent) than the basin set during the 30-minute grinding session (Figure 3.12). The increased efficiency rate is probably due to the much larger grinding surface area (63 percent) and heavier weight (57 percent) of the flat/concave mano. It was also noted that there was more contact between the surfaces of the flat/concave mano and metate than between the basin mano and metate surfaces due to how much product was pushed off the surface. The result was that more rock particles sifted out of the flour produced with the flat/concave mano and metate.

Without considering metate type, dried and parched, mature kernels of Tohono O'odham 60-day maize were easier to grind, and produced 60 percent more flour during a 30-minute grinding task than the dried and parched kernels of Chapalote or Reventador (Figure 3.13). The flour kernels are larger and flatter with more flour endosperm than the popcorn kernels. The taste of the Tohono O'odham 60-day flour is bland compared with the flour from either of the popcorns, although parching turns the bland flour into a better, almost nutty taste.

Overall and irrespective of metate type, parching improved grindability (Figure 3.14), but more so for the popcorn maize varieties than for the flour maize. After the 30-minute exploratory grinding sessions, there was 12 percent more flour than meal in the product from parched Reventador kernels, 20 percent more flour in the product from parched Chapalote kernels, but only 1 percent more in the product from the parched Tohono O'odham 60-day kernels. The most efficient combination for grinding popcorn kernels was to parch them and grind them with a basin mano and metate (Figure 3.15). Improvements brought about by parching for all maize varieties include easier kernelling and improved taste. The flour from the parched kernels is oilier, has a nuttier taste, and seems less gritty than the flour from the dried kernels.

Other observations can be summarized. Dried immature ears are not as productive as dried mature ears, but they are easily kernelled, the pericarp is easily winnowed away, the kernels are easy to grind, and the product is finer and sweeter than that from mature ears. The easiest stage for processing popcorn kernels is when they are fresh and immature. The kernels can be scraped off the cob with a blunt tool and processed into sweet dough without adding water. The cooks at Las Capas could have dried the dough for later use, cooked it in the ashes of a fire, or dropped it into a stew stone-boiled in a basket.

The kernels from mature ears are much more difficult to remove from the cob and to grind. Parched kernels of any kind are easier to grind, producing finer-textured flour than dried kernels. The kernels are easily crushed so that they can be ground on a flat metate surface more efficiently than dried kernels (see Table 3.1).

Subjectively, the taste of meal or flour from dried kernels of Chapalote, Reventador, or Tohono O’odham 60-day is bland compared to the sweet taste of flour from their immature kernels or the nutty taste from their parched kernels. Other seed types that could have been parched or popped to add taste to maize flour include amaranth, sunflower, and teosinte (Beadle 1939:247, 1972:10; Doolittle 1992:74; Mangelsdorf 1974:151).

Figure 3.10. Dried mature maize: (a) harvested ears of Chapalote left to dry on the stalk; (b) husked ears of dried Chapalote; (c) husked ears of dried Reventador; (d) bags containing dried Reventador kernels, ready to be ground with the replicated tools; and, (e) bag containing 1 cup of dried Tohono O'odham 60-day kernels (photographs by Val Hintze).

Figure 3.11. Parched kernel grinding: (a) basin mano and metate used to grind parched Chapalote during a 30-minute grinding session; and, (b) flat/concave mano and metate used to grind parched Chapalote during a 30-minute grinding session.

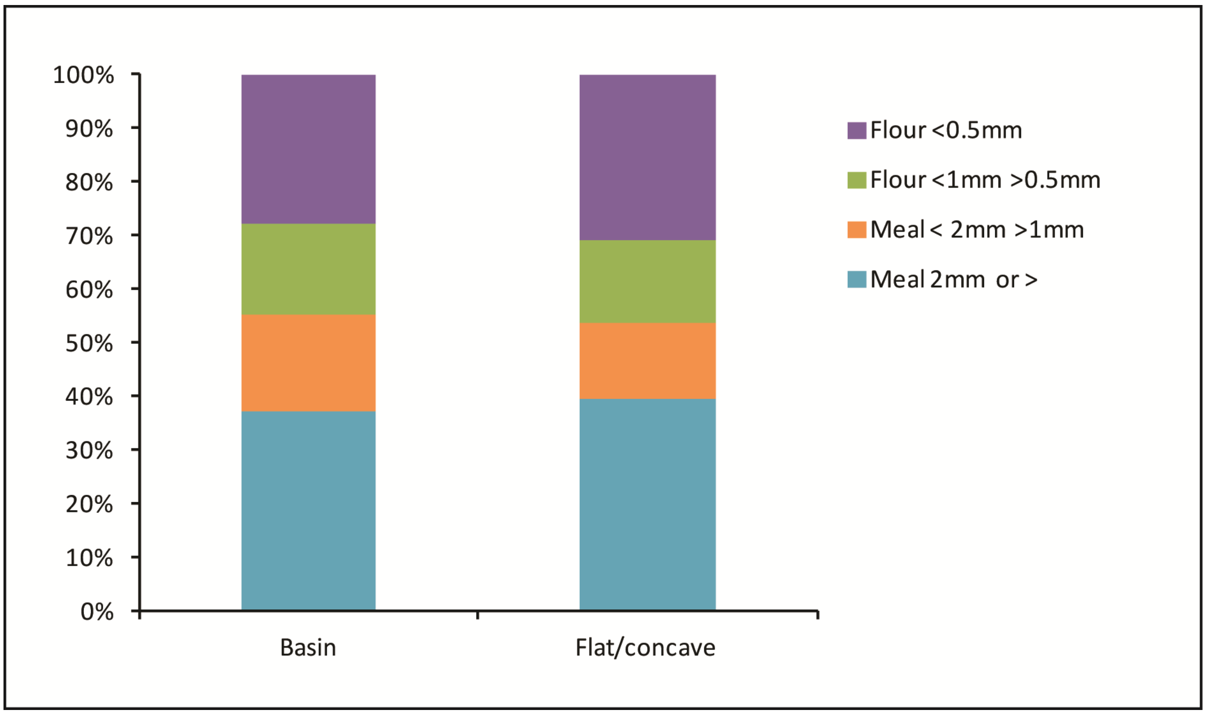

Figure 3.12. Results comparing meal product ground on two types of metates.

Juicing Tasks

The juicing tasks explored various techniques for extracting juice from maize stalks. As mentioned, twentieth century farmers in northern Mexico pounded maize stalks until they were limp enough to twist and squeeze out the juice (Bennett and Zingg 1976:47; Bruman 2000:58; Pennington 1963:150, 1969:103; Smalley and Blake 2003:680-681, citing Pennington 1963:150). The experimental juicing tasks (Figure 3.16a) were designed to determine if: (1) it is possible to juice stalks using the tools available to the Las Capas inhabitants; (2) a sense can be had of how much juice can be squeezed from corn stalks; (3) stalk maturity impacts how much juice is in stalks; (4) there is a difference between maize varieties in the amount, consistency, or sweetness of the juice; and, (5) there is a difference in the consistency or sweetness of the juice depending on the maturity of the stalk defined as young, no tassels; immature, tassels but no ears; and mature, with ears. Stalks were cut from Chapalote and Tohono O'odham 60-day varieties and two mano/metate sets and one wooden mortar with stone pestles were used to juice the stalks.

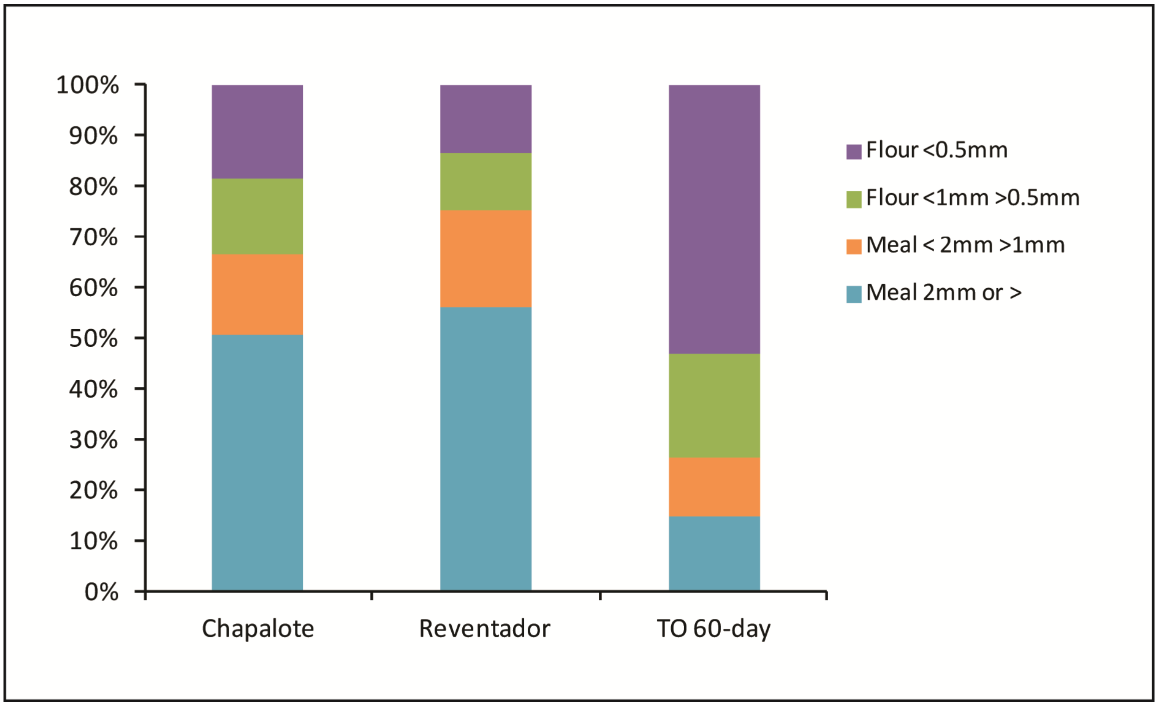

Figure 3.13. Texture results from experiments comparing grindability of maize varieties.

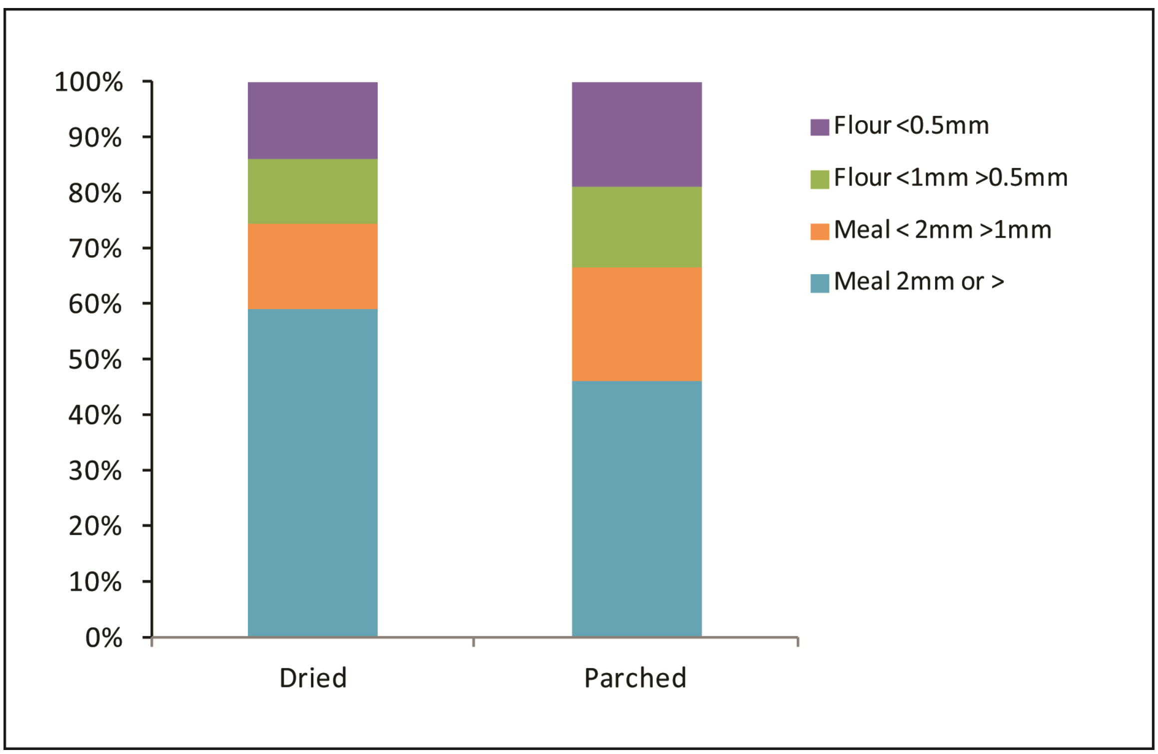

Figure 3.14. Comparison of product textures after grinding dried and parched kernels of Reventador and Chapalote.

