TRIALS AND TRIBULATIONS OF ANCIENT STARCH RESEARCH: AN INVESTIGATION OF CONTAMINATION AND EARTH OVENS AT FORT HOOD, TEXAS

A Dissertation

by

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ABSTRACT

Historically, earth ovens have been used to provide direct evidence of ancient plant use through the recovery of charred macrobotanical remains and indirectly by means of experimental archaeology and the ethnographic record. Experiments suggest that direct evidence of ancient starch-rich plant use can be obtained through the recovery of starch granules deposited on fire-cracked-rock (FCR) during cooking episodes even in regions where macrobotanical remains are scarcely preserved. Starch contamination, however, can enter into the archaeological record providing “background noise.” Therefore, this study analyzes the results of the Paluxy Sand Geophyte Project to determine if archaeological starch (starch that is both cultural and ancient in origin) can be differentiated from contamination using FCR recovered from heating elements in well-preserved earth ovens at Fort Hood, Texas.

FCR, non-cultural rock control samples (RCS), and air control samples (ACS) were processed and analyzed from 27 earth ovens at 6 sites. Contamination control measures were used, including the use of a clean bench, powder-free latex gloves, washing samples prior to processing, spot sampling, and comparisons between starch granule assemblages recovered from FCR and control samples. Laboratory and field equipment were processed and analyzed for contamination. Only one feature (Feature 4 from 41CV984) yielded starch granules that are unambiguously archaeological in origin, rather than the result of contamination, whereas starch assemblages from the other sites could be archaeological or contamination in origin. Small sample sizes, differential

preservation, and/or the cooking of non-starch-rich plants could account for the lack of differences between FCR and RCS samples. Finally, maize (*Zea mays*) starch granules were recovered from all sample types suggesting that maize starch, most likely from "powder-free" gloves and air-fall is a significant source of starch contamination.

DEDICATION

To Anastasia Gilmer

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NOMENCLATURE

ACS	Air control sample
Deg	Degraded
FCR	Fire-cracked-rock
Gel	Gelatinized
RCS	Rock control sample
UnID	Unidentifiable
UnK	Unknown

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CHAPTER I

INTRODUCTION

In the fall of 2009, a collaborative research project between the Cultural Resource Management, United States Army, Fort Hood, Prewitt and Associates Inc., and Texas A&M University Archaeological-Ecology Laboratory titled the Paluxy Sand Geophyte Project began to determine the viability of applying starch granule research to earth ovens. The purpose of this project was to look at earth oven features to address three main research questions including; (1) can microfossils, particularly starch granules, phytoliths, and calcium oxalate crystals can be recovered from earth ovens, (2) if microfossils can be used as direct evidence of ancient plant use in regions around the world where macrobotanical plant remains are scarce, and (3) where are microfossils most likely to be located within an earth oven? The author of this dissertation served as the primary starch granule analysis for the Paluxy Sand Geophyte Project. Over the course of this study, it became apparent that contamination from modern starch granules was a significant problem that needed to be addressed. Therefore, this dissertation assesses the methods used during the Paluxy Sand Geophyte Project and analyzes the results asking one significant question; can archaeological starch (starch that is both cultural and ancient in origin) be differentiated from contamination?

Earth ovens (Figure 1.1-1.2) have largely been ignored by archaeologists. These features, however, have an enormous potential to inform about ancient subsistence practices, particularly with regard to ancient plant use and understanding land-use intensity over time (Thoms 1989; Thoms *et al*. 2011). Historically, archaeologists generally relied on charred plant materials to provide direct evidence of ancient plant use, most of which were obtained in earth oven features. In Central Texas, as well as many other regions of the world, charcoal is not abundantly preserved (Collins 2004:109). However, microfossils such as starch and calcium oxalate crystals may be more resilient to degradation and may be recovered from earth ovens in regions with both good and poor charcoal preservation (Thoms *et al*. 2011). Therefore, microfossil research may provide direct evidence in places where macrobotanical remains are scarce thereby increasing our understanding of land-use intensity through time (Thoms *et al*. 2011).

The utility of using microfossil research, such as pollen, starch granules, phytoliths, calcium oxalate crystals, and plant-fibers in archaeology has been well documented (Briuer 1976; Bryant 1974, 2007; Dering and Shafer 1976; Jones and Bryant 1992; Loy 1994a, Loy *et al*. 1992; Mercader 2009; Perry 2008; Piperno 2006; Shafer and Holloway 1979; Torrence and Barton 2006; Zarrillo *et al*. 2008). Starch granule analysis in particular is an increasingly utilized tool applied by archaeologists as it is believed to provide direct evidence of plant utilization. Experiments suggest that residues from starch-rich plants adhere to artifacts during cooking and food-processing activities and starch granules within these residues can later be recovered and analyzed to obtain direct evidence of ancient plant use (Fullagar 2006:195; Thoms *et al*. 2011; Messner 2011; Torrence 2006:17; Zarrillo *et al*. 2008). Given that starch granules can be recovered from residues adhering to artifacts, most starch-granule studies focus on the recovery of starch from processing tools rather than case studies exploring starch taphonomy (Barton and Matthews 2006; Chandler-Ezell *et al*. 2006; Haslam 2004; Perry *et al*. 2007). While studies confirm that starch granules from cooked or processed plants adhere to artifacts as a result of cooking and processing activities, there is evidence that modern starch can contaminate artifacts during or after excavation (Laurence *et al*. 2011; Loy and Barton 2006; Wadley and Lombard 2007). In this context, "modern starch contamination" refers to starch granules deposited on artifacts once artifacts are exposed to the atmosphere during and after excavation.

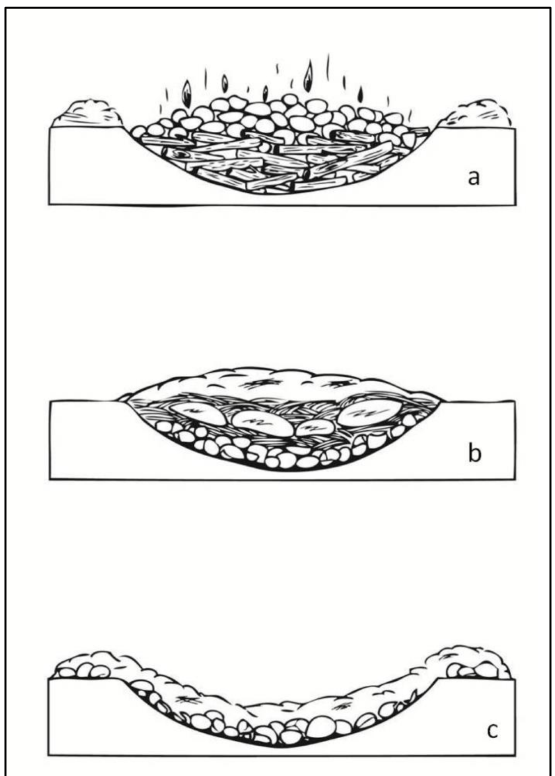


Figure 1.1. Sketches of generic earth oven cross-sections. (a) Firing stage using wood fuel to heat cooking stones, (b) baking stage with food packets between layers of green-vegetation packing material, and (c) abandonment stage after removal of food and decomposition of packing material (courtesy of Thoms 1989, Figure 21, p. 268).


a


b

Figure 1.2. Earth oven in (a) cross-section and (b) plan view from 41CV947, Feature 5 (images courtesy of Doug Boyd).

The issue of airborne starch contamination in archaeological studies has been mentioned by numerous researchers. Barton and Matthews (2006) noted the possibility that airborne starch deposited during excavations can affect interpretations of “fossil” starch granules from archaeological materials. To identify possible contamination of artifacts, Loy and Barton (2006) suggested leaving microscope slides out in the field to test for airborne starch deposited from industrial activity. Archaeologists have also tested for airborne starch contamination by leaving microscope slides exposed to the air in research laboratories and curation facilities (Loy and Barton 2006; Parr 2002; Zarrillo and Kooyman 2006). Nugent (2006) recovered unmodified and damaged airborne starch granules in a curation facility and a lab, which averaged 12.6 µm and 18.4 µm in size, respectively. Similarly, Williamson (2006) identified contamination within the lab from starch granules that originated from a nearby flour mill while Laurence *et al*. (2011)

recovered starch in air traps placed in laboratory and outdoor settings. While these studies demonstrate the possibility for modern airborne starch to contaminate artifacts, starch rain is not the only medium through which starch granules can contaminate artifacts.

The research presented here assesses methods used to test for and minimize sources of contamination at various stages of artifact recovery and processing both in the field and in the lab through an archaeological case study (Thoms *et al*. 2011). In conjunction with Prewitt and Associates Inc., 27 earth oven features from Fort Hood, TX have been excavated and analyzed for starch granules as part of the ongoing Paluxy Sand Geophyte Project using methods developed by the Archaeological-Ecology Laboratory at Texas A&M University, aimed at minimizing and controlling for contamination, including washing artifacts to remove contamination and the use of a clean bench in the lab.

To verify whether or not the methods employed by Thoms *et al*. (2013) as part of the Paluxy Sand project were successful in their ability to limit modern contamination (contamination that occurs during and after an artifact is exposed during excavation), the results of the fire-cracked-rock (FCR) processed with control measures in place are compared to artifacts processed prior to the use of control measures. Given the importance of earth oven research, specifically its ability to inform upon past subsistence strategies, the issue of starch granule contamination needs to addressed. Furthermore, the results of this study have important implications regarding the reliability of starch granule research in archaeology, regardless of the tool or feature class under investigation. If modern contamination can be reliably differentiated from archaeological starch (starch granules that are both cultural and ancient in origin) then archaeologists can more securely obtain direct evidence of past starch-rich plant use.

CHAPTER II

BACKGROUND

Research presented in this dissertation attempts to determine if starch granules recovered from ancient earth ovens can be confidently ascribed as archaeological in origin (both ancient and cultural in origin) rather than the result of contamination. Toward that end, the author relied on an archaeological case study. The following chapter discusses the background information pertaining to general starch granule research, earth ovens, and the study area as it is relevant to this study.

Starch Granules

In the most technical sense, starch is a polysaccharide (multiple chains of simple sugars) glucose polymer formed within the chloroplasts (specialized cytoplasmic body containing chlorophyll) of green plants or in the amyloplasts (specialized body containing one or more starch grains that also serves as the center for starch formation) of the storage organs in the form of tubers, seeds, or sporocarps (Field 2008). Therefore, starch is a complex carbohydrate comprised of multiple chains of simple sugars (as opposed to simple carbohydrates that are comprised of one or two chains of simple surgars) that serves as the long term source of energy for green plants (Gott *et al*. 2006).

Transient and storage starch granules are the two main types of starch found in starch-rich plant species (Gott *et al*. 2006). Starch-rich plants include domesticated species such as maize (*Zea mays*) and Irish potatoes (*Solanum tuberosum*) as well as wild geophytes, including false garlic bulbs (*Nothoscordum bivalve*) and winecup tubers

(*Callirhoe involucrata*), which are known ethnographically or archaeologically to have been used as food (Havard 1895; Moerman 1998:304-305; Thoms 2008a). Transient starch granules are generally described as small (~1 μm in size), although they may be as large as 7 μm. These generally non-diagnostic, temporary granules are formed within the chloroplasts of cells (Buléon *et al*. 1998; Haslam 2004). They form during the day when energy is produced from sunlight and later are broken down at night for use in other parts of the plant or transferred to storage organs for later use (Raven *et al*. 1999).

Storage starch granules are located in storage organs (roots, seeds, and fruits) of starch-rich plants and are usually described as being comparatively large, typically > 5 μm (Gott *et al*. 2006). Significant size and morphological variation has been reported for starch granules recovered from an individual plant, as well as among members of the same species (Delcour and Hoseney 2010:23-25; Hoseney 1994:40; Kent 1975; Laurence *et al*. 2011; McDonough *et al*. 2000; Reichert 1913; Rooney and Suhendro 2001; Serna-Saldivar 2010:109). For instance, Kent (1975) reports that starch granules recovered from maize seeds can be anywhere from 2 to 30 μm in diameter with spherical, angular, or polygonal morphologies. Starch granule variation within an individual seed has been argued to be the result of the starch granules location within a storage organ (Kent 1975). Finally, the number and size of starch granules located within storage organs varies based on environmental conditions. During times of environmental stress, plants develop fewer starch granules that are smaller in size (Gott *et al*. 2006:42; Messner 2011:48). With regard to the archaeological record, transient starch granules are rarely studied since they are considered to be non-diagnostic (Haslam

2004). Storage starch granules, however, are used as direct evidence for plant utilization because they are more readily identified to the family, genus, or species level (Gott *et al*. 2006; Haslam 2004).

Present State of Starch Research in Archaeology

Starch research in archaeology has been predominantly concerned with recovering starch from processing tools such as manos and metates (Chandler-Ezell *et al*. 2006; Haslam 2004; Perry *et al*. 2007). To date, only a few studies have focused on starch taphonomy, including the point at which starch gelatinizes (e.g. Henry *et al*. 2009; Reichert 1913), morphological characteristics of starch granules following various processing and cooking techniques (e.g. Babot 2003; Henry *et al*. 2009), decomposition rates in sediments (e.g. Haslam 2004), and airborne starch as a contamination source (e.g. Laurence *et al*. 2011). Barton and Matthews (2006:75) sum up the state of starch taphonomic studies by stating; "To date archaeologists have not been concerned with the taphonomy of starch in terms of its very long term preservation or how it might be moved around the landscape. In contrast, the specialist starch literature contains useful descriptions and discussions about the mechanisms that explain how starch granules degrade and transform." In this context, as with this dissertation, starch taphonomy is defined as the processes affecting starch granule survival once it enters the archaeological record (Barton and Matthews 2006:75). With the exception of Laurence *et al*. (2011), studies addressing sources of non-cultural contamination (i.e.

contamination from non-human related processes and activities) and methods for controlling or minimizing contamination are virtually non-existent.

Without a firm understanding of starch taphonomy, inaccurate conclusions may be drawn from recovered starch assemblages. Too often, starch granule analysts describe the condition of ancient starch recovered from plant processing tools as being excellent without citing or performing taphonomic studies that support the findings. For instance, when describing the starch assemblage recovered from tools in a dry rockshelter in southeast Africa, Mercader (2009:1681) states "About 64% of the total assemblage is well preserved and displays features comparable to those seen in fresh modern specimens." The remaining 46% of the starch granules are described as showing signs of modification (Mercader 2009). According to Babot (2003), starch granules exhibit signs of physical modification (i.e. damage) when plants are processed using physical instruments such as groundstone tools. If this is true, then the majority of starch granules that did not show signs of modification may be the result of contamination rather than use. Other researchers (e.g. Perry 2004; 2005) discuss how tool form does not equate to tool function given that starch granules from the same plants (usually those from domesticated species) are found on all tool classes tested from a site. Upon analyzing all of the artifacts from the Pozo Azul Norte-1 site in the Orinoco Valley, Perry (2005:423) described the recovery of maize starch as "the most intriguing and unexpected data from this study, particularly because maize starch occurred on every artifact that was examined," which included two core control samples. Although Perry (2004; 2005) does not comment on the condition of the starch granules, the fact that the same starch types were recovered on all tool classes may be indicative of airborne contamination, a taphonomic process that has largely been ignored by ancient starch research (Laurence *et al*. 2011). Even if the starch is ancient in origin, grinding maize in the past with groundstone tools would put thousands of maize starch granules into the atmosphere that would coat nearby objects with maize starch. Since Perry (2004; 2005) did not look at non-cultural rocks as control samples and/or air samples to gauge the amount of contamination at her sites, it is unknown whether the recovery of maize starch from all of the different tool classes discussed by Perry (2004; 2005) may be the result of contamination rather than tool use.

Plant Processing Technology

Plant processing refers to any activity that physically modifies plant materials, as opposed to chemical alterations. In terms of plant processing activities, groundstone and battered-end tools form the backbone of the major tool classes and contain several types of tools under their broad heading. In its most simple sense, groundstone tools are abraded lithic tools, usually in the form of grinding slabs and their associated hand-held component (i.e. manos and metates or mortars and pestles), which are used to modify plant materials through the action of grinding (Ebeling and Rowan 2004). In the mano and metate system, manos are rounded handheld stones used to grind foodstuffs, whereas metates are large relatively flat or basin-shaped coarse grained stones that serve as the grinding platform (Schlanger 1991). This contrasts with mortars and pestles where the pestles may be a rounded rock or heavy stick used to grind or pound plant material and the mortar is a bowl-shaped grinding surface. In terms of the types of plants processed, it has been purposed that grinding slabs (i.e. manos and metates) were used to process dried seeds while mortars and pestles were used to process oily seeds and "wet" plant material since the bowl contains the less viscous material (Adams 1999). Battered-end tools, however, are lithic tools that were used to pound a variety of materials (Ebeling and Rowan 2004). Although these tool classes may not be mutually exclusive, their physical characteristics allow a differentiation between them. Finally, if starch-rich plants were processed using groundstone tools, then it is possible to recover starch granules from those plants thereby providing direct evidence of their use (Fullagar 2005:185).