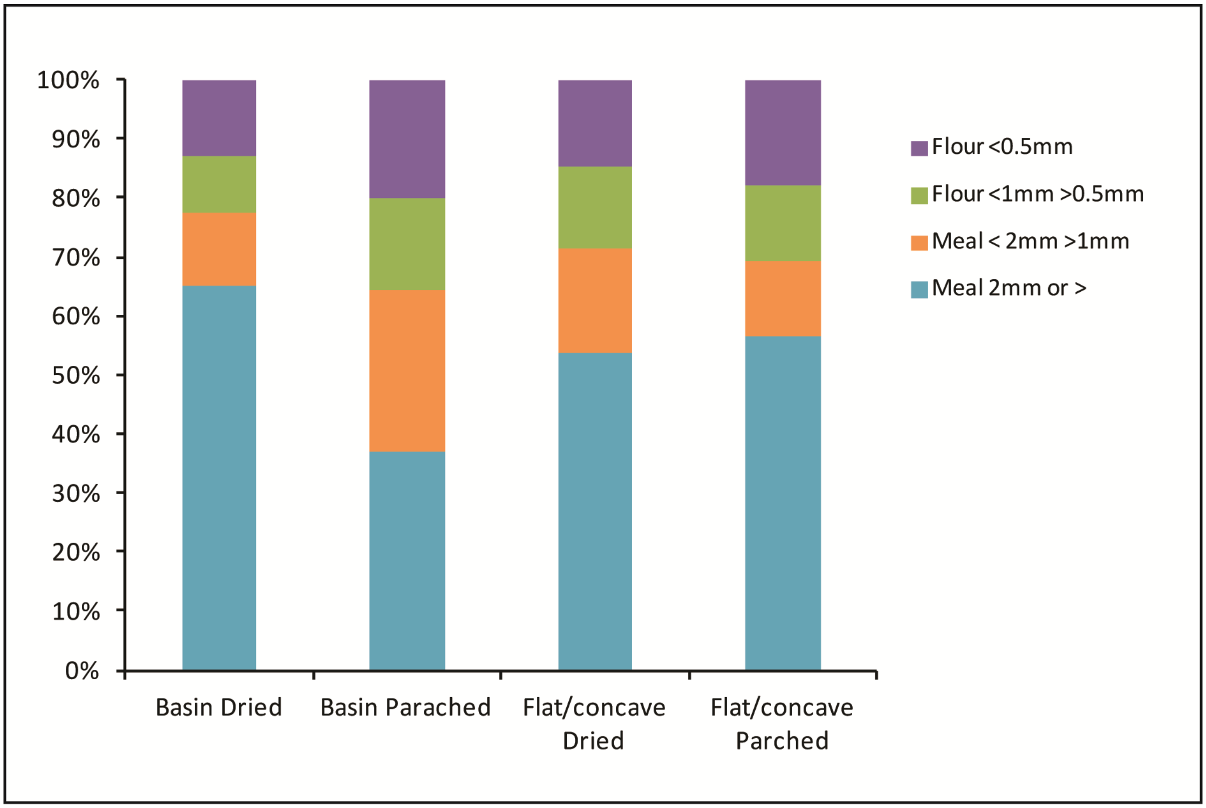

Figure 3.15. Results from grinding parched and dried kernels of Reventador and Chapalote with different metate types.

Stalks were pounded with three tool sets: (1) a basin mano and metate made from vesicular basalt; (2) a basin mano and metate made from well-cemented sandstone; and, (3) a wooden mortar and stone pestle. The stalks were crushed with a forceful pounding of the mano edge against the metate, causing more damage to the stalks with less juice splash than pounding with the mano surface (Figure 3.16b). Juicing is messy, especially if much juice is allowed to collect in the bottom of the basin while smashing the stalks. The most efficient way to extract the juice after smashing is to squeeze the stalks (Figure 3.16c) and let them rest a few minutes before pounding and squeezing again. The metate and mortar basins each served the purpose of catching juice, but because it was difficult to efficiently extract the juice from the basins for measurement and evaluation, stalks were squeezed over a plastic bowl. The Las Capas inhabitants could have used a gourd or skin container. Three average-size stalks, about 3-4 ft in total length, produced about 1 cup of juice.

As noted by others, the stalks are sweetest before the sugars move into the kernels (Smalley and Blake 2003:679). The same refractometer used to measure the sweetness of kernels was used to measure the sweetness of the extracted juices. The juice from immature stalks with no tassels or ears (Figure 3.16d) measured 4.5, about the same as immature kernels. The juice from stalks with new tassels measured only slightly sweeter at 5.0, but the juice from stalks with new ears is not quite as sweet at 3.5. Other differences were noted in the amount, consistency, and taste of the juice. Juice from new stalks is more transparent (Figure 3.16e), and tastes like green grass. Stalks with tassels have less, but thicker juice that tastes not as "green" as the juice from the new stalks (Figure 3.16f). The juice from stalks with new ears is thicker yet, and is cloudy, with diminished taste and a starchy feel to it. Stalks with mature ears are nearly dry. Only stalks with no tassels were compared between Chapalote and Tohono O'odham 60-day, but there was no obvious difference in the quantity or sweetness of the juice from these two maize varieties.

Figure 3.16. Juicing task: (a) setup of stalks and tools used in the juicing task (photograph by Joyce Rychener); (b) technique used to smash stalks with a mano and metate; (c) twisting the juice out of a smashed stalk; (d) immature stalks ready to juice (photograph by Joyce Rychener); (e) juice from and immature stalk; and, (f) juice from a stalk with new ears.

DISCUSSION AND CONCLUSIONS

Multiple excavations over several years at Las Capas (Diehl 2005; Mabry 2008; Sliva 2005; Vint 2014; Vint and Nials 2015; Whittlesey et al. 2010) have accumulated a rich data set documenting the physical layout of the fields, the water systems, the types of early maize grown there, the types of tools used to process food, and the pits for storing and cooking foods. Missing from the data is information about how people worked the fields and incorporated the harvests into their diets. Results from the exploratory experiments reported here model diet and cuisine choices that could have been available to early agriculturalists.

Diet consists of what and how much people eat and the nutritional values of their food, while cuisine is a reflection of the cultural values that create a shared identity expressed in recipes. Recipes are the rulesfor proper cooking techniques, the proper use of tools and utensils, and for who eats what, where, and when (Crown 2000:225). With the recognition that their diets included other grains, plants, and animals, this discussion is focused on growing and processing maize cultivated in small fields at Las Capas. Archaeologically visible expressions of diet and cuisine at Las Capas include cooking and processing tools and features, macrobotanical remains, such as seeds, cobs, and stems, and microremains, such as pollen, phytoliths, and residues, left on tools. Inferences about diet and cuisine can be derived from the maize varieties planted, the types of processing techniques possible with the recovered tools, and the types of features available for storing and cooking food.

Inferences about the nutritional values of the diet can be made for early agriculturalists with the assumption that there is parity in the nutritional values of modern maize and the maize grown by early agriculturalists. The exploratory experiments demonstrated the potential for early agriculturalists to have exploited immature maize stalks and ears. As noted, there are nutritional advantages to eating immature maize, including high protein value and more available essential minerals. Immature Reventador ears ground during the experiments created extremely fine, sweet flour. The most obvious advantage to eating the kernels from dried, mature maize ears is their durability for storage; however, as noted, their storage time also has limits. Less obvious is that once kernels have matured, niacin and other vitamins and minerals are bound in a way that hinders their digestion. Digestibility can be improved by grinding or by various cooking methods, such as roasting, parching, popping, and boiling.

Examples of maize preferences and recipes that use whole kernels, meal, or flour have been documented among historic native groups in the borderlands, and these provide models for inferences about early agricultural cuisine (Adams 1999:Table 1; Beck 2001; Pennington 1963,1969, 1980; Rea 1997:344-352). Chapalote was not used by the Onavas Pima for tortillas unless it was the only type available, but they specifically chose Chapalote to make a favorite dish of popped corn with honey (Pennington 1980:126-127). Flour of any texture was used to make griddle cakes, used as a thickener for stews, or mixed with water as a beverage. Fine flour was used for unleavened breads, tortillas, dumplings, puddings, and for a special bread called *piki* by the Hopi and *he we* by the Zuni (Beaglehole 1937:63-64; Cushing 1920:305; Whiting 1939:15). Juice was extracted from stalks and used for various purposes (Bennett and Zingg 1976:47; Bruman 2000:58; Pennington 1963:150, 1969:103). The Tarahumara removed the husks from fresh maize ears before cooking them in an open fire. The ears were eaten immediately or were dried for storage. Ears were also left to dry on the stalk while still in the field. Dried kernels were removed from the cob, popped in pots filled with hot sand, and then either eaten whole or ground into flour with manos and metates. These examples allow at least the possibility that farmers choose to plant specific maize varieties according to their preferred recipes and that taste, flour textures, and stalk juices were as important to the recipes of early agriculturalists as they are to historic farmers.

The Cuisine of Early Agriculturalists

The experimental and ethnographic studies reported here have identified and quantified the performance characteristics that make flour kernels better than popcorn kernels for tortillas and recognized that while parched Chapalote kernels can be ground into flour fine enough for tortillas, parching changes the taste in a way that might not be considered appropriate for tortilla recipes. The components of cuisine begin with the decisions made while planting and harvesting and continue with cooking and processing to create a product that has the appropriate texture and taste for preferred recipes.

For early agriculturalists, these choices did not include flour maize, although flour maize was included in all the experiments as a control for consistent comparison.

Harvest

Three seasons of growing and harvesting the experimental fields at Steam Pump Ranch have demonstrated that Las Capas style fields could have become a food source about 2 months after planting. The first harvests would have been the very nutritious and sweet, immature stalks and ears. The harvesting of immature stalks and ears is a decision made for immediate consumption, whereas leaving the ears to mature or even dry on the stalk is a decision made for delayed consumption. Sequential planting and harvesting techniques lengthen the use-life of a field, make immature and mature produce available simultaneously, and provide a hedge against the loss of an entire crop to late or early frost.

As noted, the stalks are sweetest before the sugars move into the kernels and the ears are sweetest in their milky state before the sugars turn to starch. Deterioration in Reventador kernel sweetness was evident 36 hours after peak sweetness and almost complete after 5 days (see Chapter 2). If sweetness or sugar content is important to the recipe, harvest timing is important. In addition to the sweet taste, there are the previously noted nutritional and production advantages to eating fresh, immature stalks, ears, and kernels.

Product

Several strategies available to early agriculturalists were explored for deriving product from maize plants. Observations were noted during the experiments that answered some questions and generated others. Fresh kernels of any maize variety are easily reduced to masa with any type of mano and metate for immediate consumption. If the recipe requires masa or dough, fresh kernels have an advantage over dried kernels by needing little or no added water. Another observation is that less product was generated from mature, fresh kernels than from mature, dried kernels. Surprisingly, the small dried kernels and cobs of immature maize can be ground into finer flour than dried or parched kernels of either popcorn variety (see Figure 3.6).

Tohono O'odham 60-day kernels, whether immature, mature, fresh, or dried, were much easier to remove from the cob than Reventador or Chapalote kernels in the same condition. Kernels with abundant flint endosperm and dense pericarp, which describes both the popcorns, benefit from winnowing or sifting during grinding. Grindability of dried or parched kernels is affected by the shape of the kernel, which is somewhat influenced by the proportions of flint and flour endosperm, but more so by the placement and spacing of kernels on the ear and by the thickness of the pericarp. Most dried kernels of Chapalote and Reventador are round enough to roll around on the metate surface and are more difficult to grind on a flat metate surface. Other kernels are flatter on two sides, and these are easier to grind on any metate surface. Overall, Tohono O'odham 60-day kernels are larger, flatter, and less durable than either Chapalote or Reventador kernels. These characteristics make them easier to dry grind.

Mano/metate grinding efficiency was compared during the experiments, and preliminary measurements show that mano/metate configuration makes a difference in grinding efficiency, depending on the condition or durability of the kernels. Parched kernels worked with the basin mano and metate produced 5 percent more flour than parched kernels worked with the flat/concave mano and metate (see Figure 3.15). However, the flat/concave mano and metate were slightly more efficient at grinding dried, mature kernels than the basin mano and metate. As noted by the experimenters using the replicated tools, the better efficiency rate is probably due to the heavier flat/concave mano. This observation needs additional testing before making a conclusive statement about tool design efficiency.

Juicing is a processing task that is rarely considered in the archaeological literature, although it is beginning to receive more attention. The end product as known today, ears full of plantable kernels, was probably not the intent of those who tended the first *Zea mays* ssp. *parviglumis*, teosinte plants, or planted the earliest fields of *Zea mays* spp. *mays*, domestic maize (Smalley and Blake 2003:689). They may have been more interested in the stalk for juice and immature ears for sweetness than in the mature ears for grain (Blake 2006:68; Iltis 2006:29; and Smalley and Blake 2003 call it the stalk-sugar hypothesis;

Weatherwax 1954:109 and Webster 2011 call it the alternate use hypothesis). The selection of seed stock from plants with the largest sugar-producing stalks lead eventually, by various adaptive measures, to *Zea* plants with ears full of kernels attractive enough to become a staple grain source (Blake 2006:68-69; Smalley and Blake 2003:679). Stable isotope analysis provides some support for the hypothesis that maize played a minor role in precontact diets until around 3,000 B.P (Smalley and Blake 2003:684), which is about the time frame for the introduction of maize to borderland farmers. The nutritional benefits may not have been obvious to the average farming community, but with the ability to consume immature maize and cook mature maize by roasting, parching, and dry grinding, most nutritional needs were met without even considering the added benefits of beans, squash, or other gathered foods (Brenton 2003:24).

Cooking

Roasting and parching are dry heat cooking techniques, and there are thermal features that would have served such functions at Las Capas (Sinensky et al. 2014). Roasting techniques surround the food in a deep pit with hot rocks, which seals in the moisture. The thousands of fire-cracked rocks counted at Las Capas attest to the importance of this technique at the site (Adams 2015). Roasting requires less constant attention than parching, but the product is not suitable for storage and must be consumed much sooner than the product of parching. Parching is a quicker process of heat transfer, either directly from charcoals to the food or indirectly through hot sand to the food. As revealed during the experiments, ears of dried maize placed over hot charcoals in shallow hearths char quickly if not turned and removed from the charcoals after a few minutes.

During the Early Agricultural period at Las Capas, before the use of clay pots, dried ears of maize were most likely parched directly over charcoals. Parching continues to dry the kernels while heating expands them slightly or a great deal, depending on the amount of moisture escaping from the starch grains, on the hardness of the endosperm, and on the thickness of the pericarp (Doebley and Bohrer 1983:32; Weatherwax 1954:87). If left long enough at the correct temperatures, the endosperm pops out of the pericarp of popcorn kernels. Parched flour kernels do not generally pop because the thinner pericarp allows moisture to leave the kernel before it explodes. Parching and popping improves nutritional accessibility of the kernel (Weatherwax 1954:87), but also exposes the soft, starchy endosperm, making them more susceptible to spoilage than dried kernels. After the experimental parching tasks were completed, a reference was found describing how corn ears were attached to long sticks and held over charcoals (Wilson 1987:64). This technique needs to be explored and compared with parching techniques described here.

Comparisons of grinding dried kernels and parched kernels shows that if the desired end product is flour, parching improves the flour content of popcorn kernels by 19.5 percent for Chapalote kernels and 12.3 percent for Reventador kernels. Parching Tohono O'odham 60-day flour kernels improves the flour content by a mere 1.0 percent (see Figure 3.14). Based on these results, the benefit to parching flour kernels is to improve taste, not grindability. Additionally, parched Chapalote and Reventador kernels taste about the same, but Chapalote kernels create more flour than Reventador kernels, which may have influenced the decision about which popcorn variety to plant.

Taste is a qualitative, somewhat personal variable, but certain characteristics such as sweetness can be measured, at least in a relative sense. The experiments allowed us to experience the taste of immature kernels and stalks measured with the refractometer and Brix scale at values of 3.5-5.0, which are considered low for corn by modern standards, but to us, tasted much sweeter than mature stalks and ears. The flour and meal from grinding dried Reventador and Chapalote kernels had more interesting tastes than the flour and meal from Tohono O'odham 60-day kernels. The taste of all varieties was improved by parching.

Concluding thoughts are that a variety of end products are possible simply by managing harvesting time, picking immature ears and stalks for recipes that need sweet juice, meal, or flour, and parching kernels for recipes that need fine flour or a nuttier taste. Qualitatively, the products resulting from grinding parched kernels of Chapalote, Reventador, or Tohono O'odham 60-day have completely different tastes than the products from grinding immature kernels or dried kernels of the same varieties. The potential was there for early agriculturalists to choose from among their popcorn varieties and processing techniques to fulfill the requirements of specific recipes. Even if the recipe required fine flour, several techniques were available that would result in fine flour from popcorn varieties. Dried, immature popcorn could have been quickly ground into fine, sweet flour. Dried, mature popcorn kernels could also have been ground into fine flour, although the process would have been labor intensive, involving winnowing and long grinding sessions before achieving the proper texture. Dried, parched kernels could have been ground into fine flour more efficiently than dried, unparched kernels, but less efficiently than dried immature kernels. It seems reasonable to propose that, even without cooking and storage pots, early agriculturalists had a varied cuisine derived from an assortment of processing techniques utilizing the maize varieties identified in the Las Capas fields processed with basin and flat/concave manos and metates. These experiments did not consider the possibilities of processing amaranth, mesquite, grasses, agaves, and cactus products, which would add even more richness to the cuisine.

CHAPTER 4

REPLICATING THE MANUFACTURE OF STONE AND FIRED-CLAY PIPES

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Both stone and fired clay pipes (Figure 4.1a-c) were used at Las Capas, AZ AA:12:111 (ASM), long before the advent of fired-clay containers (Adams 2015). Based on the recovery of whole and broken pipes and certain abrasive tools, stone pipes were clearly manufactured on site. Nine of the 15 stone pipes were made from vesicular basalt and from these, two complete pipes (Figure 4.2), two pipes that broke during manufacture (Figure 4.3) (see also Adams 2005:108, Figure 4.8, 2008:Figure 14.5), and two unfinished pipes, exemplify their manufacture sequence (Figure 4.4; see also Figure 4.1b). Three whole fired-clay pipes were recovered from Las Capas; one was intentionally broken (Adams 2015). The clay used to make these pipes looks similar to the clays along the Santa Cruz River near Las Capas, and the assumption is that they were also manufactured there. Assumptions about the local manufacture of stone and fired-clay pipes are the focus of the replication studies described here.

Prior to excavations at Las Capas, there was very little evidence of smoking technology during any time period in the Tucson Basin. Individual pipes were found at the Wetlands site, AZ AA:12:90 (ASM), the Clearwater site, AZ BB:13:6 (ASM), and the Stone Pipe site, AZ BB:13:425 (ASM). It is now clear that early agriculturalists made and used at least two types of pipes (Adams 2015). Stone and fired-clay pipes from Las Capas have similar features, even though they were manufactured with different strategies (Figure 4.5).

Self-stemmed pipes were made so that the same material was used for the bowl and the shank (see Figure 4.1a, c). Smokers of self-stemmed pipes put their lips directly on the stone or fired-clay bit. Composite pipes have one material for the bowl and perhaps the shank, but an added bone stem is where smokers put their lips. The purpose of the bone stem is to create a shank if one was not formed when the bowl was made or, in some situations, to lengthen the stem of a self-stemmed pipe. A mortise or a mortise notch is unique to composite pipes, apparently providing space for some type of glue to secure the stem within the bore (see Figure 4.5). At Las Capas, fine-grained stone was used to make self-stemmed pipes, and vesicular basalt, also called scoria, was used to make the bowls of composite pipes. One fired-clay pipe from Las Capas is classified as composite, because it also had a bone stem that probably lengthened its relatively short shank. Unfortunately, the stem is broken and barely visible in the shank, so it is unknown how much longer the bone stem would have been.

The bone stem was added to the pipe after it was fired. A small mortise notch is visible in the bit (Figure 4.6a). A similar mortise notch was noted in a second fired-clay pipe (Figure 4.6b), but there is no bone stem in the draft hole. The third fired-clay pipe (Feature 4.6c) was recovered from the same mortuary feature as the pipe with the bone stem. The pipe was intentionally broken before it was placed in the upper fill of the feature (Adams 2015). It has a relatively long shank and no mortise notch, raising the possibility that there is an optimal length for proper smoking performance. This is a hypothesis worthy of future experimentation.

Fired-clay pipes were made with an additive strategy. The three fired-clay pipes from Las Capas are similarly shaped with a wide bowl and a narrow shank (see Figure 4.6a-c). The impressions visible inside two of the tobacco chambers, the smooth rim and exteriors, and the mica inclusions in the clay used to make one of the pipes are clues to how and where the pipes were manufactured. Mica is common in the clays and soils that comprise the floodplain upon which Las Capas was settled (Macphail 2015), and it is unclear if the mica was intentionally added to the pipe clay or if the clay was self-tempered with natural inclusions.

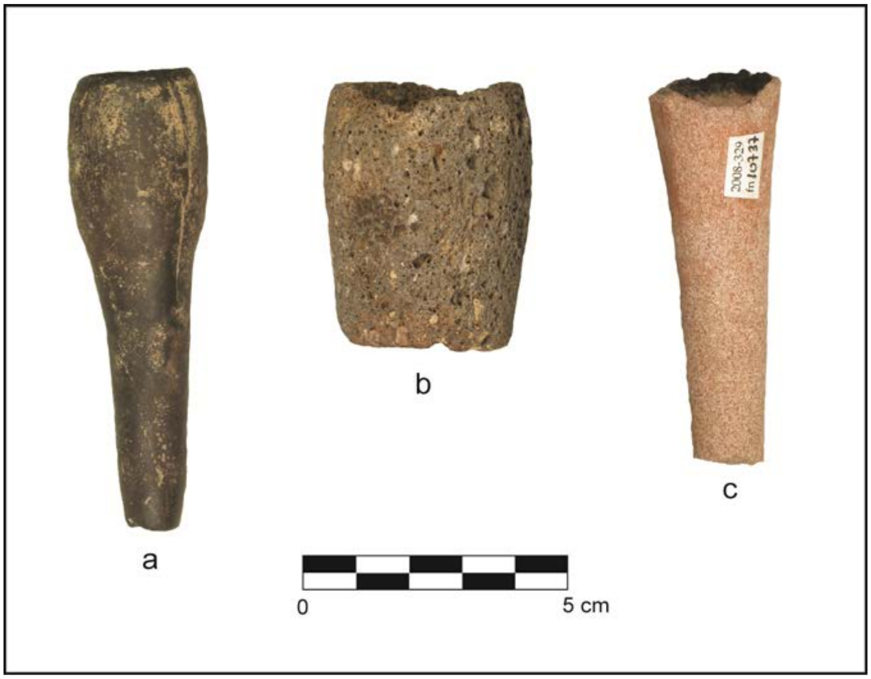

Figure 4.1. Three pipes recovered from Las Capas, AZ AA:12:111 (ASM): (a) self-stemmed, fired-clay pipe recovered from an early San Pedro phase, extramural bell-shaped pit (Feature No. 8024, FN 4405, Catalog No. 2008-329-463); (b) unfinished vesicular basalt pipe bowl recovered from a late San Pedro phase bell-shaped pit; red pigment around the rim (Feature No. 23830, FN 10634, Catalog No. 2008-329-497); (c) self-stemmed stone pipe broken below the bowl, found in an early San Pedro phase bell-shaped pit (Feature No. 7771, FN 10737, Catalog No. 2008-329-496).

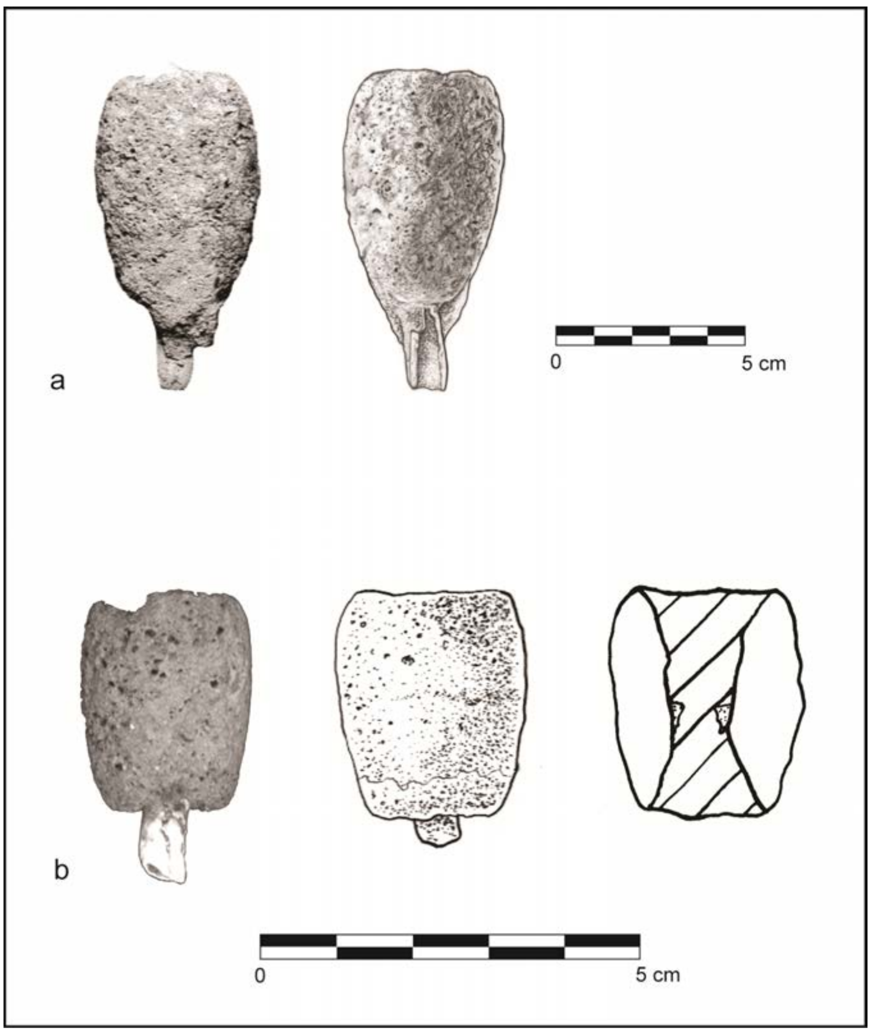

Figure 4.2. Complete stone pipes recovered from the same late San Pedro phase pit at Las Capas, AZ AA:12:111 (ASM): (a) carefully shaped bowl with a bone stem sealed into the mortise with clay (Feature No. 386, FN 2900); (b) small, cylindrical bowl with a loose bone stem in the mortise (Feature No. 386, FN 2899). See also Adams 2008:Figure 14.6 and Adams 2005:Figure 4.7, where the captions are switched between (a) and (b) (drawings by Rob Ciaccio).