While plant processing has its own technological components, so too does cooking. There is a wide range of diversity in cooking features associated with the preparation of plant materials in North America (Wandsnider 1997). Cooking features can be ascribed into two broad categories including open-air fire hearths and hot-rock cooking. Hot-rock cooking refers to the use of heated rocks to cook foods (Thoms 2003). Once heated, rocks often break or fracture resulting in fire-cracked-rock (FCR) that can be recovered from archaeological contexts. With regard to the utilization of plant foods, earth ovens/steaming pits and stone boiling fall under the category of hot-rock cooking (Figure 2.1). Earth ovens/steaming pits are large pits "lined" with heated rocks overlaid by food that is layered between packing materials, and covered with sediment or earth, where water was sometimes added to create a steaming pit. Stone boiling facilities, however, refers to any container or lined pit that is filled with water which is brought to a boil by the addition of rocks heated by an outside source (Thoms 2008a). Hearths, however, are open air fires (not covered by sediments or earth), either on the ground's surface or in a basin, that do not use hot rocks as the heating element (Thoms 2008a).

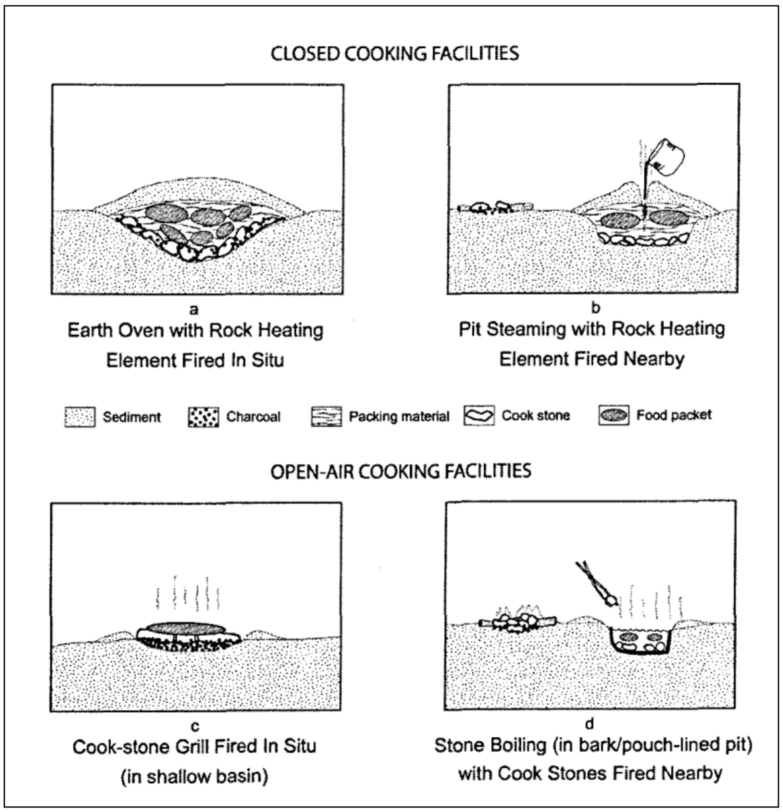


Figure 2.1. Hot rock cooking feature. Note: The cook-stone grill is not mentioned in text since it is not associated with the cooking of plant foods (Thoms 2008b).

Earth Ovens

The importance of understanding the function of earth ovens resides in the fact that anatomically modern humans need to cook food in order to increase nutritional value (Petraglia 2002; Wrangham 2009). Despite the antiquity of cooking, controversially 1.8 million years ago with *Homo erectus* as evidenced by body form (Wrangham 2009:102), the earliest evidence of hot-rock technology in the Old World dates to around 30,000 years ago (Dogome 2000; Thoms 2009). Tephra-dated sediments in the Bismarck Archipelago off the northeast coast of New Guinea, however, date FCR features to 35,000-45,000 years old, suggesting that the earth ovens are older than the earliest known earth ovens in Europe, Asia, or Africa (Torrence *et al*. 2004). The advantage of using rock heating elements lies in its ability to conserve fuel while allowing prolonged baking and boiling that renders some foods, including geophytes with complex carbohydrates (such as starch and inulin) and animal fat more readily digestible (Brace 1967, 1980, 2005; Brace *et al*. 2008; Gott *et al*. 2006; Samuel 2006; Thoms 1989, 2009; Wandsnider, 1997).

For this reason, fire-cracked-rock features are often associated with plant foods (particularly geophytes) due to their ability to render otherwise inedible plants edible (Thoms 2009; Wandsnider 1997). Earth ovens are also used to cook animal tissues (Wandsnider 1997). However, since the focus of this study is starch-rich plants, the role earth ovens play in cooking animal tissues will not be discussed (see Wandsnider 1997 for discussion of earth oven use and animal tissues). Many plants contain lipids and complex carbohydrates, in the form of inulin and/or starch, that cannot be processed by the human body in their natural state and therefore require chemical modifications before humans can extract nutrients from the plant tissues (Wandsnider 1997). This is done process called hydrolysis, which Wandsnider (1997:4) describes as a "process by which complex molecules are cleaved into smaller molecules through the uptake of a water molecule." This process, however, can take several hours or days, therefore requiring long term cooking facilities (i.e. earth ovens) to render foods digestible for humans. Furthermore, many plants contain toxins as a defense mechanism against insects and other predators. Prolonged cooking also helps to remove harmful toxins and change the pH levels of plant tissues by denaturing proteins responsible for the generation of harmful toxins (Ames 1983; Jackson 1991; Leopold and Ardrey 1972; Wandsnider 1997). Earth ovens are particularly adept at rendering otherwise inedible foods edible since they allow humans to cook foods at the required temperatures, moisture regimes, and time period (Wandsnider 1997).

Thoms (2003) provides a good overview of the antiquity of cook-stone technology in North America. The oldest evidence for the use of hot-rock technology in North America date to 11,000-10,000 radiocarbon years B.P. at the Moose Creek site in central Alaska (Pearson, 1999), the Wilson-Leonard site in central Texas (Guy 1998), and Dust Cave in northwest Alabama (Homsey 2009). By 9000-8000 B.P. earth ovens are a common feature throughout North America. Across western North America, geophyte exploitation and earth-oven use intensified between 4,000 and 2,000 years ago as suggested by the increased frequency of earth ovens and the recovery of charred lily-family bulbs (Thoms 2003, 2009). The initial onset and increased use of earth ovens through time suggests that plant foods were intensified by Native Americans beginning in the early Holocene (cf. Binford 2001), a process in which Thoms (2008b) has termed the pre-agricultural carbohydrate revolution.

Use of Earth Ovens as Indicators of Ancient Plant Use

In one fashion, FCR from earth ovens is ideal for obtaining direct evidence of ancient plant use. Herein, when the term "FCR" is used, it is referring only to FCR recovered from earth ovens. When rocks are used as the heating element for cooking features, they are heated in excess of 500^{o}C. Starch granules will combust at temperatures greater than 380^{o}C (Gose 2000). Therefore, heating rocks for an earth oven should remove any previous contamination, as well as the airborne starch contamination falling on the FCR during the construction of the oven. As a result, starch granules recovered from the FCR must have been deposited on the artifacts during or after the cooking episode when the rocks have cooled to temperatures below 380^{o}C.

Earth Ovens and Intensification

Earth ovens are a marker of land use intensification (Thoms 2003). Thoms (2003:87) defines land use as "the patterned exploitation of resources by human groups, the manner in which they used places on the landscape, the technologies they employed in the process, and the effect of exploitation on the ecosystem." Earth ovens (and hot rock cooking in general) are very labor and cost intensive subsistence strategies (Thoms 2003). Binford (2001: 373-399) outlines a model where resources are ranked based on their availability and caloric return. According to Binford, large game is the most highly ranked resource. As populations continue to increase over time and groups of people are forced to subsist on increasingly smaller tracts of land, large game hunting may not be able to support the larger populations. Consequently, hunters and gatherers will begin to exploit lower ranked resources that have a higher procurement cost to return caloric value, beginning with aquatic resources. If aquatic resources are not available or available in sufficient quantities to support increasing populations, then hunters and gatherers will more intensively utilize plant foods, including geophytes (Binford 2001). Since earth ovens represent increased energy expenditure in terms of construction and the amount of time and energy required to cook inulin- and starch-rich foods, the presence of earth ovens in the archaeological record demonstrates the need to extract more energy from the landscape (Thoms 2008a). Therefore, earth ovens represent an intensification strategy of increasing the caloric return of small tracts of land, regardless of the types of foods cooked in the ovens (Thoms 2008b).

Earth Ovens as Risk-Minimizing Strategy

Earth ovens also serve as a risk-minimizing strategy, as defined by Winterhalder *et al*. (1999). In regions where the dominant edible plants are in the form of complex carbohydrates (i.e. starch and inulin) people used earth ovens to extract more nutrients from the environment. Since earth ovens allow humans to extract more resources out of an area, they can also be seen as a risk-minimizing strategy with regard to increasing population pressures and resource intensification (Black and Creel 1997:302-303; Thoms 2008a). As human populations increase, groups of people are confined to smaller tracts of land and must therefore extract as many nutrients as possible from the landscape to allow them to survive in a given region by utilizing previously under-used or unused resources (Ames 2005; Thoms 2008a). In this capacity, increased earth oven use becomes a risk-minimizing strategy which provides a buffer against economic short-fall since more energy can be obtained from otherwise inedible plant resources (Thoms 2008a).

Earth ovens also play a significant role in risk-minimizing strategies with regard to fuel sparing capabilities (Black and Creel 1997:302; Thoms 1989). Rocks capture and retain heat from fast burning fires, and can reradiate that heat over longer periods of times than coals. This characteristic is especially useful in areas where there is not an abundance of woody plant material that suitable for generating long-burning hot fires (Thoms 1989, 2003). Since rocks absorb, retain, and reradiate heat for longer periods of time than coals, earth ovens allow humans to cook plant foods for extended periods of time without consuming too much of the available woody plant resources (Kibler and Mehalchick 2010). Kibler and Mehalchick (2010:115) describe the collection of firewood through a mechanism which they describe as the "Firewood Indifference Hypothesis." Their hypothesis states that humans collected the nearest available deadwood for use as fuel due to their low procurement costs, where the majority of firewood would have come from trees that naturally pruned, such as oak and pecan (Kibler and Mehalchick 2010). As a result, earth ovens are more likely to be constructed near permanent water sources where large stands of trees allow enough deadwood to accumulate so as to provide sufficient fuel for earth ovens (Kibler and Mehalchick 2010).

Earth Ovens and Starch Granule Research

Starch granule research may be able to provide direct evidence of ancient earth oven use (Thoms *et al*. 2011). Experiments conducted by Thoms *et al*. (2011) suggest that when hundreds of pounds of starch-rich USO's (underground storage organs such as bulbs, taproots, tubers, and corms) are cooked in earth ovens for at least 20 hours, thousands of starch granules are released into the oven as water containing starch granules is driven out of the USO's during the cooking process. Furthermore, starch-rich plants used as packing material during the construction of earth ovens may also exude starch granules during the cooking process. Once liberated, starch granules within earth ovens may settle on the cook-stones used as the heating element and can be subsequently recovered and identified (Thoms *et al*. 2011). Therefore, the experiments by Thoms *et al*. (2011) demonstrate that starch granules can be recovered from cook-stones, thereby providing direct evidence for starch-rich plant use. Since starch granules can be recovered from FCR, it should be possible to recover starch from ancient earth ovens (Thoms *et al*. 2011).

Occupational History of Greater Central Texas with Regard to Earth Ovens

The following section provides an overview of the importance of plant use in ancient diets with a focus on earth oven use through time in greater Central Texas (Figure 2.2). Hundreds of earth oven features have been excavated from numerous sites throughout greater Central Texas, although only a few features yielded preserved charred macrobotanical remains. Therefore, only a handful of sites where charred macrobotanical remains were identified and dated thereby providing direct evidence of the types of plant materials used as food, fuel, or packing material are discussed in the following section.

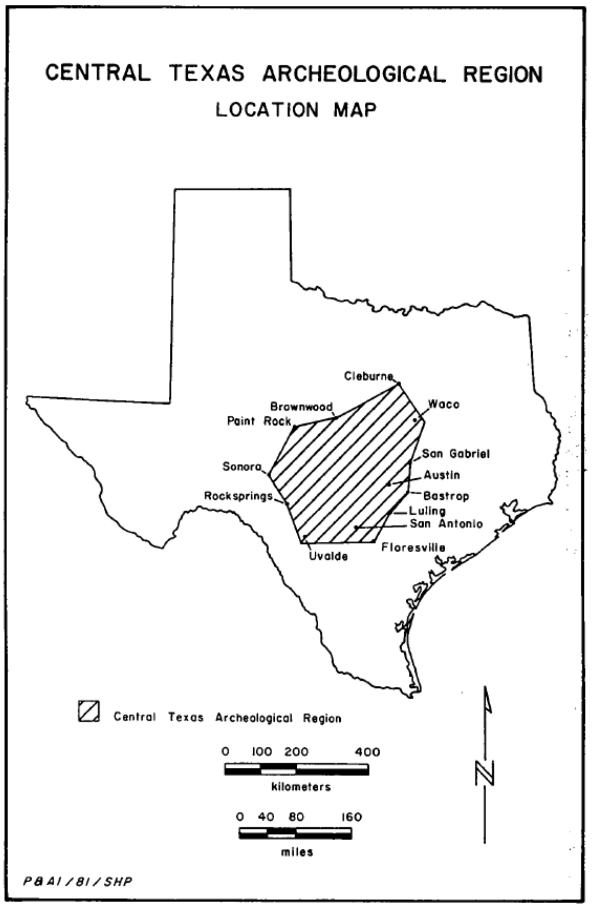


Figure 2.2. Location of Central Texas (Prewitt 1981:72, Figure 2).

Paleoindian Period Historically, the Paleoindian period (11,200-10,900 BP) had been portrayed as a time of exclusive big game hunting, based on the association of Clovis and Folsom points with mammoth and bison remains (Black 2001; Collins 2004; Haynes 1992; Trierwiler *et al*. 1995). Recent evidence from the Debra L. Friedkin site (formerly Buttermilk Creek) suggests that humans were in Texas by at least 13.2-15.5 kya (Waters *et al*. 2011). Although the current knowledge of the Buttermilk Creek complex is still in its infancy, the available assemblage from the Friedkin site suggests a high residential mobility culture (Waters *et al*. 2011). The variety of tool classes recovered from the site, specifically the lanceolate preform, graver, adze or chopper, and blades suggest a variety of tasks were carried out at the site, including plant processing. Use-wear analysis in particular supports the claim that plant processing activities were carried out at this site (Waters *et al*. 2011). Based on this evidence, the author of this study suggests that the Buttermilk Creek Complex may be a reflection of generalized hunter-gatherers, although more data needs to be collected before any definite conclusions can be made.

The Gault site, Pavo Real, and Kincaid Rockshelter provide evidence for a generalized Clovis subsistence strategy. The wide diversity in the types of tools recovered from Gault and Pavo Real, along with a variety of different fauna taxon recovered from Gault indicates that the Clovis people may not have focused on big game hunting, but rather exploited resources of opportunity (Black 2001, 2003). The sheer number of artifacts recovered from Gault indicates that Clovis people were repeatedly returning to the site over time, most likely on a seasonal basis, suggesting that Clovis people made regular rounds in their resource procurement strategies exploiting a well-known environment (Black 2001). Evidence from Kincaid Rockshelter also provides evidence that the Clovis people were routinely exploiting a familiar landscape in such a way that the inhabitants constructed an artificial living surface within the rockshelter to make an extended stay (camping in one place for more than one or two nights) more comfortable (Collins 1990; Collins 2004; Dial 2005). The Folsom culture beginning around 10,200 BP, however, is still argued to have a subsistence strategy focused on big game hunting (Black 2003; Collins 2004; Trierwiler *et al*. 1995:31). The author of this study argues that this may not be the case. The grinding-chopping tool interned with a burial at the Wilson-Leonard site suggests that plant processing was more important than it has historically been argued. Finally, no FCR features have been definitively identified at sites attributed to the Buttermilk Creek Complex, Clovis, or Folsom cultural components (Collins 2004; Waters *et al*. 2011). Finally, hearth features with FCR dating to 9990-9410 recovered from the Wilson-Leonard site, suggest that plant foods may have been an important part in Paleoindian diets, a dietary component that will become increasingly important through time (Bousman *et al*. 2002).

Archaic Period The Archaic period (8800-1350 BP) is characterized by resource intensification, particularly with the extensive use of FCR (Collins 2004). Although the transition between the Paleoindian and Archaic periods is often unclear due to temporal overlaps between projectile points a lack of clearly definable late Paleoindian and Early Archaic sites, there is a significant change in subsistence strategies that takes place during the Archaic period (Collins 2004; Trierwiler *et al*. 1995:31-32). Numerous earth ovens and burned rock middens have been found throughout Central Texas (Figure 2.2) (Black and Creel 1997:301; Hunziker 2004). The earliest known earth ovens in Central Texas date to 8250 +/- 80 and 7997 +/- 21 BP at the Wilson-Leonard site (Boyd, Ringstaff, and Mehalchick 2004:185; Collins and Weir 2011). Charred camas bulbs (*Camassia scillides*) were recovered from both earth ovens (Boyd, Ringstaff, and Mehalchick 2004:185). Following the ~8000 BP ovens at the Wilson-Leonard site, the Gatlin site along the south-eastern edge of the Edwards Plateau provides evidence for Early and Middle Archaic earth oven use (Houk *et al*. 2009). A total of 37 burned rock features with radiocarbon ages ranging from 7570-1300 BP (identified as hearths or earth ovens) were recovered. Unfortunately, Houk *et al*. (2009) do not go into detail into feature descriptions, or how they differentiated between hearths, burned rock middens, or earth ovens. Finally, excavations at the Armstrong Site in Caldwell County uncovered a burned rock cluster that yielded two charred camas bulbs with a radiocarbon age of 6780 +/- 60 BP (Dering 2002).