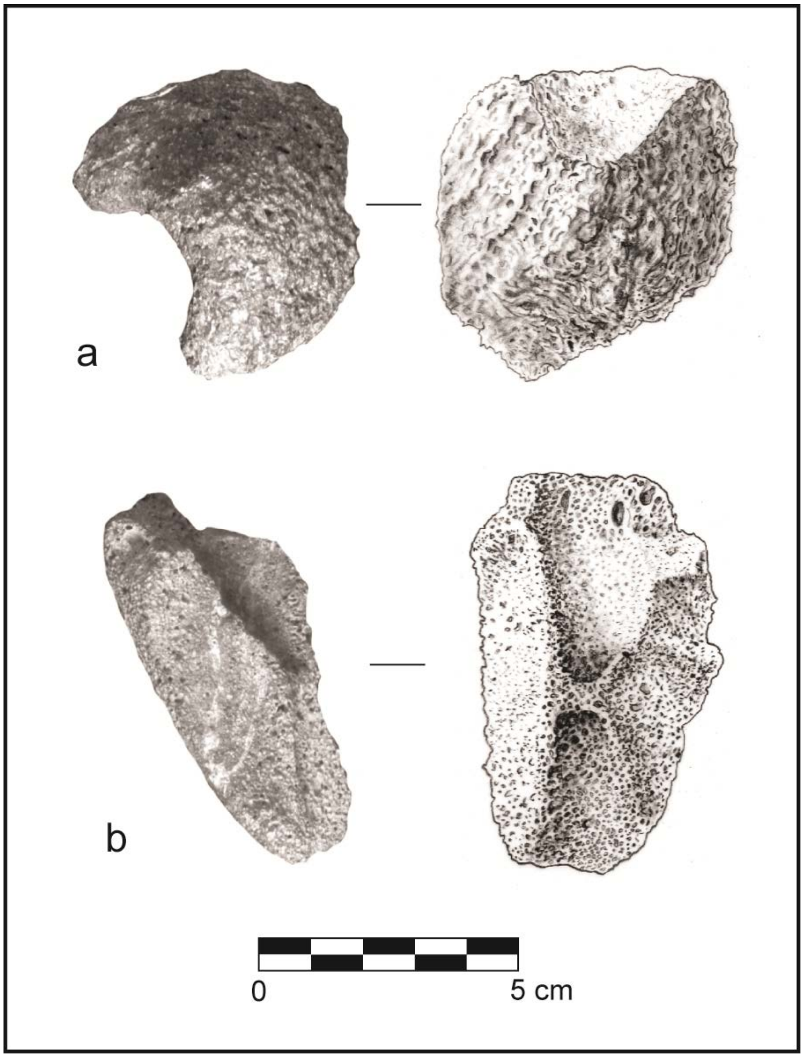

Figure 4.3. Stone pipes from Las Capas, AZ AA:12:111 (ASM), that broke during manufacture: (a) bowl that broke before the borehole was finished (Feature No. 593, FN 5648; (b) pipe that broke during manufacture of the borehole (nonfeature context, FN 851). See also Adams 2008:Figure 14.5 and Adams 2005: Figure 4.8, where the captions are switched between (a) and (b) (drawings by Rob Ciaccio).

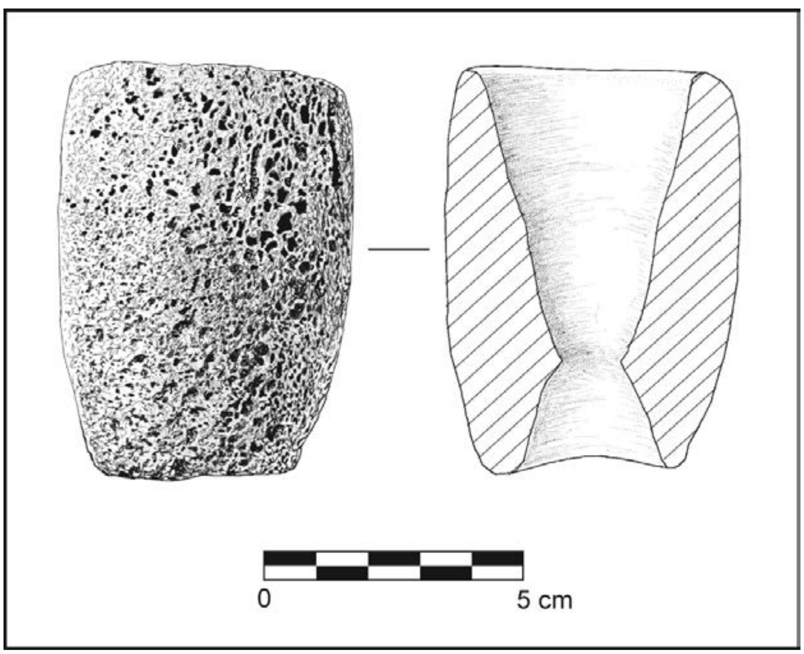

Figure 4.4. Line drawing of an unused and probably unfinished stone pipe from Las Capas, AZ AA:12:111 (ASM), late San Pedro phase, Stratum 504 extramural context (Feature No. 13000, FN 2846, Catalog No. 2008-329-498) (drawings by Rob Ciaccio).

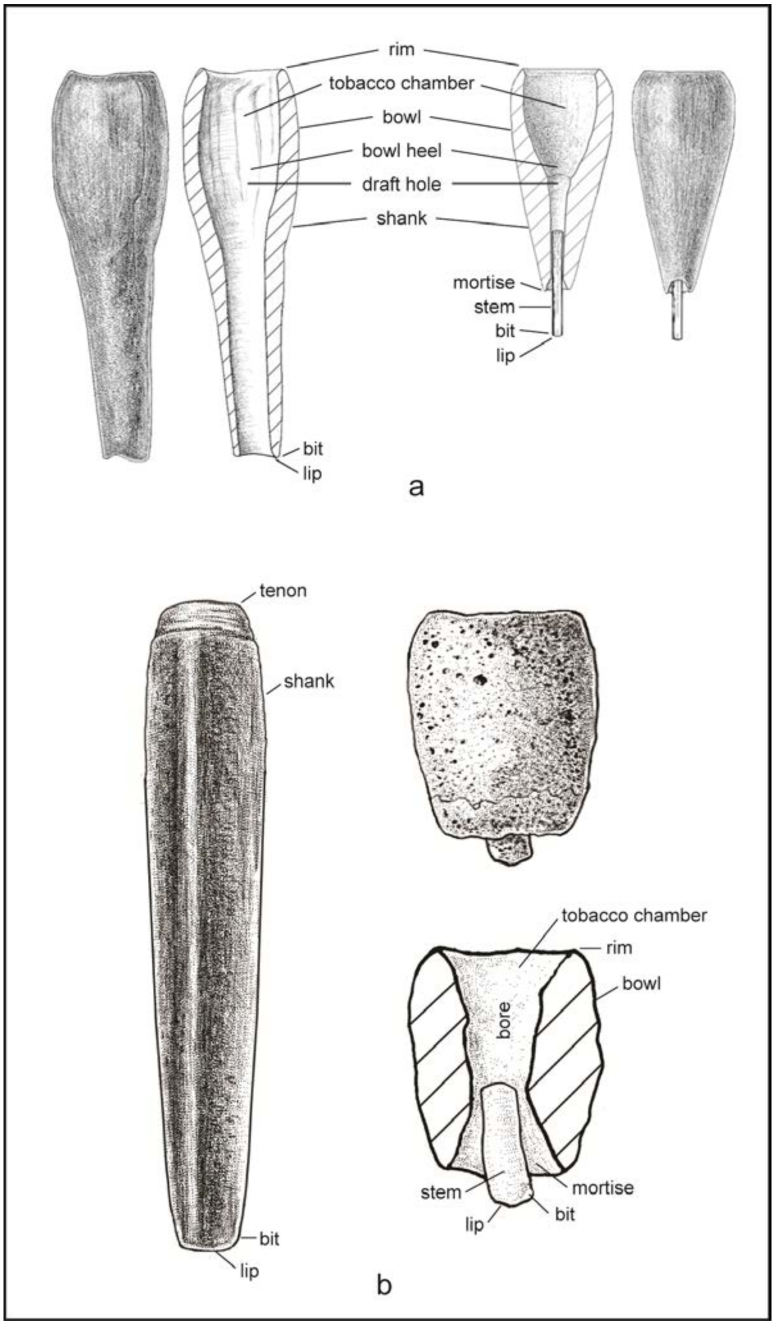

Figure 4.5. Terms used to describe stone and fired-clay pipes recovered from Las Capas, AZ AA:12:111 (ASM): (a) a composite pipe with a stone bowl and bone stem; (b) a self-stemmed, fired-clay pipe (Feature No. 8024, FN 4405, Catalog No. 2008-329-463); (c) a composite pipe with a fired-clay bowl and stem enhanced with a bone stem; the bone stem is broken and probably extended beyond the fired-clay stem (Feature No. 8580, FN 12790) (Adams 2015:Figure 3.1) (drawings by Rob Ciaccio).

Either way, clay was wrapped over a mold that had been carved from a piece of wood. The diameter of the rim is less than the widest diameter of the bowl on each pipe so the rim was shaped, and the pipe fired, after the mold was removed. The pipe with a broken bone stem was so carefully burnished on the exterior and so carefully fired that is resembles fine-grained argillite, which is a brown-to-red mudstone. In fact, it took analysis using scanning electron microscopy with energy dispersive X-ray spectrometry (SEM-EDS) to be certain that it was fired clay (Appendix A, this volume).

In contrast to the clay pipes, stone pipes were made primarily using reductive strategies. They were pecked and ground to form the shape and drilled to make the borehole, a tobacco chamber, and on some pipes, a mortise (see Figure 4.5a). Most often, the bore is biconical in cross section, with two basins on either side of the narrowest part of the bore, also known as a bowl heel (see Figures 4.5a). Based on a sample of three pipes, the larger basin is the tobacco chamber and the smaller basin is the mortise (see Figure 4.4).

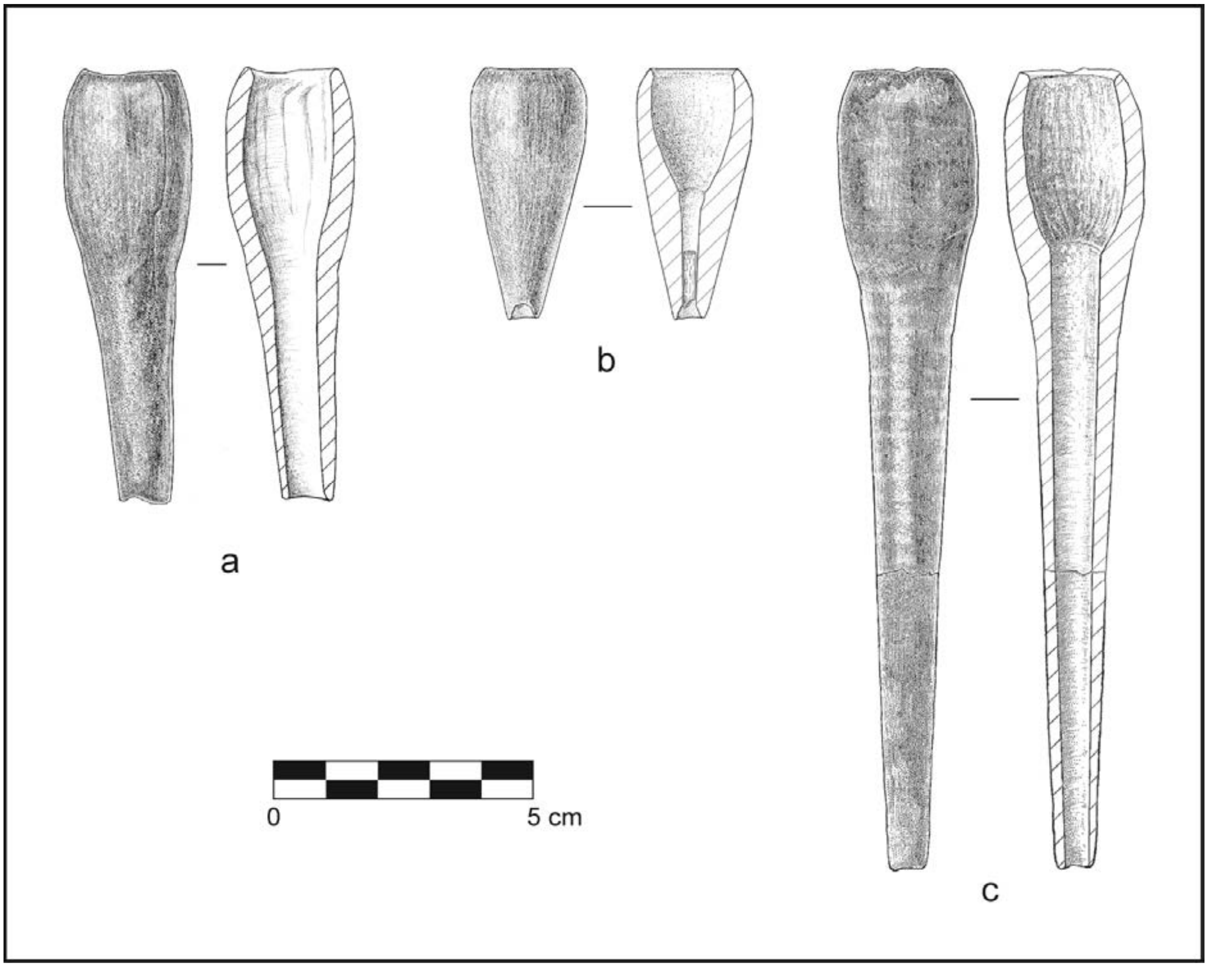

Figure 4.6. Three fired-clay pipes recovered from Las Capas, AZ AA:12:111 (ASM): (a) line drawing of a fired-clay pipe associated with an early San Pedro phase primary inhumation in an extramural bell-shaped pit (Feature No. 8580, FN 12780); (b) line drawing of a fired-clay pipe recovered from an early San Pedro phase extramural bell-shaped pit (Feature No. 8024, FN 4405, Catalog No. 2008-329-463); (c) line drawing of a fired-clay pipe intentionally broken across the stem, pipe recovered from the fill of the same primary inhumation as (a) (Feature No. 8580, FN 12380) (drawings by Rob Ciaccio).

REPLICATIONS

Because Las Capas is the only pipe manufacturing locus identified to date in the Tucson Basin, it seemed appropriate to replicate their manufacture. Replicas were made of the vesicular basalt stone pipes and the fired-clay pipes.

Stone Pipes

Two pipes were manufactured from vesicular basalt. One was shaped by grinding the exterior and the other by pecking the exterior. Damage patterns from both techniques were noted on the pipes recovered from Las Capas. The holes were drilled, by hand, with bifaces. All the bifaces used to drill the pipe preforms are shorter than the pipes are long and are narrower at their tips than their bodies. As they drilled through the stone, the resulting hole was conical, and by completing the hole from both ends of the pipe, the bore became biconical in cross section. In each pipe preform, one side of the biconical hole was wider and deeper than the other (Figure 4.7), because the hole was drilled more from one of the two ends.

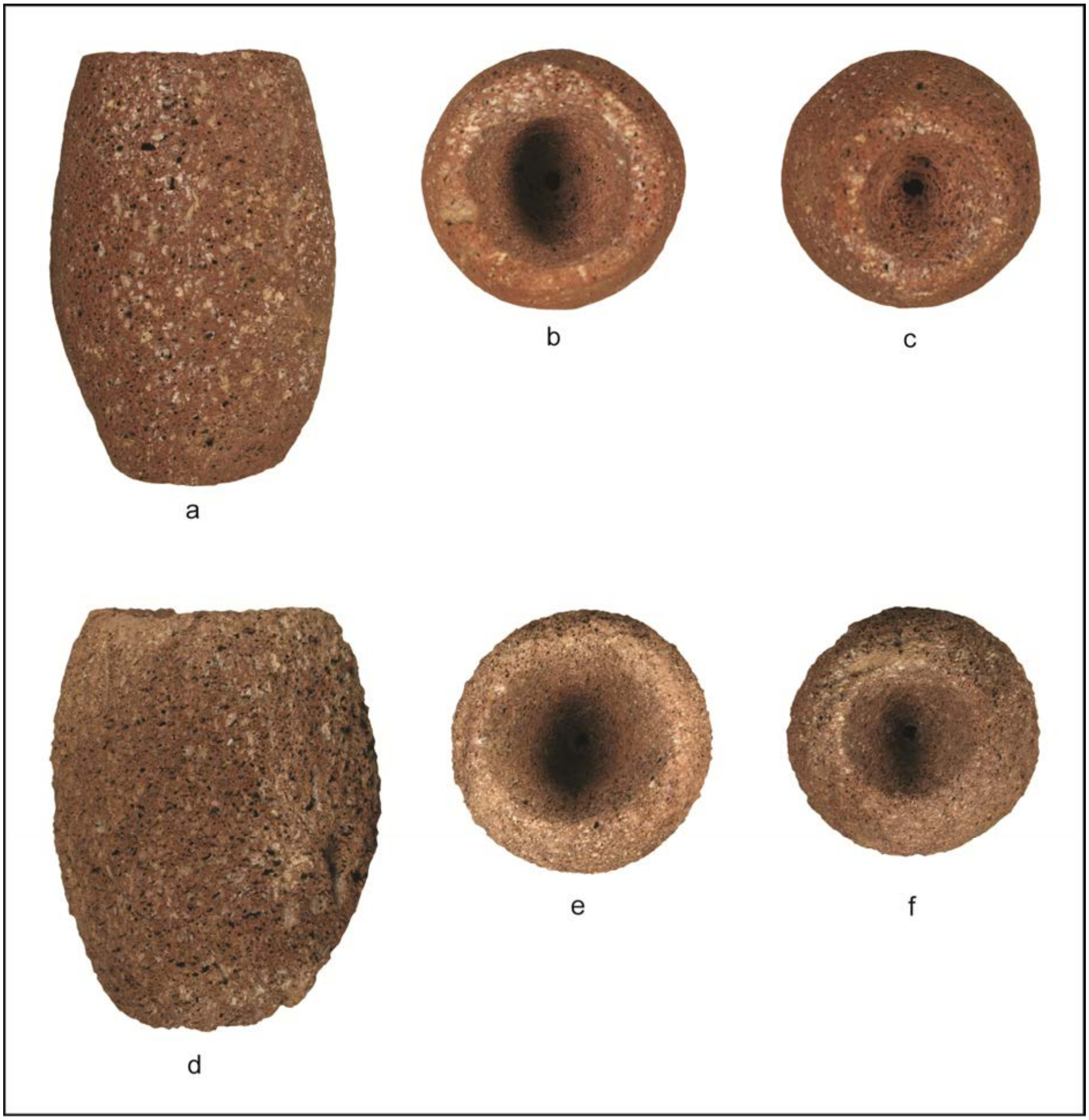

Figure 4.7. Replicated stone pipes: (a) stone pipe 1 preform made from vesicular basalt by grinding it against a netherstone; (b) rim and tobacco chamber; (c) mortise; (d) stone pipe 2 preform made from vesicular basalt by pecking with biface 1; (e) rim and tobacco chamber formed with biface 2; (f) mortise.

The preform for stone pipe 1 was ground against a netherstone of coarse-grained sandstone (see Figure 4.7a). Water was added during the grinding process, lubricating the surfaces, making it easier for the netherstone and pipe preform to glide across each other. The water also held together any dislodged rock grains, adding them to the abrasives that shaped and smoothed the surface (Figure 4.8a). A biface made from fine-grained, metasedimentary rock found in the Rillito riverbed (Figure 4.9a) was used to peck small depressions into each end of the ground preform. Within these depressions, the biface was used in a combination of pecking and drilling strokes (Figure 4.9b-c). It took 1 hour, 40 minutes to drill the bore into the tobacco chamber on one end and the mortise on the other end. The pipe bowl was completely shaped and drilled in 2 hours, 19 minutes.

Stone pipe 2 was manufactured with two bifaces. Biface 1 is chert (Figure 4.10a-b) from the Santa Cruz riverbed. It was used to peck away the vesicular basalt until it was the appropriate size and shape for a pipe (see Figure 4.7d), leaving a relatively rough surface compared to stone pipe 1 (Figure 4.8b). Biface 2 is basalt from the Sentinel Peak area, and it was used to drill the borehole (Figure 4.10c-e). The pecked pipe bowl is larger than the ground pipe bowl, taking 4 hours, 26 minutes to make, 2 hours, 16 minutes of which was spent drilling the borehole.

The replica stone pipes were finished with the addition of a bone stem. Two stems were made in about 10 minutes each, one from a rodent femur and the other from a chicken femur. The stems were prepared by cutting the proximal and distal ends off the bones with a chert flake. The resultant tubes were glued into the mortise of each pipe bowl using clay from Stratum 506 in Locus B at Las Capas (Figure 4.8b, d). Altogether it took less than 5 hours to make each vesicular basalt pipe, not including the time spent finding a good rock with which to start.

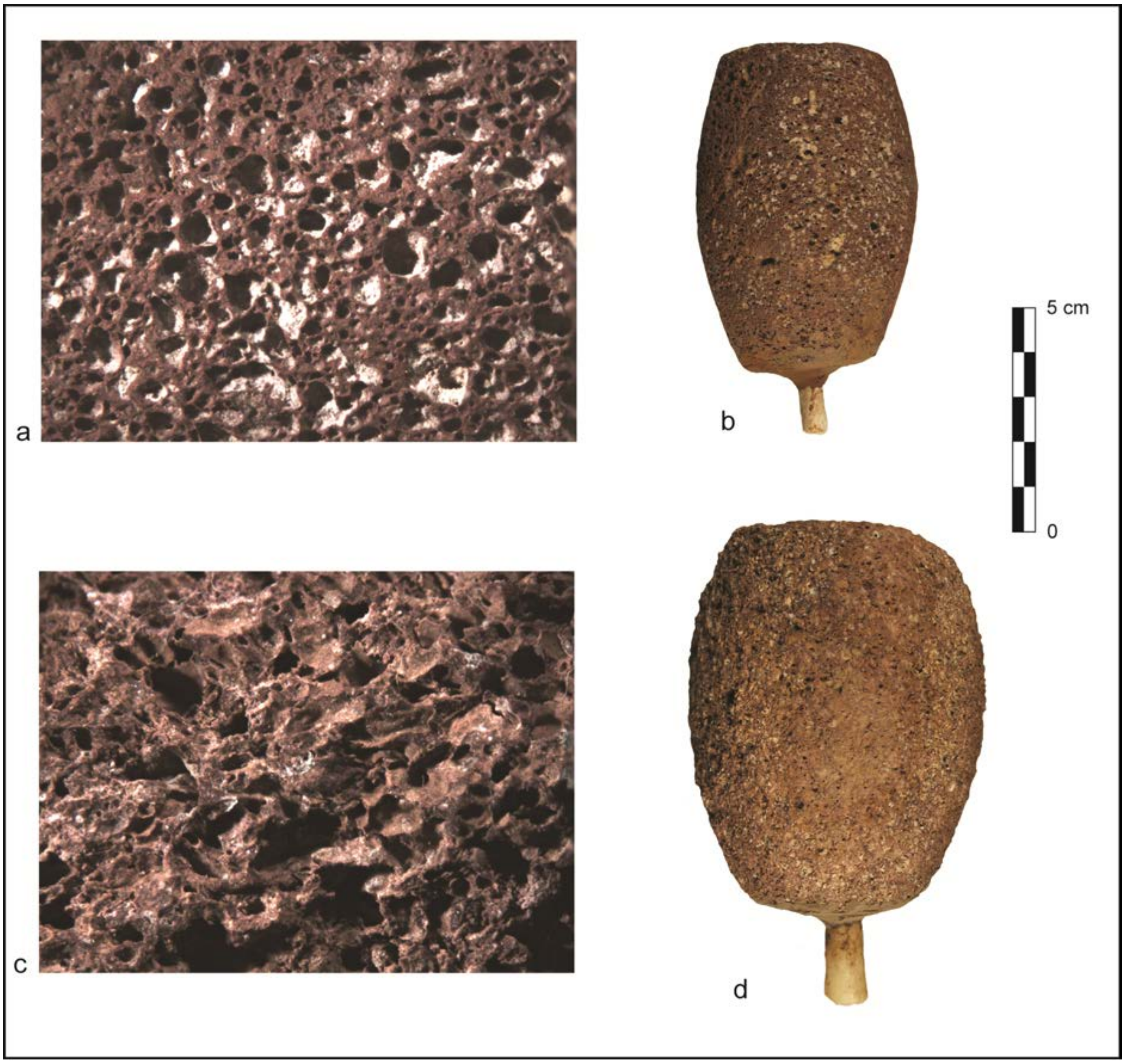

Figure 4.8. Surfaces of replicated stone pipes: (a) stone pipe 1, photomicrograph, 18x, of surface ground against a netherstone, 18x; (b) stone pipe 1 completed, with a bone stem cemented with clay into the mortise; (c) stone pipe 2, photomicrograph, 18x, of surface pecked with a biface, 18x; (d) stone pipe 1 completed, with a bone stem cemented with clay into the mortise.