Earth oven use continued through the Middle Archaic (Black and Creel 1997:302). Pavo Real provides evidence for Middle and Late Archaic earth oven use in Central Texas (Black 2003). Three burned rock middens were excavated along with 15 hearths, three of which are associated with burned rock clusters and may represent earth ovens rather than hearths. Although few macrobotanical remains were recovered, a few samples of charred wood believed to have been used as fuel for the earth ovens were recovered and radiocarbon dated (seven radiocarbon dates in all), of which six radiocarbon dates date to the Middle and Late Archaic and one dates to the Early Archaic (Black 2003).

The use of earth ovens continued through the Late Archaic period. Nineteen burned rock middens excavated at Camp Bowie, each of which measure 10-15 meters in diameter, demonstrate that earth oven use continued through the Late Archaic period (Hunziker 2004). All of the burned rock midden features had clearly defined central pits that contained high concentrations of carbonized plant material. Of the total of 31 radiocarbon ages obtained from the burned rock middens, three of the dates fall within the Late Archaic time period (600-1200 BCE). Excavations of burned rock middens have yielded carbonized remains of 400 bulbs and pieces of bulbs. Of the 400 charred bulb remains, only eastern camas (*Camassia scilloides*), wild onion (*Allium* spp.), and dog's-tooth violet (*Erythronium grandiflorum*) were positively identified where eastern camas represented the majority of the charred bulbs (Hunziker 2004). The dominance of eastern camas at this site may suggest that inulin-rich plants were more frequently cooked in earth ovens than starch-rich foods. Other carbonized plant material was recovered, including wood from oak, mesquite, juniper, and willow, where oak was the dominant wood type recovered. A single carbonized mesquite seed was also recovered (Hunziker 2004).

Investigations at Fort Hood provide evidence for Precolumbian subsistence and settlement strategies at the tail end of the Late Archaic, leading into the Late Prehistoric Period. Given that a large number of sites have been excavated at Fort Hood, only 41CV988 is included in this section since it provides abundant evidence for subsistence strategies. Initial testing at 41CV988 uncovered two basin shaped "hearths" containing FCR with associated lithic tools [quotation added by author, since the hearths may actually be earth ovens] (Mehalchick and Ringstaff 2004). One "hearth," (quotations added by present author) dating to 1280 +/- 40 BP, was approximately 1.75 meters in diameter and contained charred remains of oak wood and unidentifiable corm fragments. The second hearth had a radiocarbon date of 1230 +/- 40 BP, and contained charred oak, holly, and unidentifiable wood (Mehalchick and Ringstaff 2004). Finally, a burned rock feature (identified as a hearth) yielded charred oak wood (Mehalchick and Ringstaff 2004).

In sum, earth ovens are the most notable feature class of the Archaic Period in Central Texas (Black 2005; Collins and Weir 2011). Over 150 earth ovens or burned-rock-middens have been recorded in Central Texas while dozes have been dated (Black and Creel 1997:269). Based on radiocarbon ages, earth oven use continued to increase through time (Figure 2.3), suggesting that humans were utilizing a wider range of resources, particularly geophytes and hemicryptophytes (perennial plants that partially cover their overwintering buds at ground level such as *Yucca* sp. and *Sotol* sp.), as suggested by the increased occurrence of charred macroboantical remains associated with earth ovens (Black and Creel 1997:298-299; Black 2005; Collins 2004). The marked increase in earth ovens throughout the Archaic suggests that humans were intensifying geophyte resources in response to decreasing territory sizes due to increasing populations (Thoms 2003, 2008a, 2008b).

Although plant use increased throughout this period, hunting still remained an important aspect of Central Texas subsistence strategies, and was most likely the primary means in which Archaic hunter-gatherers made a living, as evidenced by the variety of dart points and the presence of faunal remains, particularly ungulates (Trierwiler *et al*. 1995:31). The preference of game resources over wild plant foods is predicted by Binford's (2001:373-399) model based on the fact that game animals provide a greater ratio of energy gained vs. energy expended in resource acquisition. Regardless of the role hunting played in ancient diets, subsistence and settlement patterns during the Archaic Period reflect one of generalized hunter-gatherer groups exploiting territories that were continually decreasing in size through time, as opposed to the heavier reliance on hunting during the Paleoindian Period (Black 2005; Collins 2004).

Late Prehistoric Period The Late Prehistoric Period is marked by the use of the bow and arrow with the onset of the early Late Prehistoric period (Austin phase) beginning around1350 BP (Prewitt 1981; Trierwiler *et al*. 1995:33-34). Despite the new hunting technology, subsistence strategies during the Austin phase did not change significantly from the Archaic period, and people continued to live as generalized hunters and gatherers (Prewit 1981). Following the Austin phase, the Toyah phase (650 BP), or late Late-Prehistoric, marks a change in subsistence strategies from generalized hunting and gathering to a reliance on bison hunting, coupled with the use of pottery (Quigg and Peck 1995; Trierwiler *et al*. 1995:34).

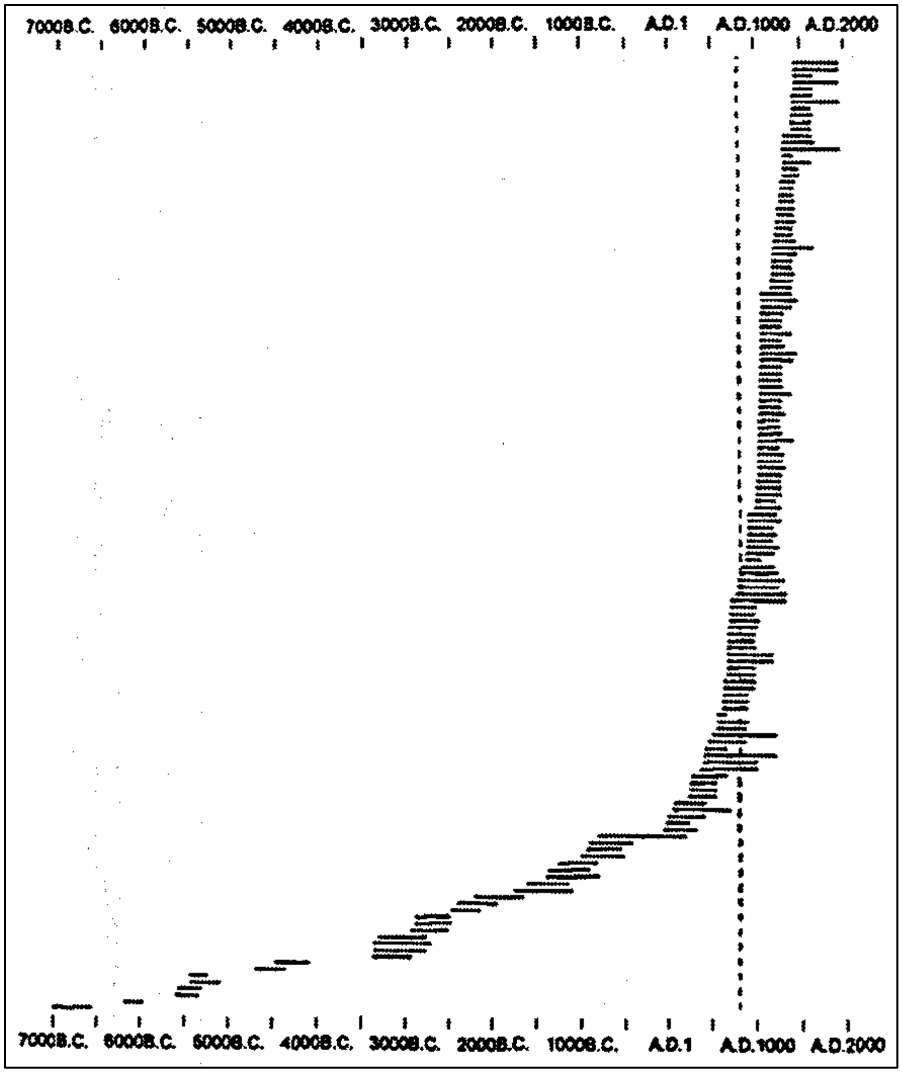


Figure 2.3. Radiocarbon ages obtained from 35 burned-rock-midden sites from Central Texas. Figure from Black and Creel (1997:274 Figure 133).

Despite the adoption of the bow and arrow and the increased hunting abilities afforded by this technology, the use of earth ovens reach its high throughout the Late Prehistoric period in greater Central Texas (Black and Creel 1997:304; Collins 2004). Investigations at the Firebreak site (41CV595) at Fort Hood provide evidence of earth oven use during the Late Prehistoric period in Central Texas (Mehalchick *et al*. 2004).

Although radiocarbon ages place occupations at this site both in the Late Archaic and Late Prehistoric periods (radiocarbon ages span from 3200 BP to 714 AD), the majority of radiocarbon samples date to the Late Prehistoric. While three of the four earth ovens excavated at this site only yielded charred remains of oak, elm, ash and maple wood, Feature 12 yielded 42 charred bulb fragments that have been identified as eastern camas or wild onion (Boyd, Ringstaff, and Mehalchick 2004:175-176; Dering 2004). Along with the bulb fragments, 132 fragments of charred wood were recovered from this feature, identified as oak, pecan, dogwood, soapberry, mulberry, elm, and rose family, where oak was the most common type (Dering 2004:248-256). Charred acorn shells were also recovered (Boyd, Ringstaff, and Mehalchick 2004:176).

Ethnographic Accounts of Plants Cooked in Earth Ovens across Texas

The ethnographic record provides insight into Native American plant utilization in earth ovens across Texas. Unfortunately, the ethnographic record regarding earth oven use with regard to plant material in Central Texas is limited, as is the ethnographic record of Texas in general. Therefore, this section will look at the ethnographic record of plants cooked in earth ovens across Texas rather than just the study area. A summary of the known plant foods cooked in earth ovens can be found in Table 2.1.

Along the Coastal Plains (Figure 2.4), several different plant resources baked in earth ovens were utilized by Native Americans. According to accounts by the naturalist John Lewis Berlandier, the native people along the Coastal Plains and Marshes collected wild plants in the swamps, particularly those belonging to the Nympheacea family, which were used as a supplement to hunting, fishing, and corn (Berlandier 1969:45).

More specifically, the Karankawas, who subsisted mainly on aquatic resources, would also eat the bulbs of American lotus (*Nelumbo* sp.), cattails (*Typha latifolia*), and possibly other marine plants (La Vare 2004:59; Newcomb 1961:41; Ricklis 1996:107).

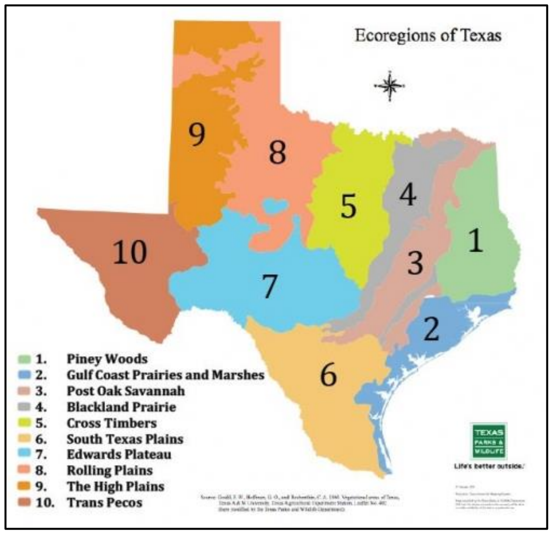


Figure 2.4. Ecological zones of Texas. Image from Texas Parks and Wildlife.

In the South Texas Plains, a group of people known collectively as the Coahuiltecans were reported to have roasted agave, lechuguilla (*Agave lecheguilla*), and sotol (*Dasylirion texanum*) (La Vere 2004:66; Newcomb 1961:41). Ethnographic accounts report that these foods "were roasted in pits, ground into flour, and eaten or stored for future use" (Campbell 1983; Newcomb 1961:41). Cabeza de Vaca, who provides the best evidence for cooking geophytes, also describes Indians on the Southern Plains cooking prickly pear pads and roots in earth ovens (Krieger 2002:194-195; Thoms 2007).

In the east, Native Americans living in the Piney-Woods of east Texas also ate a variety of plant foods that were cooked in earth ovens. Native Americans along the Louisiana boarder were reported eating wild potatoes growing in the lowlands, although no specific plant identifications were made (Adair 1775; Atkinson 1953:77). Beyond the general statement made by Adair, the only plant to be named specifically as being utilized by inhabitants of the Piney-Woods was water chinquapin (American lotus; *Nelumbo* sp.) (Sjoberg 1951).

Further to the west, in the Edwards Plateau, the native inhabitants of this region utilized a variety of plant resources in earth ovens. The Tonkawa ate several different kinds of roots, including the genus *Nymphaea* (Berlandier 1980:313; Campbell 2001). The Lipan Apache, however, are known to have baked a variety of desert succulents in earth ovens, including sotol, agave stalks, hearts, and leaves, and yucca, while the Yorica and Lipan Apache were reported to have baked agave hearts (Campbell 2010; Denis and Denis 1925:98; Newcomb 1961:115). To the north in the Cross Timbers region, the Comanche cooked *yampa* roots (*Perideridia gairdneri*) in earth ovens (Bolton 1914:88). Although roots are often reported to have been consumed by the inhabitants of the Post Oak Savannah, very few identifications have been made. According to the Spanish priest Father Solis, wild sweet potatoes (*Ipomoea pandurata*?) were utilized by the inhabitants of this region (Forrestal 1931:26).

In the westernmost region in Texas, the Trans Pecos region, several groups of people ate a variety of desert succulent plants. Among these groups, the Gueiquesale, baked sotol and lechuguilla in earth ovens (Kenmotsu 2005). Similarly, the Jumanos baked agave hearts in earth ovens while the Lipan Apache baked sotol, agave, cattail, and yucca (Bourke 1895; Denis and Denis 1925; Newcomb 1961:239; Vestal 1952). Along with agave, sotol, and cattail, Opler (1983a) also describes the Mescalero Apache as roasting prickly pear tunas, wild potatoes, and wild onion. Similarly, the Lipan Apache are described as baking agave, sotol (which was considered a staple food), yucca stalks, cattail, wild potatoes, devil's claw (*Harpagophytum*), and wild onions (Opler 1983b) There are also accounts of the Cahuilla baking Texas beargrass (*Nolina texana*) in earth ovens (Bean and Saubel 1972). Although no specific groups are identified, Bourke (1895) describes wild onions as being an important plant in the Southwest.

Finally, in the Northern Plains (High and Rolling Plains), the Kiowa, Kiowa Apache, Osage, and Comanche are described to eat various roots and tubers (Newcomb 1961:115,163). To supplement the meat obtained through hunting, the Osage collected and cooked prairie turnips (*Psoralea esculenta*) and water chinquapin, which were usually eaten during the winter (Bailey 2001). The Comanche were observed to bake camas (*Camassia scilloides*) bulbs in earth ovens (Sternberg 1931:223). Furthermore, the Kiowa and Kiowa Apache (Plains Apache) baked a variety of tubers including wild onion and prairie turnip, whereas the Lipan Apache baked agave, sotol (which was a staple), yucca, cattail, wild potatoes, and wild onions in earth ovens (Foster and McCollough 2001; Newcomb 1961:115; Opler 2001). Finally, based on the available ethnographic evidence, the most common types of plants cooked in earth ovens are inulin-rich plants such as wild onions and camas rather than starch-rich plants such as false garlic.

Table 2.1. Summary of ethnographic accounts of plant foods cooked in earth ovens across Texas listed in text. This table does not include ethnographic accounts where animals were cooked in earth ovens.