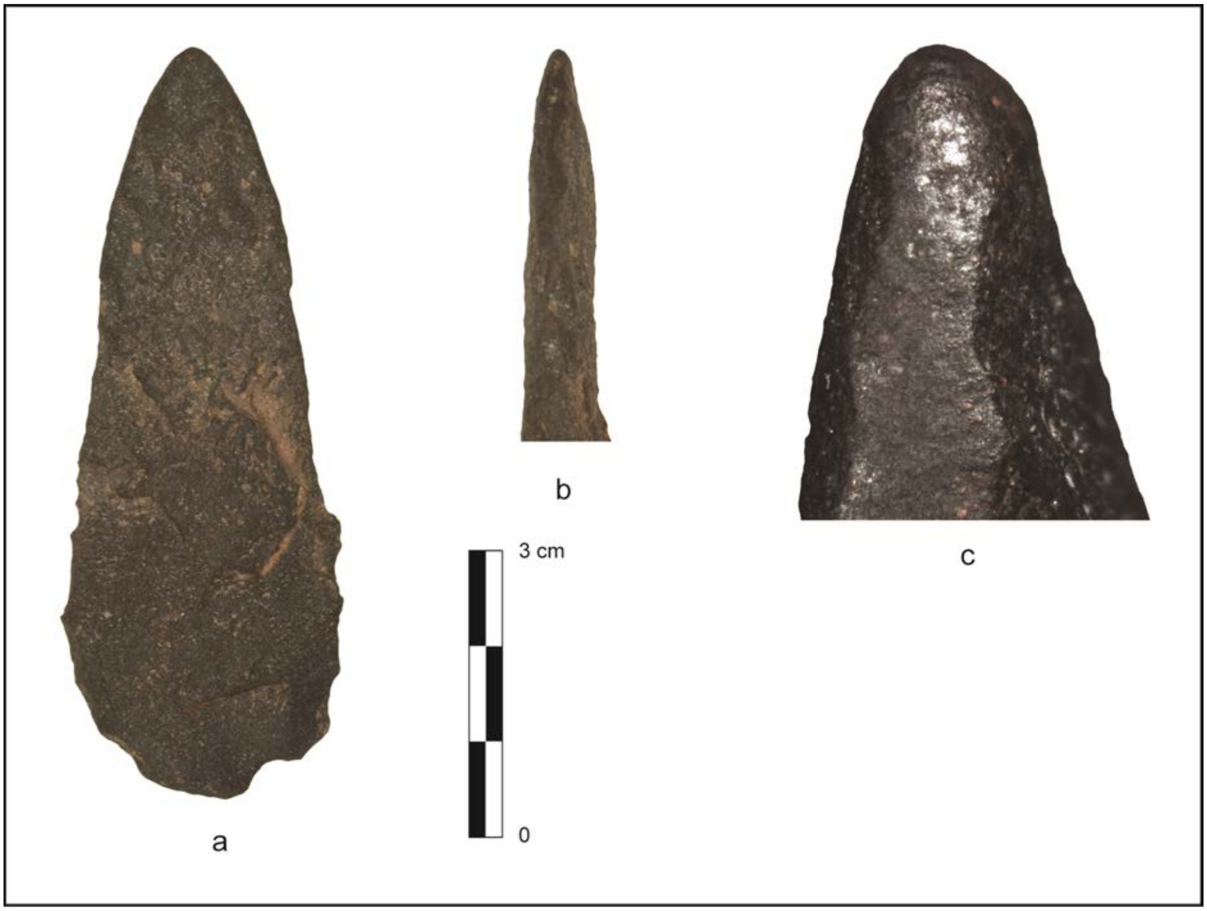

Figure 4.9. Bifacial flake used to make stone pipe 1: (a) plan view after use; (b) abraded edges with striations perpendicular to the point; (c) photomicrograph, 18x, of the point with sheen on the tip and the flattened edges of the biface.

Fired-clay Pipes

The manufacture of fired-clay pipes began with shaping two molds from two mesquite sticks that were cut to lengths of 10 cm and 11 cm. The longer mold was made from a dried mesquite branch and used to form fired-clay pipe 1 (Figure 4.11a), and the other mold, from green mesquite wood, was used to form fired-clay pipe 2 (Figures 4.11b, 4.12a). It took 27 minutes to carve the green stick and 18 minutes to carve the dry stick using a single flake on each mold. Manufacture of each pipe began by pressing clayaround the mold; it only took a few minutes to cover the mold with a 0.3- to 0.5-cm-thick layer of clay (Figure 4.12b). Enough stick was left outside the bowl to pull the mold out of the clay before the final shaping of the rim (Figures 4.11c, 4.12c). Clay completely covered the proximal end of the stick so that after the mold was removed, the shape was completed by poking a hole in the end, exposing the bore and shaping the lip (Figure 4.11d).

The exterior of each pipe was smoothed with a stick before firing. A small fire was lit in a hearth and burned long enough to create coals and ash into which the clay pipes were placed (Figure 4.12d). The pipes were left there overnight. After firing, the replicas are similar to the three fired-clay pipes from Las Capas in appearance, texture, and with stick impressions in the rim and tobacco chamber (see Figure 4.11).

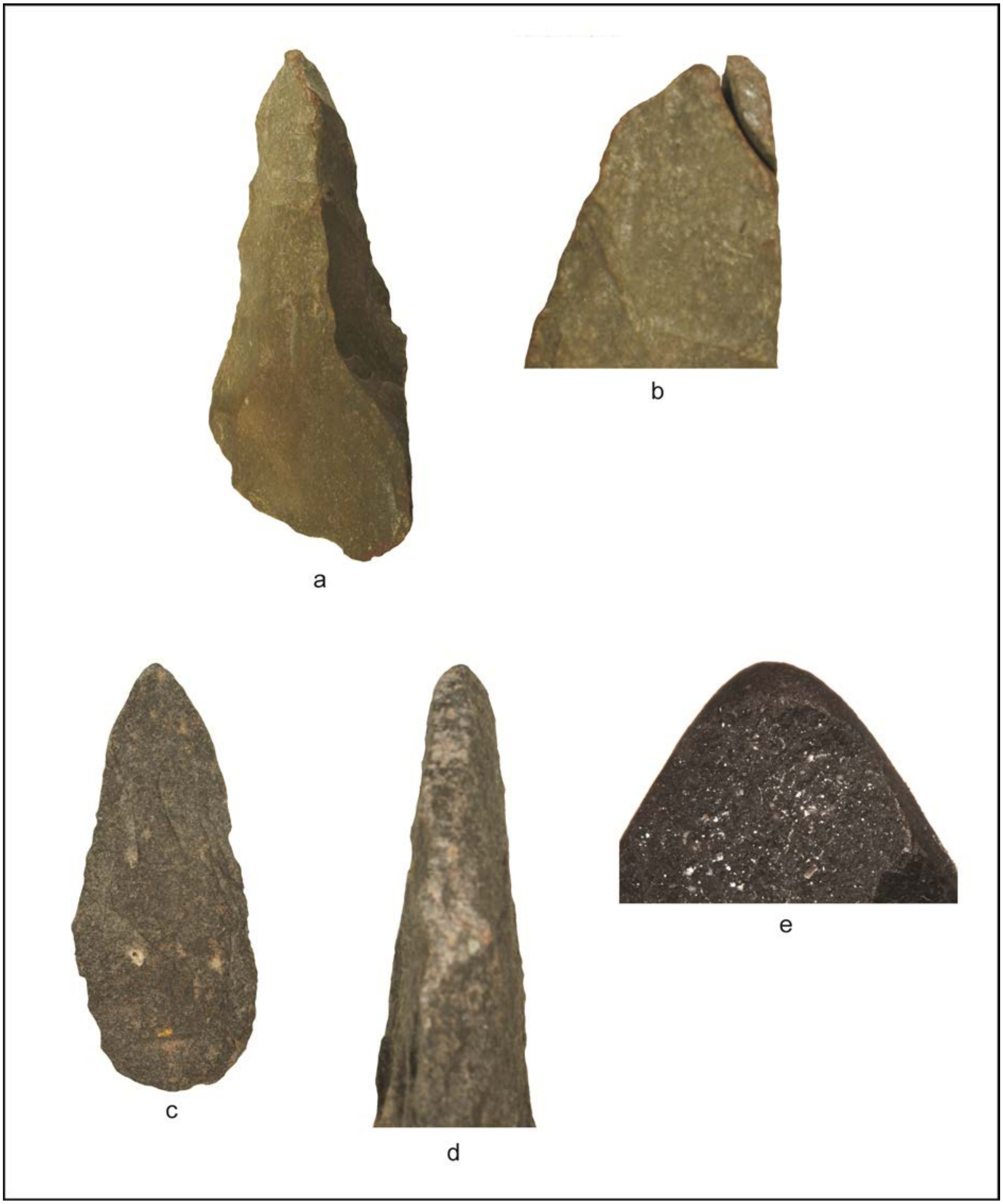

Figure 4.10. Two flakes used to manufacture stone pipe 2 preform: (a) plan view of biface 1 after use; (b) close up of the biface 1 tip used to shape stone pipe 2 by pecking away the vesicular basalt; note the spall that was dislodged during use; (c) plan view of biface 2 after used to make the borehole; (d) tip and abraded edge of biface 2; note the abrasions at the arrows; (e) photomicrograph, 18x, of the tip used to drill the borehole in stone pipe 2.

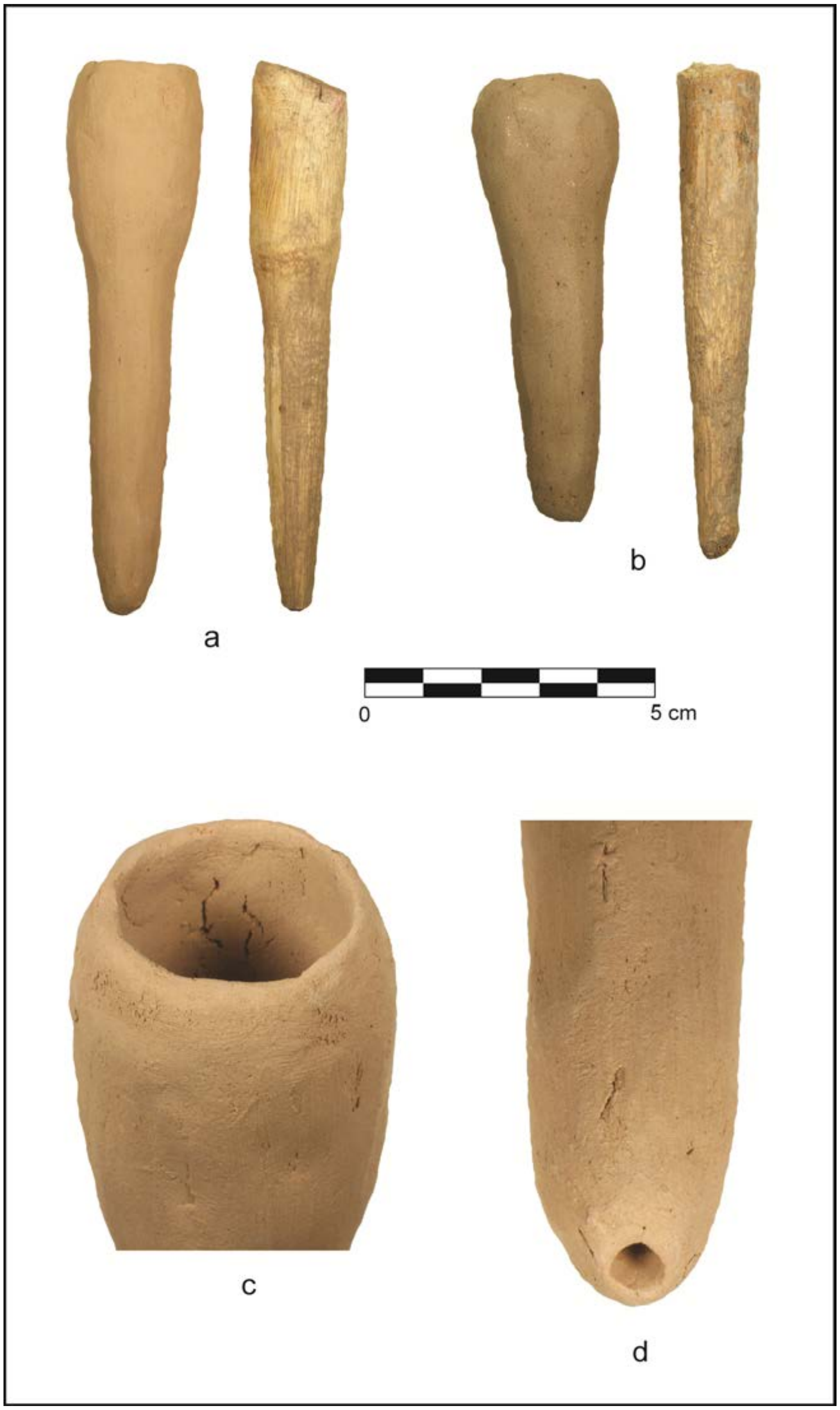

Figure 4.11. Two replicas of fired-clay pipes from Las Capas, AZ AA:12:111 (ASM): (a) fired-clay pipe 1 and the wooden mold used to form the pipe; (b) fired-clay pipe 2 and the wooden mold used to form the pipe; (c) close up of the finished rim and tobacco bowl of fired-clay pipe 1; (d) bit, lip, and borehole of fired-clay pipe 1.

DISCUSSION

Ethnographic descriptions of Puebloan pipe smoking include the social sharing of a pipe among men and the blowing of smoke over objects or people in ritual observances (Fewkes 1894; Parsons 1939; Stephen 1936). These accounts provide different models for how pipes could have been used prehistorically. At Las Capas, whole fired-clay and stone pipes were associated with mortuary contexts and extramural pits. A pipe buried with an individual may reflect personal use, but might also indicate that the ritual in which the pipe was used was transformed by the death of the individual (Adams 2008:223).

Figure 4.12. Manufacturing process for two replicas of fired-clay pipes from Las Capas, AZ AA:12:111 (ASM): (a) flake and green mesquite stick used to make the mold for fired-clay pipe 2; (b) clay partially wrapped around the mold; (c) final shaping of the rim after the mold was pulled out of the pipe; (d) replicated pipes in the coals of a hearth.

A single seed of *Nicotiana* was recovered from a Cienega phase (800 B.C.-A.D. 50) context at the Wetlands site (Diehl 1998:239). The pipe from Wetlands is different from most of the pipes recovered from Las Capas by being slender and subtly conical, wider at the distal end. Although missing a stem and smaller, it is similar to a conical pipe recovered from a mortuary context at the La Playa site, SON F:10:3 (ASM), that probably also dates to the Cienega phase (Carpenter et al. 2002a:120-122). The La Playa pipe is basaltic scoria and has a tube made by a marine worm, *Vermetus* spp., as a stem. Roney and Hard (2002:164) mention evidence for local manufacture of tubular pipes made from volcanic tuff at Cerro Juanaqueña, but these were not illustrated, making it impossible to determine if they are shaped similarly to the Las Capas pipes.

The earliest evidence for pipe smoking in the borderlands noted so far comes from the Archaic period deposits in Pintada Rock Shelter and Chiracahua-Armogosa II cultural deposits at Ventana Cave, AZ Z:12:5 (ASM) (Ferg 1998:602; Haury 1950:329, Figure 79e; MacNeish 1998). The Las Capas pipes are the earliest and most persistent in the Tucson Basin, with their presence in contexts dated from the early San Pedro phase through the Early Cienega phase (Adams 2015:Table 3.6). The few other pipes mentioned from Tucson Basin contexts are the Cienega phase pipes with tenons from the Clearwater and Stone Pipe sites, for which there is no evidence that either was locally made.

As a final thought, the pipe replication studies have demonstrated a technique that could have been used at Las Capas for forming and firing small clay containers in the form of pipes. Even though the inhabitants of Las Capas did not make cooking and storage pots, they did have the technological knowledge for making figurines and small vessels in addition to the fired-clay pipes (Heidke 2014). Basic potting techniques of acquiring, forming, and firing clay were present among at least some of the Las Capas inhabitants. The ubiquitous clays at Las Capas allowed for the successful construction of these small pieces.

CHAPTER 5

FROM MORE EXPLORATION TO MORE CONTROL

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Planting, harvesting, processing, and manufacturing are activities recognized at Las Capas, AZ AA:12:111 (ASM), by the discovery of agricultural field systems, the remains of maize plants, food-processing tools, and pipes in various stages of manufacture. Knowing which activities occurred in a particular location is important, but learning how they were performed brings more contemporary relevance to the archaeological research. There is no way to verify our conclusions about activities that occurred 2,000-3,000 years ago; however, models built from ethnographic sources, as well as replication and experimental studies recognize a range of possibilities. The exploratory nature of this research allowed us to decide which experimental tasks provided useful information, what needs to be changed in the structure of the tasks, what variables need to be held constant during the next round of experiments, and if our hypotheses were correct in their orientation or if they need to be redirected.

Harvesting and processing experiments conducted for the Las Capas project are not the first, but they build on and contribute to the research of others studying farming techniques and yields (Adams et al. 2006; Toll et al. 1985) and comparing the relative efficiencies of food-processing tool designs (Adams 1999). The replication of vesicular basalt and fired-clay pipes, however, are unique. The addition of experimental and ethnographic research from the Las Capas project creates a significant baseline for an extensive research project that will incorporate more ethnographic resources, involve interested Native American farmers, conduct more exploratory experiments, and add tightly controlled confirmatory experiments.

FIELD REFINEMENT

From the research conducted in the Las Capas fields, we now know that early agriculturalists improved their soil by adding organic substances (Macphail 2015), and they grew varieties of maize that were genetically closer to teosinte than the varieties grown today (Cummings et al. 2013). The fields planted at Steam Pump Ranch were fertilized, but future agricultural field preparations will replicate, as closely as possible, the soil improvements made at Las Capas, and plantings will include teosinte and other popcorn varieties in addition to continuing to plant Chapalote, Reventador, and Tohono O'odham 60-day. It is important to grow the same varieties again to replicate and confirm observations from the exploratory experiments presented here, but it is also critical that maize varieties closer to teosinte in genetic makeup be grown and processed to create better models for the crops of early agriculturalists.

Native Seeds/SEARCH, a traditional agricultural heritage seed bank in Tucson, was the source for most of the seeds grown during three seasons in the Las Capas experimental fields at Steam Pump Ranch. Seeds from the previous year's harvest were mixed with new Native Seeds/SEARCH seeds so that the largest, healthiest looking seeds could be chosen for planting. Other varieties of popcorn are available from Native Seeds/SEARCH. Northern Tepehuan Teosinte (*Zea mays mexicana)*, is described on the Native Seeds/SEARCH website as a prolific seed producer with a sweet-tasting stalk and, as an added benefit, it apparently hybridizes and improves the health of the maize crop when planted nearby.

After the success of sequential plantings at the Steam Pump Ranch fields, it is important to replicate that strategy in one field and, for comparison, plant another field with a uniform strategy. Measurements will be taken and compared, recording stalk counts and ear yields. The second planted field will be harvested for a few immature stalks and ears, leaving the rest to mature. Spaces left in both fields after stalk harvesting will be replanted. Ears will be left on the stalks to dry, or they will be harvested and laid out to dry in a protected area depending on weather conditions and presence of predators.

During the exploratory experiments, Reventador maize stalks were at their prime for juicing about 10 weeks after planting, and the first ears of maize were mature after 18 weeks. If the next fields are sequentially planted and harvested, immature stalks will be coming into their prime for juicing, on average, every week after the first 10-week harvest, and mature ears will be available every week after the initial 18-week harvest until the end of the growing season. The riskiest decisions would be when to plant the first seeds and when to take the last harvest. With planning, immature stalks for juicing and mature ears for eating could be harvested at the same time.

Future planting and harvesting tasks will be carefully documented by written and photographic records kept for each field to test the hypothesis that sequential planting and sequential harvesting lengthens the number and type of productive days in the field. The next experimental season will track yields for immature and mature product, soil preparation, water amounts, and loss of plants more carefully than was done during the exploratory experiments.

EXPLORING MORE PROCESSING TECHNIQUES

Smalley and Blake (2003) note that stalks are sweetest before the juice moves into the kernels. Our subjective consensus was that the stalks contained more juice after the ears were just starting to form on the stalks, but that the juice was sweeter from stalks that had no ear formation. Future juicing experiments will compare sweetness of different varieties of maize and the sweetness of teosinte stalks. Sweetness was not measured during the Las Capas experiments for Tohono O'odham 60-day maize stalks, but subjectively, everyone agreed that it tasted less sweet than either of the popcorn varieties. This needs to be measured and documented for all stalk types. Future measurements will be made using something like Benedict's reagent, to more directly measure sugar content than the refractometer and Brix scale used during the Las Capas experiments.

From the nutritional literature, we learned that as the ears mature, the sugar in kernels becomes starchy and, therefore, less sweet than immature kernels. The experimental processing of immature kernels will be expanded, with comparisons among different varieties and more care given to selecting immature ears at the same level of maturation than was given during the exploratory experiments. The same Benedict's reagent used to measure juice sweetness will be used to measure kernel sweetness as well.

Also from the nutritional literature, we learned that niacin, nitrogen, potassium, and other essential minerals are more easily digested from immature kernels than from mature kernels. Additional processing of mature kernels, such as parching and grinding, may make these important dietary components available for digestion and absorption by human bodies. This is an area in which it will be necessary to work with a nutritionist. Even though it is outside the realm of early agricultural processing techniques, future exploratory experiments will be designed to identify and replicate the important tasks involved in nixtamalization, that is, boiling in an alkaline solution.

Future experiments with processing and parching maize will be more carefully standardized based on what was learned during these exploratory experiments. The replicated tools used to grind the maize need to be slightly redesigned to test if mano weight compared to mano length or surface area makes a more efficient tool. Consensus among the researchers working the Las Capas grinding experiments was that the flat/concave mano was more efficient than the basin mano because it was heavier. Flat/concave manos typically have more surface area in contact with the metate than basin manos. The existing database at Desert Archaeology on mano dimensions will be used to evaluate the range of variation in the size and weight of basin and flat/concave manos. This information will be used to create size categories for experimental comparison. Size/efficiency experiments will be conducted to test the hypothesis that large manos are more efficient than small manos at grinding dried maize kernels of any type.

Afer the results are compiled from the size/efficiency experiments, the various types of manos will be sorted into defined size categories, and carefully controlled size/type experiments will test the efficiency of each mano type made into three size categories. Replicated basin and flat/concave manos and metates will be used to create a database for comparing the efficiency of manos, by type and size, for grinding flour and pop varieties of maize when immature, mature, fresh, dried, or parched. Tohono O'odham 60-day maize will continue to be the control against which all other types of maize are compared. This flour maize was selected because it is commonly used today among the Tohono O'odham, it is a variety that has been manipulated to mature quickly, and it is a flour maize variety that has already been experimentally tested against Reventador and Chapalote pop varieties of maize, as described elsewhere in this technical report.

Parched maize will be important for the next phase of experiments, but the exploratory experiments were conclusive enough about how the ears were parched that only kernels on the cob will be parched. Dried maize ears will be parched on sturdy sticks held over the fire to explore the technique identified elsewhere (Wilson 1987:64). Future experiments will explore the arrangement of rocks and cobs in the pit as well as configuration of the pit itself. Archaeologically derived information about the shapes and depths of thermal features at Las Capas will be used to construct pits with appropriate variation for exploring which configurations may have been the best for efficient parching tasks.

Even after completion of the next round of experiments with food processing, many more new questions will be raised. Eventually, the same controlled experiments will need to be conducted using trough and flat manos (manos that are as long as the metate is wide), which are the designs of food-processing tools added to the repertoire post A.D.-450 in the U.S. Southwest.

MAKING MORE PIPES AND SMOKING THEM

Now that manufacturing techniques for some stone and fired-clay pipes have been replicated, we need to replicate the less common tube pipes that are cylindrical or slightly conical and that were recovered from Las Capas and the Wetlands site, AZ AA:12:90 (ASM). These pipes do not have bone stems, and they have longer, narrower bores than the vesicular basal pipes made at Las Capas. The tube pipes were likely ground to shape against a netherstone in the same manner as vesicular basalt pipes at Las Capas, but the technology for drilling the holes may have been different. Hafted, smaller bits may have been used to drill the longer, narrow bores in tube pipes. The hand-held bifaces used to drill the vesicular basalt bowls are large and make large biconical bores (as described in Chapter 4). It may take several attempts to replicate the drilling techniques used with tube pipes.

The manufacture of another pipe type also needs to be replicated. Only two have been found in the Tucson Basin, one at the Clearwater site, AZ BB:13:6 (ASM), and another at the Stone Pipe site, AZ BB:13:425 (ASM). Both pipes have a tenon, an unusual feature on pipes compared with those found at Las Capas and Wetlands. On modern pipes, a tenon is where the tobacco chamber is attached, but neither of the pipes with tenons has use-wear to indicate the attachment of a bowl; only one may have been smoked. The pipes with tenons are cylindrical to slightly conical, and are made from fine-grained rocks, such as steatite and lamprophyre. Ethnographic research about groups outside the borderlands is necessary to determine where else these types of pipes have been found and the nature of the bowl/tenon attachment. Replication experiments are necessary to determine if the tenon configuration would support an attached bowl.