Culture	Geographic Area	Plant Resources
Karankawa	Coastal Plains	Nympheace American lotus (*Nelumbo* sp.) Cattails (*Typha latifolia*)
Mariames	Coastal Plains	Agave Family
Yguazes	Coastal Plains	*Agave americana*
Anagad	Coastal Plains	*Agave americana*
Coahuiltecans	Southern Plains	Agave Lechuguilla (*Agave lecheguilla*) Sotol (*Dasylirion texanum*)
Unspecified	Piney-Woods	Wild potatos Water chinquapin (American lotus)
Tonkawa	Edwards Plateau	*Nymphaea*
Lipan Apache	Edwards Plateau	Sotol Yucca
Yorica	Edwards Plateau	Agave
Comanche	Cross Timbers	*Yampa* (*Perideridia gairdneri*)
Unspecified	Post Oak Savana	wild sweet potatoes (*Ipomoea pandurata*?)
Gueiquesale	Trans Pecos	Sotol Lechuguilla
Jumanos	Trans Pecos	Agave
Lipan Apache	Trans Pecos	Sotol Agave Cattail Yucca
Mescalero Apache	Trans Pecos	Prickly pear Wild potatoes Wild onion
Cahuilla	Trans Pecos	Texas beargrass (*Nolina texana*)
Osage	Northern Plains	Prairie turnips (*Psoralea esculenta*) Water chinquapin
Comanche	Northern Plains	Camas
Kiowa	Northern Plains	Wild Onion Prarie turnip
Kiowa Apache	Northern Plains	Wild Onion Prarie turnip
Lipan Apache	Northern Plains	Agave Sotol Yucca Cattail Wild potatoes Wild onions

Summary

This chapter discussed plant processing technologies including earth ovens, and the role earth ovens played in cooking starch-rich plants in the past. Earth ovens are a common feature found throughout the world. Furthermore, numerous earth ovens have been recovered in greater Central Texas, including Fort Hood, suggesting that plant foods were an important part of past diets (Collins 2004). Ethnographic accounts across Texas, while sparse, attest to the importance earth ovens played in hunter-gatherer diets.

Wandsnider (1997) demonstrates that long-term cooking in earth ovens render foods more nutritious by chemically altering plant and animal tissues as well as complex carbohydrates such as starch and inulin. Experiments conducted by Thoms *et al*. (2011) suggest that identifiable storage starch granules from starch-rich plants cooked in earth ovens can be deposited on FCR that was originally used as the heating element in earth ovens. These experiments suggest that identifiable starch granules can be recovered from ancient earth ovens, thereby providing direct evidence of ancient plant use (Thoms *et al*. 2011).

CHAPTER III

STARCH TAPHONOMY

To date, few published studies have investigated starch taphonomy relevant to archaeology. The majority of these studies focus on the survival of starch granules within sediments and soils, whereas only a few of studies specifically address the preservation of starch on artifacts (Barton 2006). Here, starch taphonomy is defined as factors that influence the incorporation of starch into the archaeological record as well as starch survival over time (Barton and Matthews 2006:75). This chapter reviews the taphonomic literature as it applies to starch-granule research in archaeology, as well as discussing its implications.

Modification of Starch during Plant Processing and Cooking

There are several studies that suggest that identifiable starch does not survive the cooking processes (e.g., Crowther *et al*. 2003; Henry *et al*. 2009). Studies show that when starch is exposed to heat and moisture, the semi-crystalline structure of individual starch granules break down via a process called gelatinization (Reichert 1913). When this occurs, starch granules are no longer considered to be identifiable given that all of the diagnostic characteristics, such as visible lamellae, are damaged or obscured (Henry *et al*. 2009). While almost all of the archaeological literature suggests that cooked starch is no longer identifiable, there are studies that demonstrate otherwise. Within archaeology, Henry *et al*. (2009) report as much as 50% of starch from various domesticated species remained identifiable after 10 minutes of boiling. Messner and

Schindler (2010) reported that starch granules in green arrow arum (*Peltandra virginica*) rizomes were identifiable after 12 hours of cooking in an earth oven. Similarly, experiments conducted by Thoms *et al*. (2011) suggest that some starch can remain identifiable even after 40 hours of baking in an earth oven. Although the acknowledgment that starch can survive cooking episodes is not widely received in archaeology, the concept of starch surviving intact after exposure to heat and moisture is well known and understood in the cereal and crop sciences.

Thoms *et al*. (2013) reviewed some of the starch literature and discuss how identifiable starch granules can survive cooking episodes due to one or more processes. First, insufficient quantities of water in a given cell may prevent complete gelatinization of all the starch within the cell (Şumnu *et al*. 1999). Second, smaller sized of a starch granules tend to be more resistant to gelatinization (Eliasson and Karlsson, 1983). Third, if a starch-rich storage organ is not heated for a long enough period of time, complete gelatinization will not occur (Lund 1984). Finally, starch granules can be protected from gelatinization by being coated with fat or sugar (Lin *et al*. 1997; Şumnu *et al*. 1999).

Given that starch can survive cooking, the author processed corn chips to see if identifiable starch could be recovered from highly processed foods. To do so, a toothpick was used to scrape a corn chip. The resulting residue was then smeared onto a microscope slide and mounted in water. Identifiable maize starch granules were recovered from the sample (Figure 3.1), confirming that starch can survive both the grinding and cooking processes involved in the modern processes food industry.

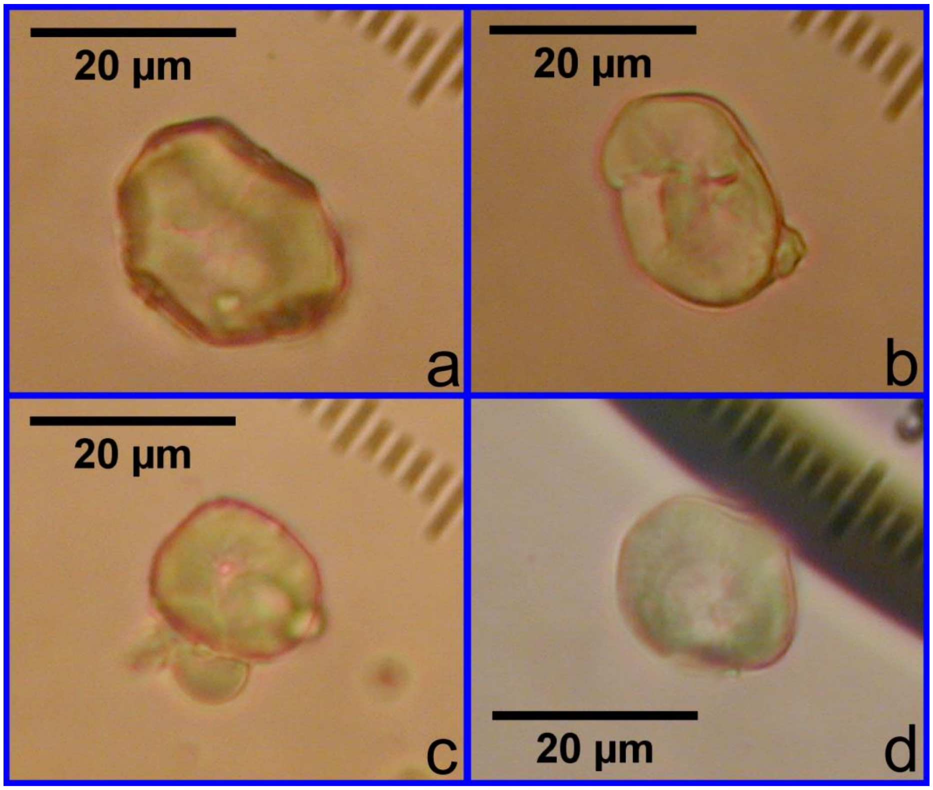


Figure 3.1. (a-d) Maize starch recovered from corn chips. Note the starch granules in a and d are undergoing hydrolysis and starch granules b and c displaying signs of partial gelatinization.

Starch in Sediments and Soils

Several factors are believed to influence the survival of starch in a sediment matrix, including enzymatic decay, microorganisms, moisture, temperature, and pH levels, none of which are necessarily mutually exclusive (Haslam 2004). Starch granules deposited in sediments serve as a major source of energy for both bacteria and fungi (Haslam 2004; Ohta 1997). To aid in the metabolizing of starch, these organisms produce enzymes, specifically polysaccharidases (enzymes that break down starch), which act as a catalyst to lower the activation energy required for starch to chemically break down through a process termed "hydrolysis" (Figure 3.2) (Greenwood and Milne 1968; Haslam 2004; Ohta 1997). These enzymes are not limited to bacteria and fungus. Many plants and animals utilize polysaccharidases either as part of their digestive system as in the case of animals, or as part of an energy storage and use system employed by plants (Haslam 2004). When plant and animal cellular material decay, enzymes are released into soils, including polysaccharidases (Burns 1982). Due to the combination of microbial activity, fungal activity, and decaying cellular material, significant quantities of polysaccharidases are present in virtually every soil type around the planet, thereby limiting the long term survival of starch in soils (Burns 1982; Haslam 2004).

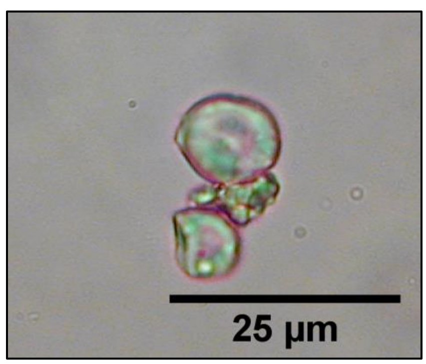


Figure 3.2. Starch granules from little bluestem grass (*Schizachyrium scoparium*) currently undergoing hydrolysis (Author's micrograph). Note the pitted and "hollowed-out" center which indicates hydrolysis is taking place. Enzymes first break down the center of starch granules and then break down the remainder of starch granules from the center out towards the edges (Barton and Matthews 2006:87).

Cheshire *et al*. (1974) estimate 20-30% of all microbes in any given soil utilizes starch as a primary food source. Starch eating microbes can be found in virtually every type of soil. Several experiments have been conducted to determine the length of time it takes for starch to decompose in various types of soils. When wheat starch was added to a fallow loam soil, the carbohydrate levels within the soils returned to normal within 28 days, suggesting that the added starch was no longer consumed (Cheshire *et al*. 1969). Cheshire *et al*. (1969) also noted a significant increase in microbial and fungal activity following the addition of the wheat starch. In a subsequent test, 10% of the added wheat starch survived after 8 weeks (Cheshire *et al*. 1974). Within sandy loams and clays, 20% of starch added to the soils was consumed within the first three days while over 50% was consumed within 24 days (Adu and Oades 1978). These studies suggest that starch survival follows a asymptotic curve where there is a high loss of starch granules within the first few days followed by a noticeable decrease in the starch decomposition rate (Cheshire *et al*. 1969; Haslam 2004). Finally, the results of these studies suggest that although the rate of starch decomposition varies based on soil type and other environmental factors as discussed below, starch is unlikely to survive in sediments unless they are in a protected setting (Haslam 2004).

Soil moisture, temperature, and pH have both direct and indirect impacts on starch survival (Haslam 2004). Changes in soil moisture can cause a starch grain to shrink and swell, thereby damaging the starch. Once damaged, starch becomes more susceptible to microbial attack (Leach and Schoch 1961). Similar, to moisture, the freezing and thawing of soils can damage starch granules via mechanical weathering, making them more susceptible to predation by microbes (Babot 2003). Soil pH also has an influence over starch survival. Starch eating microbes generally favor acidic soils.

Therefore, starch is expected to have a much lower survival rate in these types of soils due to the increased rate of predation (Cheshire 1979:291). Although microorganisms and fungi are the underlying reason for starch degradation, other factors such as moisture, temperature, and pH can help or hinder starch preservation either through directly damaging starch via mechanical weathering or increasing the number of starch eating microbes in soils (Haslam 2004).

Although microbial activity adversely affects starch survival in soils, there are several environmental conditions that favor starch survival. Starch can have an increased survival rate in soils if they are in a protective environment such as a soil aggregate, soil types, high concentration of heavy metals, or its location on or near an artifact (Guggenberger *et al*. 1999; Haslam 2004). Heavy metals within soils and soils with high clay content tend to favor starch survival given that they neutralize enzymes (Deng and Tabatabai 1995; Doelman and Hannstra 1979; Ross 1983). Soil aggregates, however, provide a physical barrier for starch granules that limits the amount of surface area exposed for microbial and fungi predation (Guggenberger *et al*. 1999; Haslam 2004).

Finally, it needs to be noted that starch can move through and within soil profiles. Starch is known to move through the ground in water (Therin 2006). Therin (2006) notes that starch granules smaller than 5 µm move further down a soil profile and travel faster than granules larger than 5 µm. The actual distance starch will move in any given profile, however, is determined by the size of the starch granules, porosity of the soil, and amount of rainfall in a given area (Therin 2006).

Starch Preservation on Artifacts

The preservation of starch on artifacts has not been thoroughly explored (Haslam 2004). In a study aimed at understanding how different depositional environments affect starch granule survival, Lu (2004) used experimental grinding tools to process different types of starch-rich foods in Southeast Asia. Lu (2004) cleaned 16 rocks using a toothbrush and running water. Each rock was then used to process one of four different starch-rich seeds, including foxtail millet (*Setaria sativa*), rice (*Oryza sativa*), yam (*Dioscorea* sp.), and taro (*Colocasia* sp.). Once processed, areas were deliniated on the rocks where starch had been processed, and the starch granules within the demarked areas were counted. The rocks were then separated into three groups where one group was buried 5 cm below the surface in sandy soil, one group was left on the surface exposed to the elements, and the final group was placed in a rockshelter. At least one rock from each processed taxon was placed in all three depositional environments. After 71 days the artifacts were removed from their depositional environments, and the starch granules were counted. On average, the survival rate of starch on the rocks in the buried sediments was 74.8+/-3.8%, whereas the survival rate in the rockshelter was 80.2+/-3.2%. The average survival rate for the surface site was 30.3% where the survival rate ranged from 1.6-64.6%. The results from these experiments demonstrate how the depositional environment can influence starch survival and that surface artifacts should not be tested for starch granules (Lu 2004).

Starch Contamination

There are three sources of contamination in which starch granules can enter into the archaeological record including airborne starch, starch transferred by means of direct contact, and "pre-contaminated" laboratory equipment. The following sections will discuss each of these sources of contamination.

Airborne Starch

The issue of airborne starch contamination in archaeological studies has been mentioned by numerous researchers. Barton and Matthews (2006) noted the possibility that airborne starch deposited during excavations can affect interpretations of "fossil" starch granules from archaeological materials while Wadley and Lombard (2007) mention how dust containing starch granules can contaminate artifacts in the lab. To identify possible contamination of artifacts, Loy and Barton (2006) suggested leaving microscope slides out in the field to test for airborne starch deposited from industrial activity. Archaeologists have also tested for airborne starch contamination by leaving microscope slides exposed to the air in research laboratories and curation facilities (Loy and Barton 2006; Parr 2002; Zarrillo and Kooyman 2006). Nugent (2006) recovered unmodified and damaged airborne starch granules in a curation facility and a lab, which averaged 12.6 μm and 18.4 μm in size, respectively. Similarly, Williamson (2006) identified contamination within the lab from starch granules that originated from a nearby flour mill. Finally, a literature review and experiments presented in a study by Laurence *et al*. (2011) demonstrated the presence of airborne storage starch, its ability to contaminate artifacts, and its sources. That study determined that airborne starch originates culturally from agricultural and industrial activities and naturally, via starch emanating from ruptured pollen grains.

Starch granules within pollen grains of starch-rich plants, often described as storage starch, provide energy for growth of the pollen tube (Baker and Baker 1979; Grayum 1985). There are several ways in which starch in pollen can be liberated. Especially common is the rupturing of pollen grains during thunderstorms by means of osmotic shock from electrical charging and thunder (Suphioglu et al. 1992; Taylor et al. 2007). Starch can be expulsed through a fracture or through an aperture in the pollen grain and this can occur on the ground or in mid-air (El-Ghazaly et al. 1996; Taylor and Jonsson 2004; Taylor et al. 2007). Pollen grains from wind-pollinated species in particular (e.g., birch, maize and other grasses) are prone to rupture due to their size or thin walls (exines). Some wind-pollinated grains lack pollen tubes, and are designed to rupture enabling genetic material to complete fertilization (Wodehouse 1935:351). Whether starch-rich pollen grains rupture or lose material through their apertures in mid-air or on the ground, their starch granules are released directly or recycled back into the atmosphere after deposition.

Apart from ruptured pollen grains, starch can become airborne as starch-rich plants decay. An air sample was taken next to a road on the Texas A&M University campus in College Station, TX (Figure 3.3) where acorns from an adjacent live oak tree (*Quercus viriniana*) were continually crushed by passing automobiles (Laurence *et al*. 2011). The air sample was left next to the road for one hour and collected thousands of live oak starch granules (Figure 3.4). While the physical force of passing automobiles was responsible for rupturing the acorns, this experiment suggests that as starch-rich plants degrade, broken apart by animals in the wild, or damaged by human activities unrelated to plant use (such as stepping on a seed or acorn), starch granules can be released into the atmosphere and thereby contributing to the starch-rain (Laurence *et al*. 2011).

Figure 3.3. Location of College Station, TX.