The replication experiments with pipe manufacture have provided some interesting conclusions, but they also raised more questions than were answered. The next step in this experimental process will be to make tube pipes and to compare the performance characteristics of each pipe during smoking. These replication experiments are not the same as experiments conducted to test variables or to determine efficiency. However, such experiments could be designed by making stone and fired-clay pipes that are exactly the same size and shape to compare how easy they are to light, to smoke, to make smoke, and other performance characteristics. Other experiments are needed to compare bone stems to those made of other material, such as wood or reed. The basic questions to be addressed with smoking experiments are: (1) do fired-clay pipes and stone pipes smoke the same; (2) do pipes with a composite stem smoke differently than self-stemmed pipes; and, (3) can the conical pipes with tenons be smoked without an attached bowl?

The exploratory experiments described here and the proposed next phase of exploratory and controlled experiments is important for improving models of how early agriculturalists may have survived. The abundant ethnographic literature in the U.S. Southwest and descendant Native Americans all have descriptions of how things are done. Like the maize plants, there have been structural and aesthetic changes over the last 3,000 years since Las Capas was occupied that make survival strategies different for contemporary groups than they were for early agriculturalists. In our desire to understand how things were done, it seems reasonable to broaden the possible solutions to technological problems of planting, harvesting, processing, manufacturing, and smoking by replicating what is seen in the archaeological record using any and all possible techniques, including experimentation. Some solutions generated by experimentation will look more like those in the archaeological record than others.

APPENDIX A

SCANNING ELECTRON MICROSCOPY OF PIPES FROM LAS CAPAS, AZ AA:12:111 (ASM)

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Scanning electron microscopy with energy dispersive X-ray spectrometry (SEM-EDS) is a technique that allows for high magnification of objects along with qualitative chemical compositional analyses where performed nondestructively. These properties are ideal for investigating a pipe, which was of uncertain material, recovered during the Las Capas, AZ AA:12:111 (ASM), excavation. Some of the attributes of the pipe suggested it had been made from stone, while others indicated the material was more likely clay. It was important to establish the material used for manufacture of the pipe to relate it to the other pipes recovered from Las Capas and to gain a better understanding for the production and use of such unique objects.

SAMPLES AND METHODOLOGY

The SEM-EDS analysis was conducted on three pipes from Las Capas. Two of the pipes were of more certain material, one being stone (FN 5022) and the other almost certainly clay (FN 12378/12380). The analyses of these pipes were used as controls, as well as to assist in interpretation of the data from the pipe of unknown composition (FN 12790). The SEM-EDS analysis of each pipe was conducted in the same way. The vacuum was set for variable pressure (50pa), with the energy of the electron beam at 15 kv and a probe current of 65. Imaging was done in the backscattered electron 3-D mode to examine the elemental homogeneity of the samples and acquire information about the morphology of the material. A single image at 40x magnification was taken of the pipe, although this showed only a section of the object.

Chemical compositional data was acquired for 100s, with a deadtime of 10 percent. The elements included aluminum (Al), calcium (Ca), chlorine (Cl), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), silicon (Si), sulfur (S), and titantium (Ti). For the stone pipe sample, the element chromium (Cr) was also detected. The EDS analysis was conducted on an area at 500x magnification. An image was taken of this area to show the heterogeneity of the material analyzed and any important charateristics. Five areas that were relatively flat were chosen for the chemical analysis. For comparison between the three samples, the five analyses were averaged. All the data were normalized to 100 percent, and are reported as weight percent oxides.

RESULTS

Examination of the three pipes by SEM-EDS revealed interesting morphological features and chemical results. The stone pipe (FN 5022) had a fairly uniform appearance, with a few flakes of a material that contained heavier elements (Figure A.1). The compositional data suggested these may be chromium, as the sample had a small amount of this element, unlike the two other pipes. In addition to its appearance, the chemistry suggested the material was a mafic rock, with high values of magnesium and iron (Table A.1).

The other control sample, FN 12378/12380, was made from clay, which had a different appearance at high magnification (Figure A.2). Significant were cracks that ran through the material, something only likely to occur with clay, which may crack due to applied pressure or during drying and use. Chemically, the sample had more aluminum, chlorine, potassium, phosphorus, sodium, sulfur, and titanium, and less iron, magnesium, and manganese than the stone pipe. The small amounts of chlorine, phosphorus, sodium, sulfur, and titanium are consistent with clay that acquires these elements during weathering.

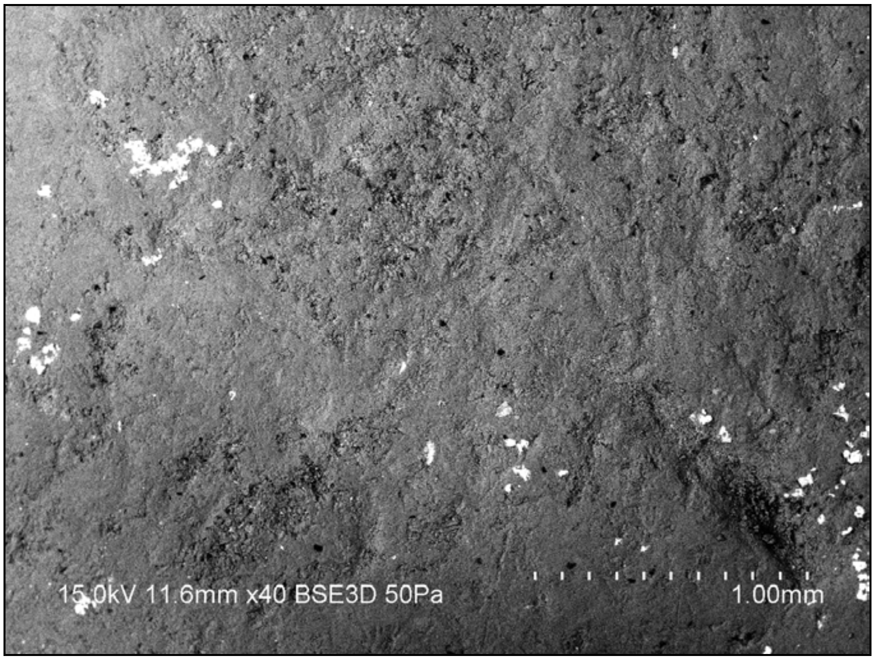

Figure A.1. Backscatter electron image of stone pipe (FN 5022) recovered from Las Capas, AZ AA:12:111 (ASM) (magnification is 40x).

Table A.1. Normalized values for 14 elements examined during scanning electron microscopy (SEM) analysis of three pipes recovered from Las Capas, AZ AA:12:111 (ASM) (in weight percent).

Element	Pipe, FN 5022	Pipe, FN 12378	Pipe, FN 12790
Oxygen	44.11	45.71	45.85
Sodium	0.58	1.79	3.31
Magnesium	14.99	1.31	2.49
Aluminum	4.35	7.09	9.13
Silicon	22.92	28.51	27.07
Phosphorus	0.06	0.24	0.14
Sulfur	0.00	0.59	0.09
Chlorine	0.67	0.94	0.17
Potassium	0.86	3.74	2.51
Calcium	4.23	4.13	2.51
Titanium	0.02	0.36	0.88
Chromium	0.27	0.00	0.00
Manganese	0.23	0.05	0.43
Iron	6.70	5.55	5.43
	100.00	100.00	100.00

These data were used as baseline information when assessing the chemistry and images from the pipe (FN 12790) of unknown material. The images showed a fairly homogenous material, but with notable inclusions having similar atomic values (Figure A.3). This could be indicative of either clay or stone. However, at higher magnification, some areas of the pipe exhibited cracking, suggesting the material was more likely clay. The chemistry supported this hypothesis to a certain extent. The values of potassium, phosphorus, and sulfur were lower than those for the clay pipe, while the amount of magnesium, manganese, sodium, and titanium were higher. The values of calcium and chlorine were not as high in this sample as in either the known stone or clay samples. Overall, the high amounts of aluminum, silicon, and minor elements, in addition to the cracks, does indicate the material is more likely clay than stone.

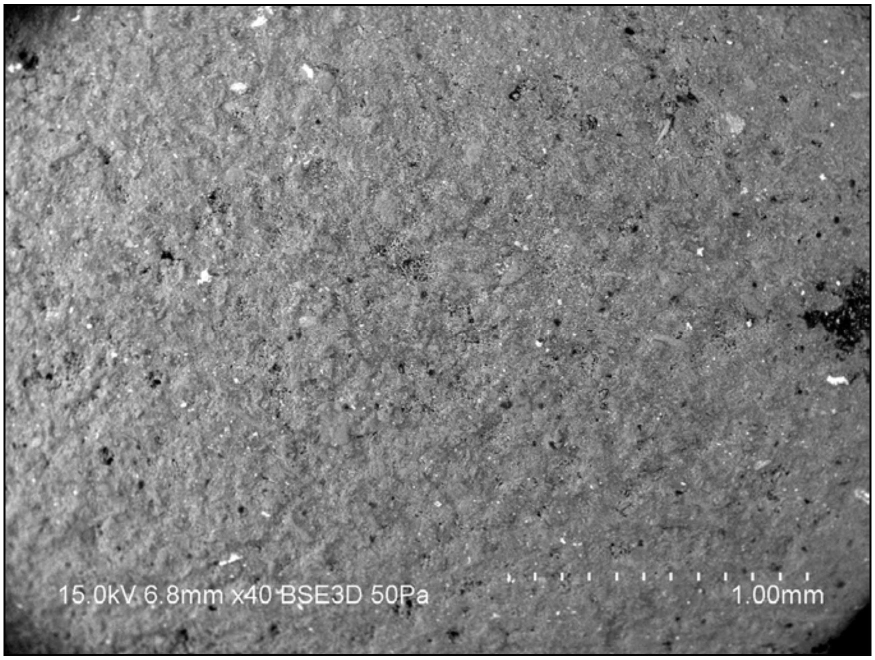

Figure A.2. Backscatter electron image of clay pipe (FN 12378/12380) recovered from Las Capas, AZ AA:12:111 (ASM) (magnification is 40x).

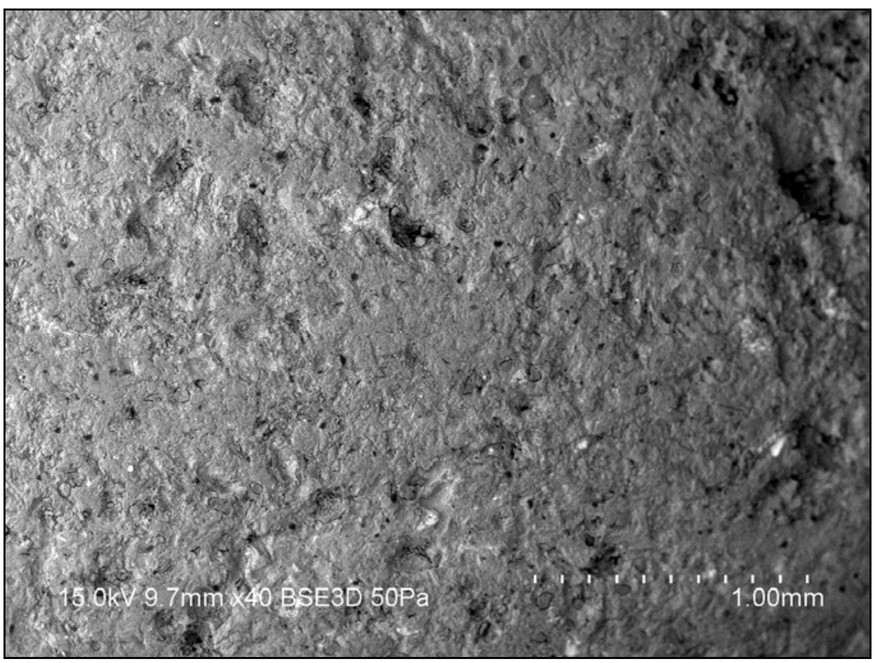

Figure A.3. Backscatter electron image of pipe of unknown material (FN 12790) recovered from Las Capas, AZ AA:12:111 (ASM) (magnification is 40x).

CONCLUSIONS

The utilization of SEM-EDS for gaining a better understanding of the material of a prehistoric pipe from the site of Las Capas proved beneficial. Both the high magnification images and the chemical analysis, although qualitative, provided important data for assessing if this object was made of stone or clay. The results support a conclusion that the material is clay, although additional analysis or further data may refute this assessment. However, there appears to be a fairly strong case for this being a clay pipe, as the method in which it was made was more similar to techniques utilized to produce clay pipes. Thus, it provides additional evidence for those physical attributes that are characteristic for clay pipes and will assist in distinguishing them in the future. It is clear that, although stone pipes were made and used, clay pipes were also utilized and could be made with materials that resembled the stone pipes. This probably speaks to certain cultural associations made with ancient stone and clay pipes, which may have played a role in past religious ceremonies.

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