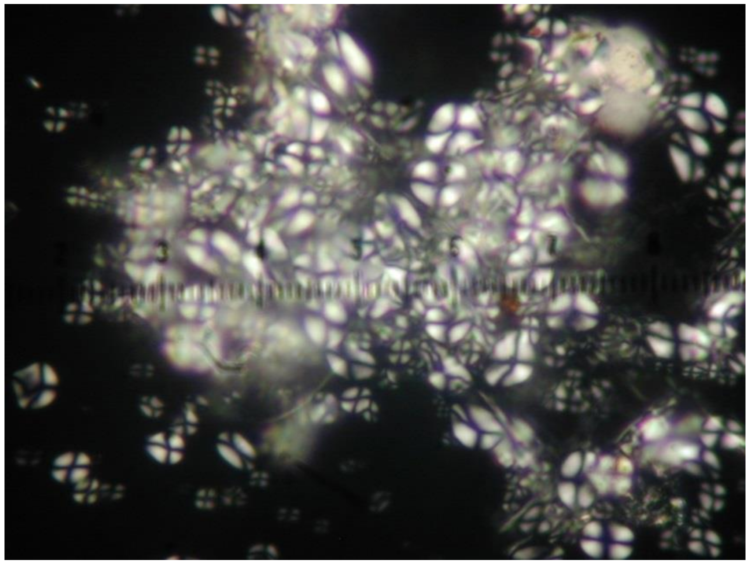


Figure 3.4. Starch granules recovered in an air sample taken next to a road where automobiles were crushing live oak acorns. Micrograph is under cross-polarized light (Laurence *et al*. 2011).

Transmission of Starch via Direct Contact

Starch granules can be transmitted from a person's hands to another object after handling starch-rich plants, foods, and/or industrial products (Fullagar 2006:189; Wadley and Lombard 2007). To test this, the author cut and handled a yukon gold potato (*Solanum tuberosum*) in a fashion reminiscent of food preparation. The author then touched a clean microscope slide and a table, leaving behind a fingerprint on both surfaces. A piece of clear "Scotch tape" was then used to remove the fingerprint from the table surface. The adhering residues were then transferred from the piece of tape to a clean microscope slide. Both the tape residue and the fingerprint directly applied to a slide were mounted in distilled water. In both cases, over 100 unmodified, diagnostic potato starch granules were recovered (Figure 3.5). This experiment confirms that starch granules are not only transferred from a plant to an analyst's hands but that the starch granules can then be re-transmitted from the hands to an artifact. In the case of the latter experiment, starch granules were transmitted from the potato to the finger, from the finger to the table, from the table to the tape, and then from the tape to the microscope slide, thereby suggesting that starch granules recovered from an object (in this case a microscope slide) can be several times removed from the original source of the starch granules.

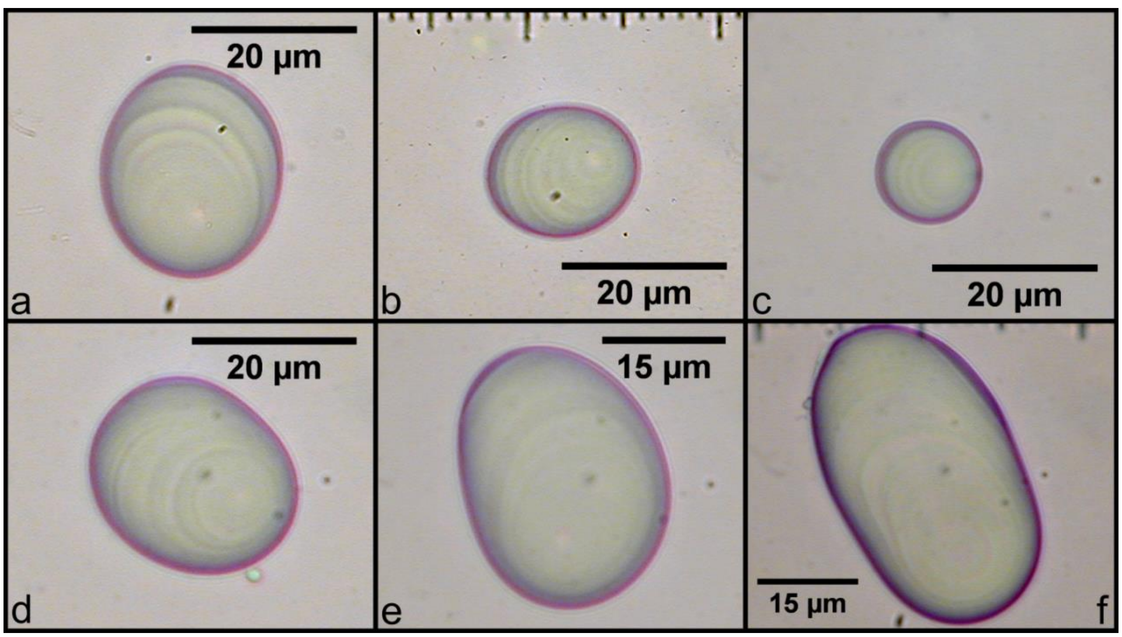
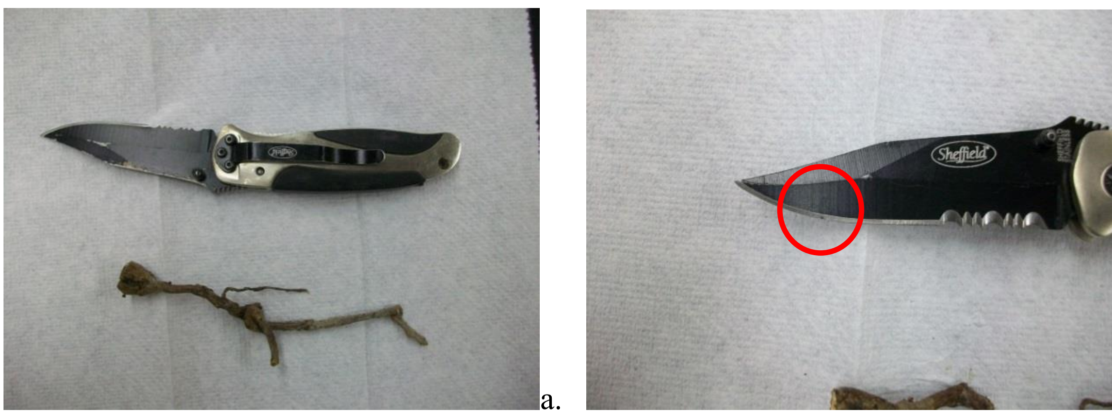


Figure 3.5. Potato starch granules recovered from: (a-c) author's fingerprint placed directly on a microscope slide and (d-f) author's fingerprint recovered off of a table.

Contact between starch-rich plants and field equipment can also transfer starch granules from one object to another. Starch granules are located within the roots of starch-rich plants (Gott *et al*. 2006:36). If roots are cut during excavation with a trowel (as often happens) and the trowel comes into contact with an artifact, then starch granules from the root may be transferred to an artifact. To confirm that a trowel cutting through a starch-rich root can become contaminated with starch granules and subsequently transfer starch granules to an artifact, a clean knife was used to cut a groundnut (*Apios americana*) root with one clean stroke (Figure 3.6). The knife was then scraped against a toothpick and any adhering residue and transferred to a microscope slide. Hundreds of starch granules and raphides (a type of calcium oxalate crystal) were recovered from the residue (Figure 3.7).



a. b.

Figure 3.6. Knife used to cut a groundnut root: (a) before and (b) after. Notice visible residue in the knife's edge in b.

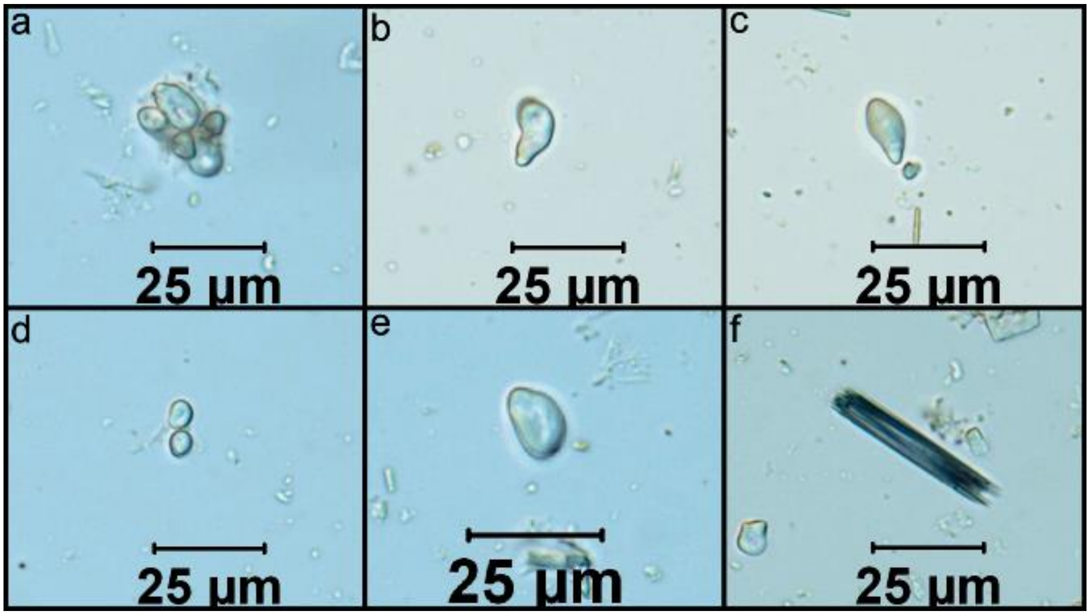


Figure 3.7. Microfossils recovered from residue on knife including (a-e) starch granules and (f) raphides. Micrographs are under differential interference contrast (DIC).

Laboratory Equipment

Another source of starch contamination comes from laboratory equipment. Starch granules are used in a wide range of industrial and consumer products, including the manufacturing of latex gloves (Laurence *et al*. 2011). Given that powder-free latex gloves are made within the same factory as their powdered counterparts and therefore subject to contamination by starch traveling through the air within the factory (Swanson and Ramalingam 2002), several pairs of powder-free latex gloves were randomly processed and analyzed for starch granules since powder-free gloves were used during all stages of artifact recovery and processing during the Paluxy Sand Geophyte Project. Maize starch granules were recovered from every pair of gloves analyzed (Figure 3.8). Of particular interest was the recovery of modified starch granules showing signs of physical modification, specifically milling activities (Figure 3.8a, c, and f), as well as gelatinized starch (Figure 3.8d). Unmodified starch granules (Figure 3.8b) and starch granules undergoing hydrolysis (Figure 3.8e) were also recovered. Historically, ancient starch researchers would assert that the damaged observed in Figure 3.8a, c, and f, was indicative of past milling activity based on the presence fractures and fissures radiating from the hilum and cavity-like damage (Babot 2003). These starch granules probably did undergo milling activities, although it was from modern industrial activities rather than ancient plant use. Furthermore, the presence of gelatinized starch has also been used by ancient starch researchers as proof of ancient plant use since it is believed that starch only gelatinized during cooking activities where there is sufficient heat and moisture for gelatinization to occur (Henry *et al*. 2009). The presence of gelatinized starch on modern latex gloves clearly indicates that other processes besides cooking can introduce gelatinized starch into an archaeological sample. Had the gloves never been tested for starch granules, the recovery of these types of starch granules in archaeological samples may have been interpreted as evidence of ancient plant use rather than contamination.

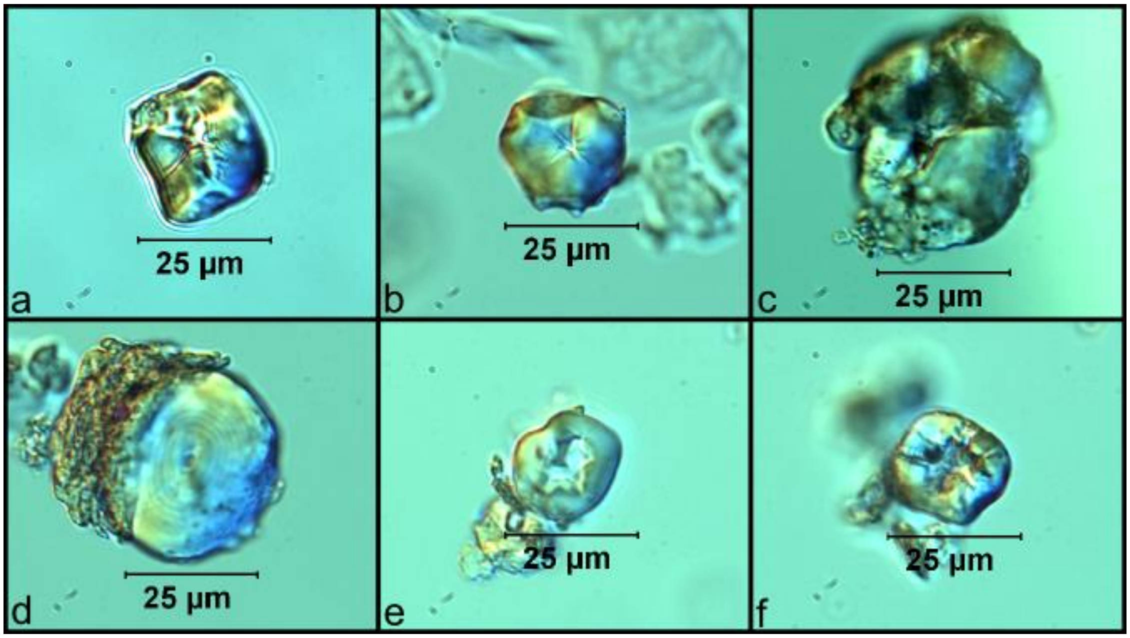


Figure 3.8. Starch granules recovered from powder-free latex gloves used in (a-c) Archaeological-Ecology Laboratory and (d-e) Palynology Laboratory.

FCR and Contamination

Fire-cracked-rocks (FCR) are ideal artifacts for obtaining direct evidence of ancient plant use. When rocks are used as the heating element for cooking features, they are heated in excess of 580°C (Gose 2000). Starch granules will combust at temperatures greater than 380°C (MSDS for Starch Solution). Therefore, heating rocks in an earth oven should remove any previous starch contamination, as well as the starch rain falling on the FCR during the construction of the oven. Therefore, starch granules recovered from the FCR must have been deposited on the artifacts during or after the cooking episode when the rocks have cooled to temperatures below 380°C.

Since starch granules that come into contact with FCR heated to temperatures greater than 380°C will combust, it is unlikely that identifiable starch granules will be deposited on the artifacts during the cooking event itself. Instead, starch granules that exuded from starch-rich storage organs and became embedded within the packing material is the most likely source of starch granules recovered from FCR. As it was stated above, starch is mobilized in the ground via water (Haslam 2004; Therin 2006). Once the FCR cools, water percolating through the soil can transport starch granules, along with other particles through the feature, and deposit it on the FCR (Thoms *et al*. 2011; Thoms *et al*. 2013). Experimental earth ovens constructed as part of an ongoing study demonstrate that starch granules from cooked starch-rich storage organs can be recovered from both the FCR and packing material once they have cooled (Thoms *et al*. 2011). These results suggest that, barring preservation issues, it should be possible to recover starch granules from ancient earth ovens.

Actualistic Earth Ovens

Thoms *et al*. (2013) demonstrated that microfossils, including starch, can be recovered from FCR after 20 and 40 hour cooking episodes (Figure 3.9). The majority of the starch granules recovered from the FCR was heavily modified, although a few were still identifiable. Although most of the recovered identifiable starch originated from the plants that were either baked or used as packing material in the ovens, one common bean (*Phaseolus vulgaris*) starch granule was recovered from the 40 hour oven used to bake the starch-rich greenbrier (*Smilax bona-nox*) and Irish potato (*Solanum tuberosum*), among other inulin-rich plants (Figure 3.10). Given that none of the plants cooked in the earth ovens belonged to the Fabaceae family (bean family), the presence of the common bean starch represents contamination. It is unknown whether or not the common bean starch granule was the result of airborne or direct transfer contamination, although common bean starch was recovered in an air sample from Fort Hood.

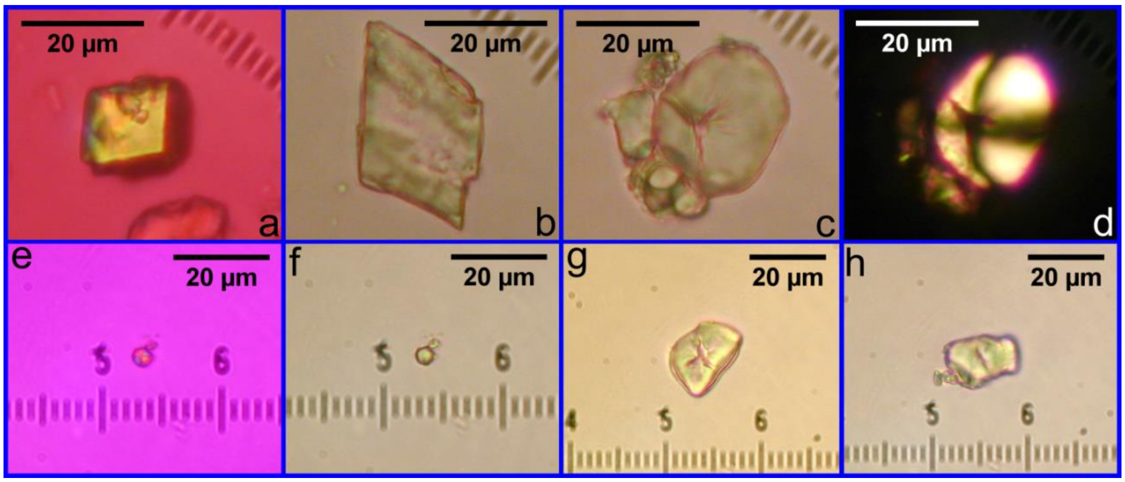


Figure 3.9. Microfossils recovered from (a-d) FCR and (e-h) packing material after 40 hour baking episode. Recovered microfossils include (a) calcium oxalate crystals, (b) phytoliths, (c-d; g-h) starch from Irish potato starch, and (e-f) starch from little bluestem grass (*Schizachyrium scoparium*). Micrographs a and e are under ¼ λ polarized light, b-c and f-h are under brightfield illumination, and d is under cross-polarized light.

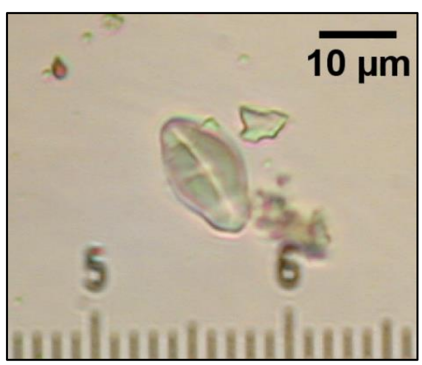


Figure 3.10. Common bean starch recovered from FCR after 40 hour baking episode.

Controlling for Contamination

Laurence *et al*. (2011) propose several methods to control for contamination. These include taking air samples in the field and in the lab to assess the amount of modern airborne contamination, using non-cultural rocks from the same depositional environment to gauge ancient contamination, the use of powder-free latex gloves (which is actually a source of contamination), use of a clean bench, wearing a surgical cap to prevent contamination from the analyst's hair, and washing artifacts prior to sampling to remove loosely adhering modern airborne contamination (Laurence *et al*. 2011; Thoms *et al*. 2013).

To assess the effectiveness of washing artifacts prior to sampling to reduce contamination, a rock was sterilized by soaking it overnight in bleach (5% hypochlorite). Once sterilized and the rock was rinsed with distilled water to remove the bleach, the rock was used to pound an Irish potato. The rock was then left outdoors in the author's back yard for 30 days where it was exposed to the atmosphere and several episodes of rain. It was then recovered and washed by placing it in a beaker of distilled water and lightly brushing it with a sterile toothbrush. Once the rock was allowed to dry, it was processed for starch (Figure 3.11a-b). No non-potato starch granules were recovered. To confirm that washing the rock removed contamination, the rock was lightly coated with a large quantity of maize starch to simulate starch rain. Once coated, it was washed and processed for starch. Maize starch was recovered from the rock after it was washed (Figure 3.11d), although in very small quantities, especially when compared to the amount of recovered potato starch (Figure 3.11c). This experiment suggests that washing an artifact in distilled water using a sterile toothbrush can remove the majority of airborne contamination while leaving the majority of "archaeological starch" intact.

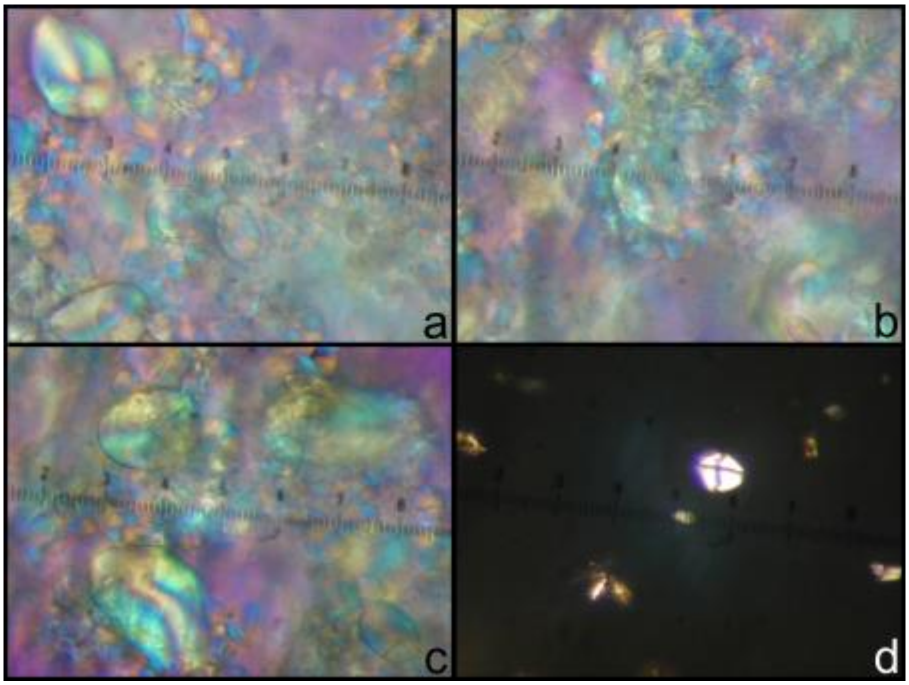


Figure 3.11. Starch granules from (a-c) Irish potato and (d) maize recovered from test rock after washing. Micrographs a-c are under ¼ λ polarized light while d is under cross-polarized light. Each tick mark is 2.5 μm and the distance between each number is 25 μm (Thoms *et al*. 2013).

Summary

The number of studies devoted to understanding starch taphonomy as it is related to the archaeological record is limited. Most taphonomic studies focus on how starch is modified during plant processing activities. With regard to cooking, it is widely believed that unmodified starch granules (e.g. identifiable) are unlikely to be recovered since starch gelatinizes in the presence of heat and water (Henry *et al*. 2009). Recent evidence, however, suggests that this is not always the case as there are natural mechanisms in which starch granules can survive the cooking processes while retaining diagnostic features (Messner and Schindler 2010; Thoms *et al*. 2011). Furthermore, the presence of starch-eating microbes in soils around the world suggests that it is unlikely that starch will preserve through time without some sort of protected setting to (Haslam 2004). Finally, the above review suggests that it is relatively easy for artifacts to become contaminated by modern or ancient non-cultural starch granules while the mechanisms as to why starch survives in the archaeological record at all is poorly understood. As Barton (2004) has suggested, more research is required before the complexities of starch taphonomy and its implications for the archaeological record can be fully understood.

CHAPTER IV

ARCHAEOLOGICAL SITES

Study Area

Fort Hood (Figure 4.1) is located within the Lampasas Cut Plain. This region is characterized by an average annual rainfall of 826 mm (32.5 in), most of which occurs in the late spring and early fall (Kibler 2004). Uplands are dominated by various species of oak (*Quercus*), juniper (*Juniperus*), and mesquite (*Prosopis*) while intermediate surfaces are composed of open grasslands dominated by little bluestem grass (*Schizachyrium scoparium*) and Indian grass (*Sorghastrum nutans* (L.) Nash) (Anderson *et al*. 2005; Kibler 2004:9). Soils tend to be clay loams although patches of sandy loam ("Paluxy Sand") also occur. Paluxy Sand tend to be well-drained areas rich in cultural materials and are believed to have been targeted as favorable camping locations (Boyd and Mehalchick 2004:1). Finally, three different limestone bedrock formations are exposed across the Fort Hood landscape, including the Glen Rose Formation, Comanche Peak Limestone, and the Edwards Limestone (Kibbler 2004:9). Limestone from these formations served as cook stones in ancient earth ovens at Fort Hood.

Figure 4.1. Location of Fort Hood, TX.

Prehistoric Climate

Central Texas, as it is defined here, includes the modern day Edwards Plateau, Lampasas Cut Plain, and the Blackland Prairie (Collins 2004). Environmental data compiled as part of archaeological excavations in or near Central Texas document changes in fauna and flora in response to changing climatic conditions (Collins 2004). Stable carbon isotope data from Fort Hood and pollen data from Boriak Bog in greater Central Texas indicates that around 15,000 BP, the late Pleistocene climate in Central Texas was cooler and wetter than any other time of occupation as evidenced by a vegetation community of 50-60 percent trees and C_3 grasses and 40-50 percent C_4 grasses (Figure 4.2) (Bryant and Holloway 1985; Nordt *et al*. 1994). Between 11,000-8000 BP, the climate became warmer and drier, slowly changing the Central Texas landscape into grassland. By 6000-5000 BP the climate was characterized as the warmest and driest interval of the Holocene, facilitating the expansion of open grasslands (comprised of 95 percent C_4 species) in the uplands and floodplains. Finally, by 4000 BP, the Central Texas climate developed into mesic conditions which continues to modern times (Bryant and Holloway 1985; Nordt *et al*. 1994). The paleoclimate of Fort Hood was conducive for the necessary elements for earth oven construction and use including, the growth of self-pruning tree species that were ideal for fuel, grasses and other taxa ideal for packing material, and a number of edible starch-rich geophyte species such as false garlic (*Nothoscordum bivalve*) and groundnut (*Apios americana*) (Kibbler 2004:10-12).

Excavated Sites

FCR from 27 earth ovens at 6 sites from Fort Hood (Figure 4.3) were examined for microfossils in general, although starch granules were the main focus (Table 4.1). All of the features were located within the Paluxy Sand with fine sandy loam sediments with variation in clay content, although 41CV1657 was deposited in gravelly clay loam colluvium (Table 4.1). Radiocarbon ages for each site are listed in Table 4.2. Finally, the results of the starch granule analysis for each site are discussed in the following chapter.

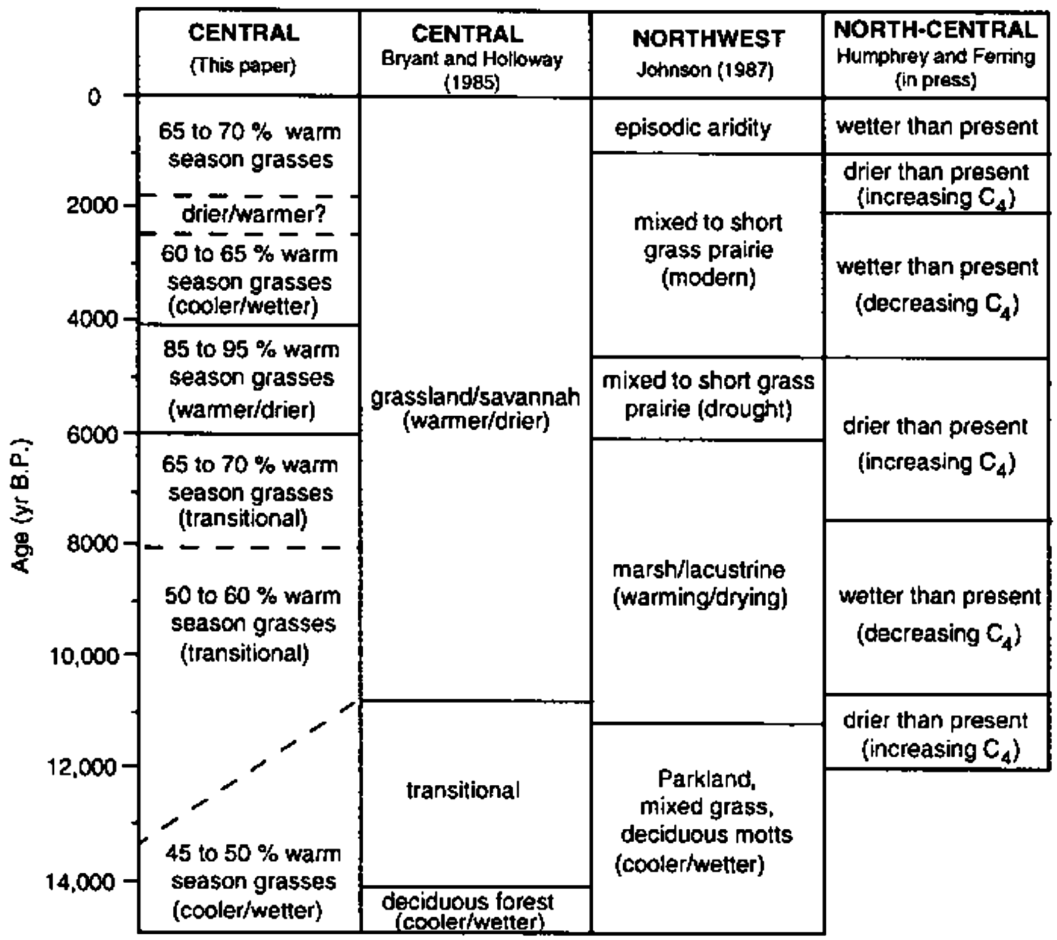


Figure 4.2. Summary of prehistoric climatic conditions in Central Texas (Nordt *et al*. 1994 Figure 4).

Table 4.1. Earth ovens excavated during the 2010-2012 field seasons and analyzed for starch granules.

Feature	Site	Diameter in Meters	Depth in Meters	Morphology	Sediment Type
2A	41CV594	1.95	0.3	flat	fine sandy loam
2B	41CV594	2.1	0.75	flat	fine sandy loam
2C	41CV594	2	0.75	flat , slab-lined	fine sandy loam
2D	41CV594	1.6	0.34	flat	fine sandy loam
2E	41CV594	1.4	0.31	basin-shaped	fine sandy loam
2F	41CV594	2.3	0.2	v-shaped	fine sandy loam
2G	41CV594	1.2	0.7	flat, slab-lined	fine sandy loam
4	41CV947	0.8		flat	fine sandy loam
5	41CV947	1.15	0.3	basin-shaped	fine sandy loam, organic rich in central pit
6	41CV947	0.6	0.2	N/A	fine sandy loam
7	41CV947	2		slight basin	fine sandy loam
8	41CV947	1.3	0.3	basin-shaped	fine sandy loam
9	41CV947	1.5	0.2	flat	fine sandy loam
4	41CV984	1.75 (central pit) 10 (feature)	0.82	basin-shaped	sandy loam with increasing clay content with depth
1	41CV1104	1.37	0.73	flat	clay loam or silty clay
2	41CV1104	1.25	0.15	shallow basin	clay loam or silty clay
3	41CV1104	0.44	0.1	flat	clay loam or silty clay
4	41CV1104	0.73	0.1	shallow basin	clay loam or silty clay
6	41CV1553	1.1	0.35	basin-shaped	fine sandy loam with limestone gravel with carbon-stained sediments
8	41CV1553	6	0.15	N/A	find sandy loam with limestone gravel
8E	41CV1553	0.8	0.3	shallow basin	find sandy loam with limestone gravel
8F	41CV1553	0.5	0.3	flat	find sandy loam with limestone gravel
1	41CV1657	0.75	0.2	flat to slight basin	gravelly clay loam colluvium
2	41CV1657	0.75	0.35-0.4	slight basin	gravelly clay loam colluvium
3	41CV1657	2	0.4-0.5	basin-shaped	gravelly clay loam colluvium
3A	41CV1657	0.75	0.2	flat	gravelly clay loam colluvium
4	41CV1657	0.75	0.15	flat	gravelly clay loam colluvium

Table 4.2 Summary of radiocarbon dates on charred materials from sites 41CV594, 41CV947, 41CV984, 41CV1104, 41CV1553, and 41CV1657 (Karl Kibler, personal communication 2012).

Site No.	Field Sample No.	Beta Analytic Sample No.	Feature	Test Unit	Depth (cm below datum)	Elevation (m)	13C/12C Ratio (o/oo)	Conventional Radiocarbon Age, Years BP	2-Sigma Calibrated Date
41CV594		64230	F 2	TP 2	10-20		-27.2	170 +/- 70	A.D. 1638 - 1955
41CV594		64231	F 2	TP 2	30-40		-26.7	4350 +/- 60	3255 - 2879 B.C.
41CV594		64229	F 2	TP 1	30-40		-25.9	1520 +/- 70	A.D. 410 - 660
41CV594		64232	F 2	TP 2	50-60		-26.9	4100 +/- 70	2882 - 2463 B.C.
41CV594	C-15	343284	F 2C	TU 4	below base of feature		-26.2	2460 +/- 30	760 - 680 and 670 - 410 B.C.
41CV947*		102090	F 2	TU 1	45-58		-22.5	1880 +/- 40	A.D. 90 - 210
41CV947*		102091	F 1	TU 3	15-20		-30.2	1370 +/- 50	A.D. 645 - 685
41CV947*	C-1	343285	F 5			97.615	-24.8	1170 +/- 30	A.D. 780 - 900 and 920 - 970
41CV947*	C-7	343286	F 5			97.584	-24.8	1050 +/- 30	A.D. 900 - 920 and 970 - 1020
41CV984*		102092	none	TU 3	30		-30.4	1130 +/- 80	A.D. 855 - 1000
41CV984*		102093	F 2	TU 1	40-50		-23.4	2750 +/-40	915 - 830 B.C.
41CV984*	F-1	269716	F 3	TU 6	10-20		-24.0	770 +/- 40	A.D. 1210 - 1290
41CV984*	C-8	281900	F 4	TU 8 and 9		99.43	-27.3	1910 +/- 40	A.D. 10 - 210
41CV984*	C-29	281901	F 4	TU 8 and 9		99.16	-28.0	2440 +/- 40	760 - 400 B.C.
41CV1049*		102097	F 1A	TU 3	28-32		-26.7	1600 +/- 100	A.D. 380 - 590
41CV1049*		102096	F 7	TU 2	45-51		-26.0	1590 +/- 50	A.D. 420 - 550
41CV1049*	C-3	269717	F 10	TU 6	30		-26.5	1900 +/- 40	A.D. 20 - 220
41CV1049*	F-1	269718	F 8	TU 5	25-30		-25.5	1490 +/- 40	A.D. 450 - 450, 460 - 480, and 530 - 640
41CV1104	C-1	343287	F 4			101.69	-25.4	3760 +/- 30	2280-2250, 2230-2220, 2210-2130, and 2090-2050 B.C.
41CV1553*		136840	F 3	TU 4	14		-25.9	240 +/- 50	A.D. 1640 -1670 and 1780 - 1795
41CV1553		136841	F 4	TU 5	50		-28.1	1900 +/- 50	A.D. 60 - 140
41CV1553		136842	F 6	TU 5	41		-27.9	2090 +/- 50	180 - 45 B.C.
41CV1553*	C-1	269719	F 8	TU 8	27		-25.4	1440 +/- 40	A.D. 550 - 660
41CV1553*	C-2	269720	F 8A	TU 11	36		-24.9	1510 +/- 40	A.D. 430 - 640
41CV1553*	C-3	269721	F 8D	TU 13	33		-25.0	1470 +/- 70	A.D. 540 - 650
41CV1553*	F-10	269722	F 8	TU 11	13-26		-25.6	1860 +/- 40	A.D. 60 - 240
41CV1553*	F-19	269723	F 8B	TU 8	35-42		-25.2	1390 +/- 40	A.D. 600 - 680
41CV1553*	F-23	269724	F 8C	TU 14	37		-27.7	1590 +/- 40	A.D. 390 - 560
41CV1553*	F-26	269725	F 8D	TU 13	37		-26.5	1730 +/- 40	A.D. 230 - 410
41CV1553*	F-30	269726	F 8	TU 20	below F 8		-26.1	1460 +/- 40	A.D. 540 - 650
41CV1657	C-1	281902	F 3				-25.3	1050 +/- 40	A.D. 900 - 1030
41CV1657	C-3	281903	F 3				-26.2	1060 +/- 40	A.D. 890 - 1030
41CV1657	F-4	289754	F 1				-27.3	1200 +/- 30	A.D. 720 - 740 and 770 - 890
41CV1657	C-6	289755	F 2				-25.4	1150 +/- 30	A.D. 780 - 980

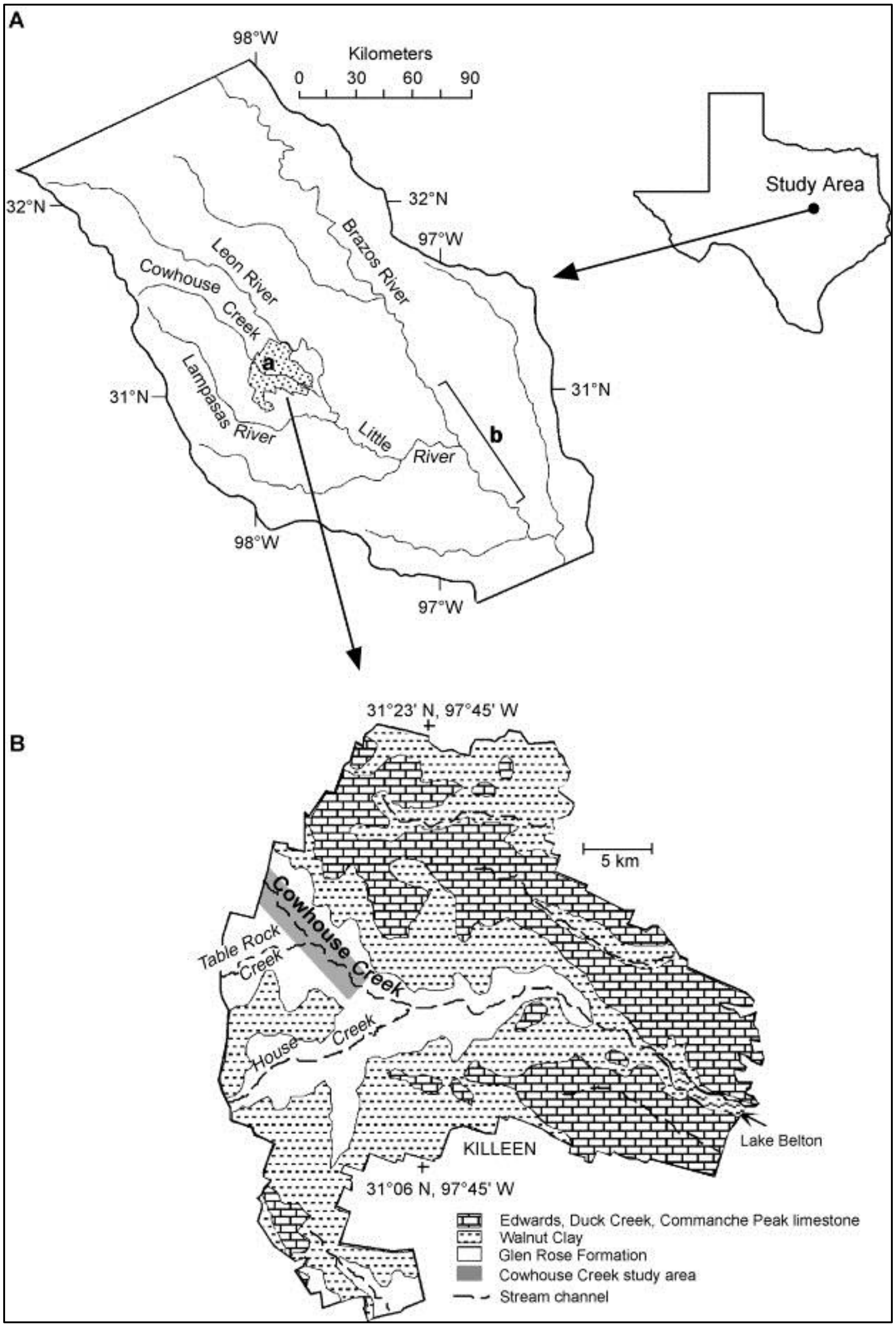


Figure 4.3. Major tributaries and bedrock formations at Fort Hood, TX (Figure from Nordt 2004:291, Figure 1).

Sites Excavated During the 2010 Field Season

41CV984 Site 41CV984 (Figures 4.4-4.6) is located south of Cottonwood Creek (Mehalchick *et al*. 1999:66). Feature 4 (formerly designated as Feature 2) consists of a large burned-rock midden approximately 1.75 meters in diameter and produced radiocarbon ages of 2750+/-40 B.P., 2440+/- B.P., and 1910+/-40 (Table 4.2), along with a charred false garlic bulb, charred onion and camas bulbs, and an unidentified charred tuber (Kleinbach et al. 1999; Karl Kibler, personal communication 2010; Leslie Bush, personal communication 2010). Wood charcoal from plateau live oak (*Quercus fusiformis*), red group oak (*Quercus* subg. *Lobatae*), and non-specified oak (*Quercus* sp.) was also recovered (Leslie Bush, personal communication 2010). This feature was excavated and sampled as part of the Paluxy Sand project at irregular levels (2-9, with level 1 being near-surface and un-sampled) defined in the field by layers of horizontal FCR that appeared to represent the bottoms of superimposed, slab-line ovens (Thoms *et al*. 2013). Finally, photographs from every site were taken from the archives of the Archaeological-Ecology Laboratory and may be included in Thoms *et al*. (2013).

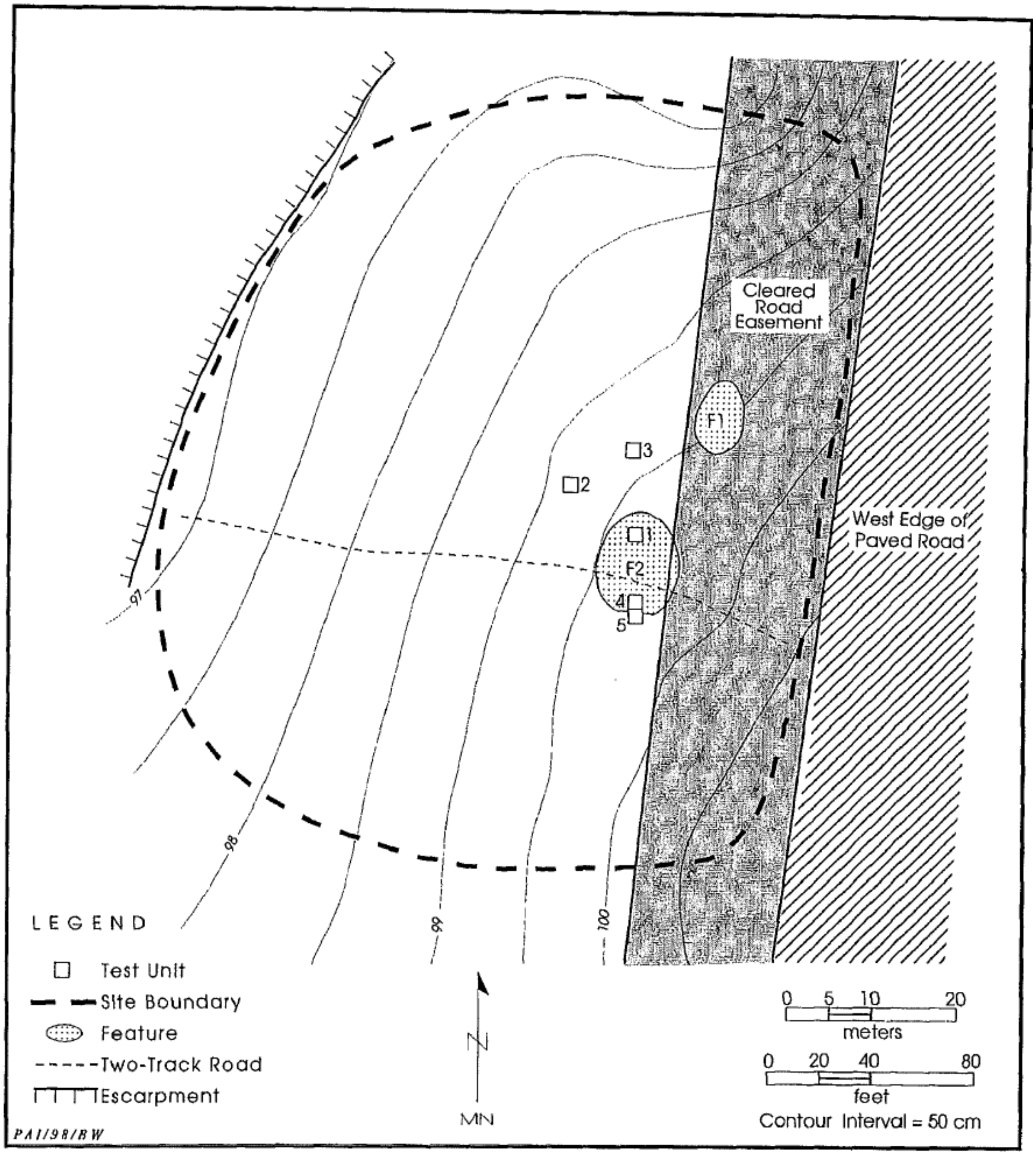


Figure 4.4. Site map of 41CV984. Investigated feature, Feature 4, is labeled as Feature 2 on map (Mehalchick *et al*. 1999:67 Figure 16).

Figure 4.5. Images from sampled sites: (a) overview of 41CV984, (b) close up of 41CV984, (c) overview of 41CV1657, and (d) close-up of 41CV1657 (Thoms *et al*. 2013).

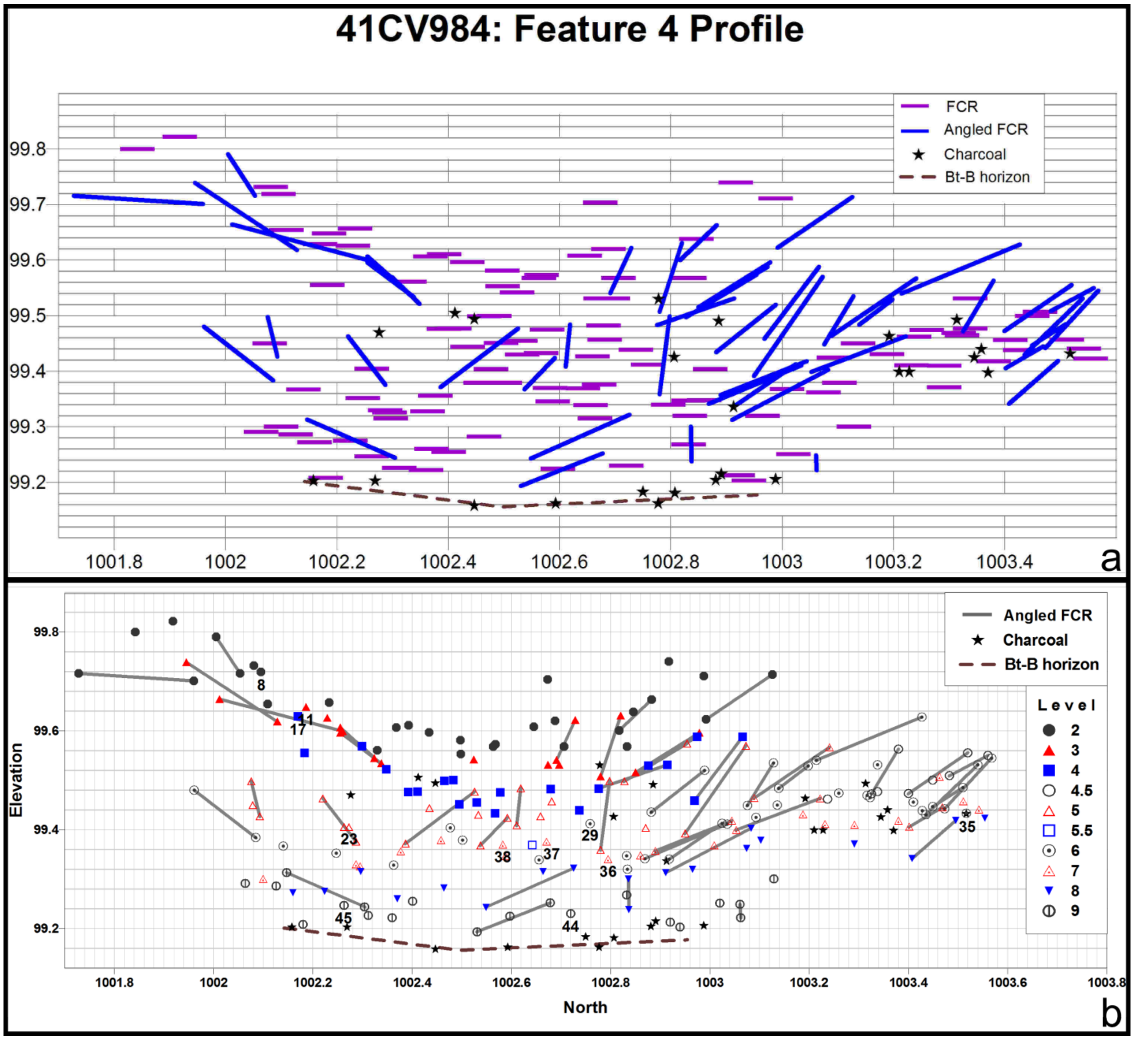


Figure 4.6. Profile of Feature 4 at 41CV984 showing (a) all FCR samples collected from the feature and (b) levels and FCR analyzed for microfossils (Thoms *et al*. 2013).

41CV1657 (Gully Mouth) 41CV1657 (Figures 4.5, 4.7-4.11) was located at the mouth of a small drainage basin south of Cottonwood Creek (Thoms *et al*. 2013). Four features, one large and three small, were exposed during road-improvement construction project. Each of these ovens was sampled for microfossils, including starch (Table 4.1). All features were buried 0.4-1 m below the surface in gravelly clay loam colluvium (Thoms *et al*. 2013). Four radiocarbon ages were acquired from 3 features ranging from 1060+/-40 B.P. to 2750+/-40 B.P. (Table 4.2). While 41CV1657 yielded a large amount of charcoal, oak (*Quercus* sp.) was the only identified genus (Leslie Bush, personal communication 2010).

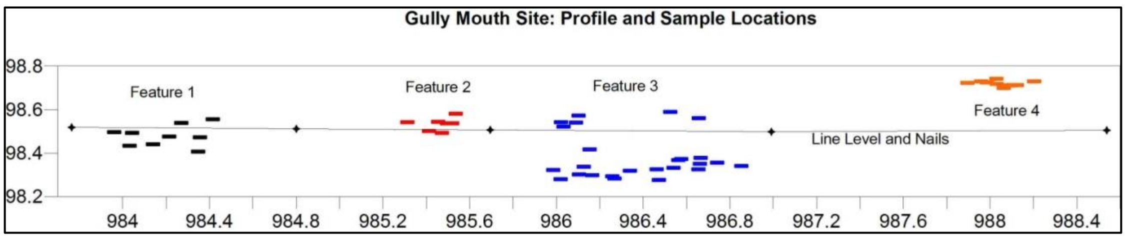


Figure 4.7. Features sampled at 41CV1657 (Gully Mouth) (Thoms *et al*. 2013).

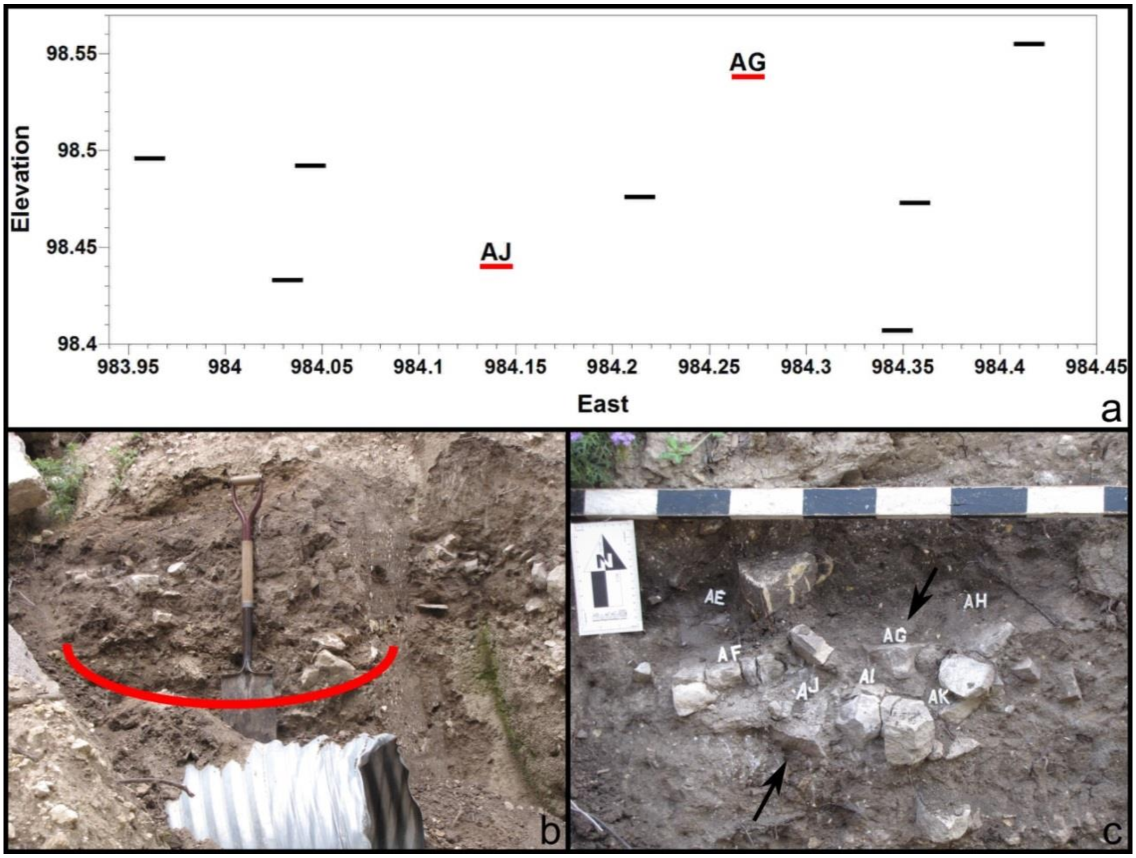


Figure 4.8. Feature 1 from 41CV1657: (a) FCR samples collected from feature (labeled samples indicate samples analyzed for microfossils), (b) Feature 1 (underlined in red) in cut bank, and (c) image of Feature 1 with samples labeled in the field (Thoms *et al*. 2013).

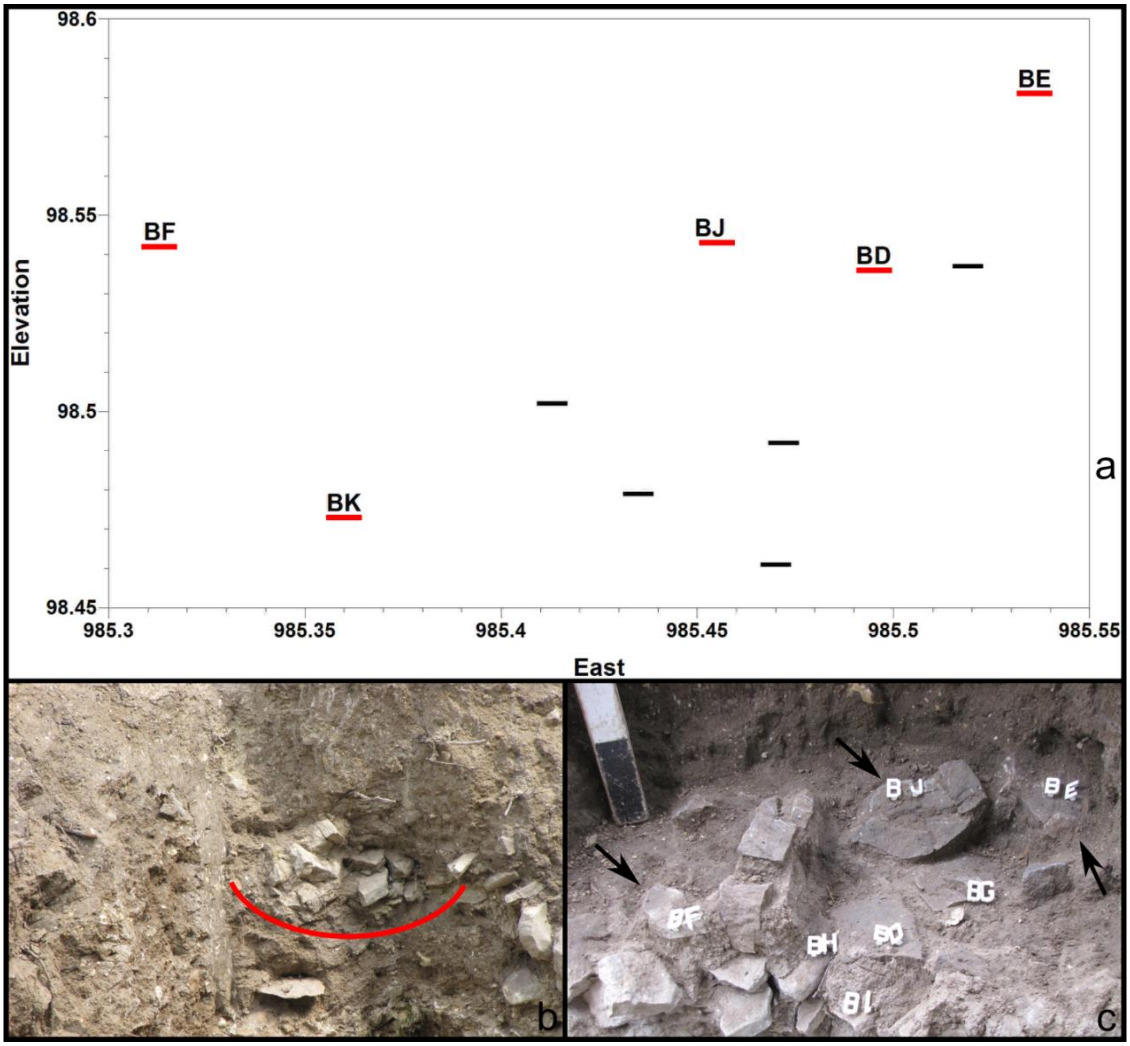


Figure 4.9. Feature 2 from 41CV1657: (a) FCR samples collected from feature (labeled samples indicate samples analyzed for microfossils), (b) Feature 2 in cut bank (underlined in red), and (c) image of Feature 2 with samples labeled in the field (Thoms *et al*. 2013).

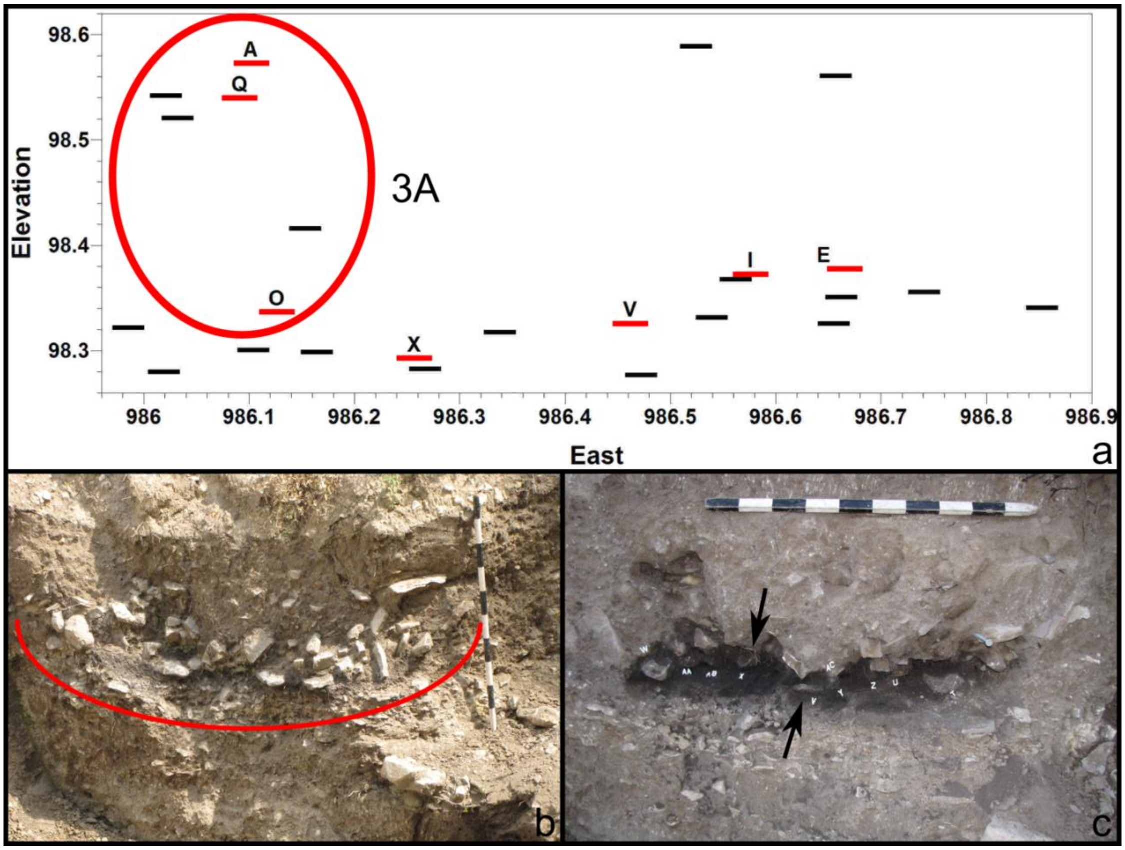


Figure 4.10. Feature 3 and possible Feature 3A from 41CV1657: (a) FCR samples collected from feature (labeled samples indicate samples analyzed for microfossils) where samples Q and A are located in possible Feature 3A, (b) Feature 3 in cut bank (underlined in red), and (c) image of Feature 3 with samples labeled in the field (Thoms *et al*. 2013).

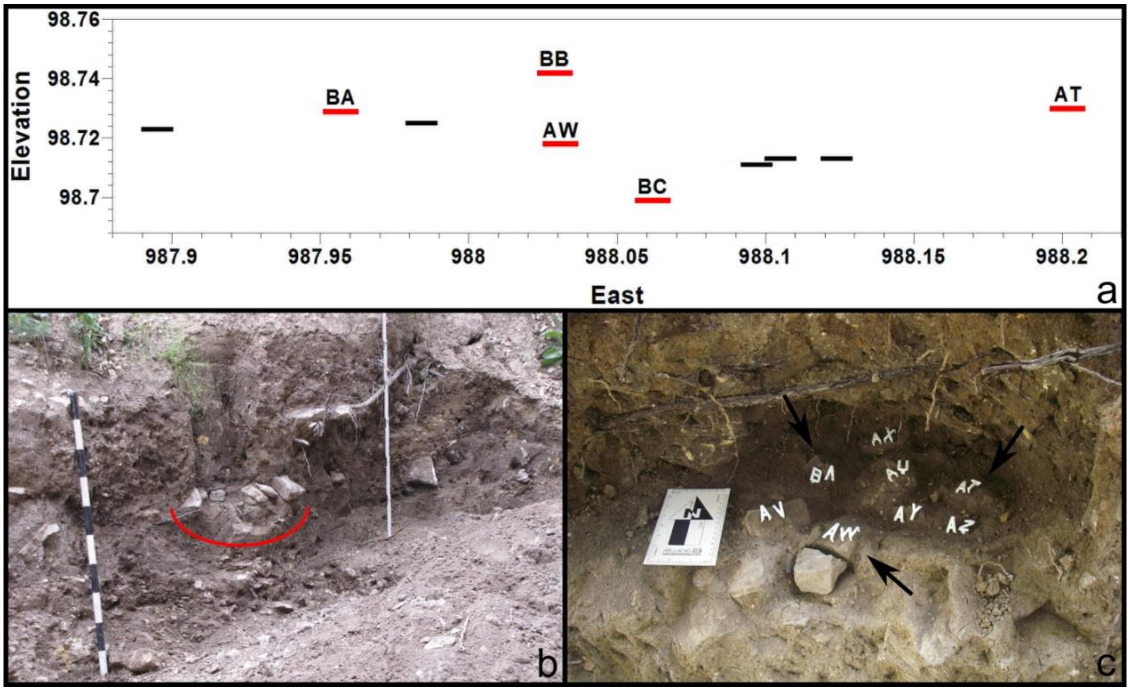


Figure 4.11. Feature 4 from 41CV1657: (a) FCR samples collected from feature (labeled samples indicate samples analyzed for microfossils), (b) Feature 4 in cut bank (underlined in red), and (c) image of Feature 4 with samples labeled in the field (Thoms *et al*. 2013).

Sites Excavated during the 2011-2012 Field Seasons

41CV594 Feature 2 was comprised of a large burned rock midden 15 m in diameter (Feature 2) with a fine sandy loam sediment matrix (Figure 4.12-4.17; Table 4.1). Note that the field profile drawings in figure 4.12-4.15 were only available at the time of this writing and are to be redrawn for Thoms *et al*. (2013). Seven distinct features were identified within the midden (Features 2a-2g). Charcoal recovered during earlier testing produced radiocarbon ages of 4350 +/- 60 BP, 4100 +/- 70 BP, 1520 +/- 70 BP, and 170 +/- 70 BP suggesting that people repeatedly built or used previously constructed earth ovens at this site for the last 4500 years (Quigg and Ellis 1994:258). During the 2011 field season, 255 wood charcoal specimens were recovered in flotation samples and identified to oak, yaupon (*Ilex* sp.), hackberry or hackberry family (Ulmaceae), and persimmon (*Diospyros* sp.) (Leslie Bush, personal communication 2012). Twenty-eight charred bulb scale fragments were also recovered. Only four of the bulbs were identifiable, all of which were identified to camas (*Camassia scilloides*). Three charred unidentified tuber fragments were also recovered (Leslie Bush, personal communication 2012).

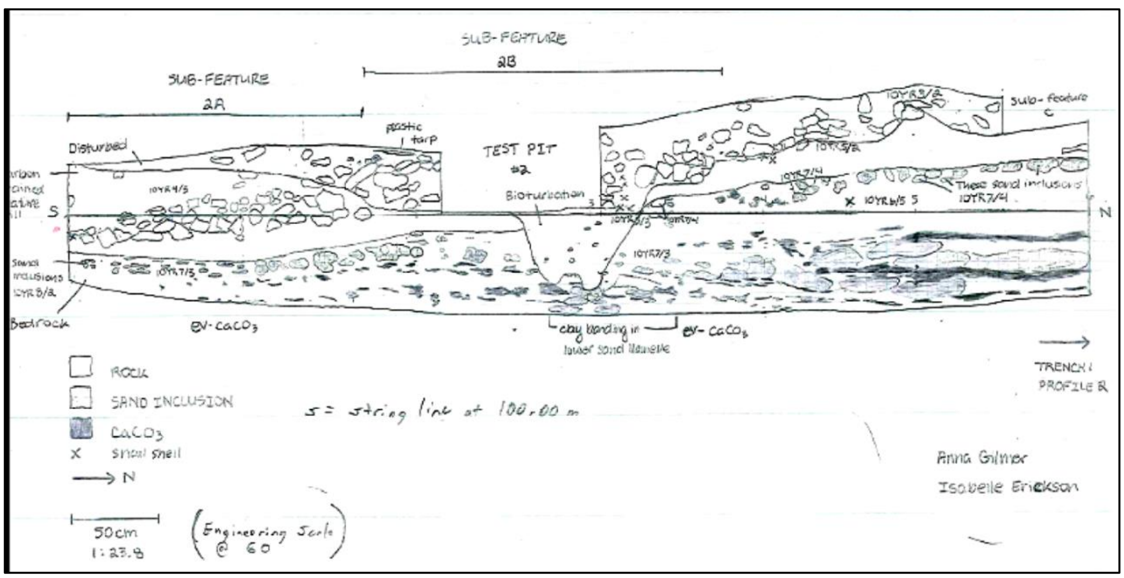


Figure 4.12. Field profile of features 2A-2B at 41CV594 (Thoms *et al*. 2013).

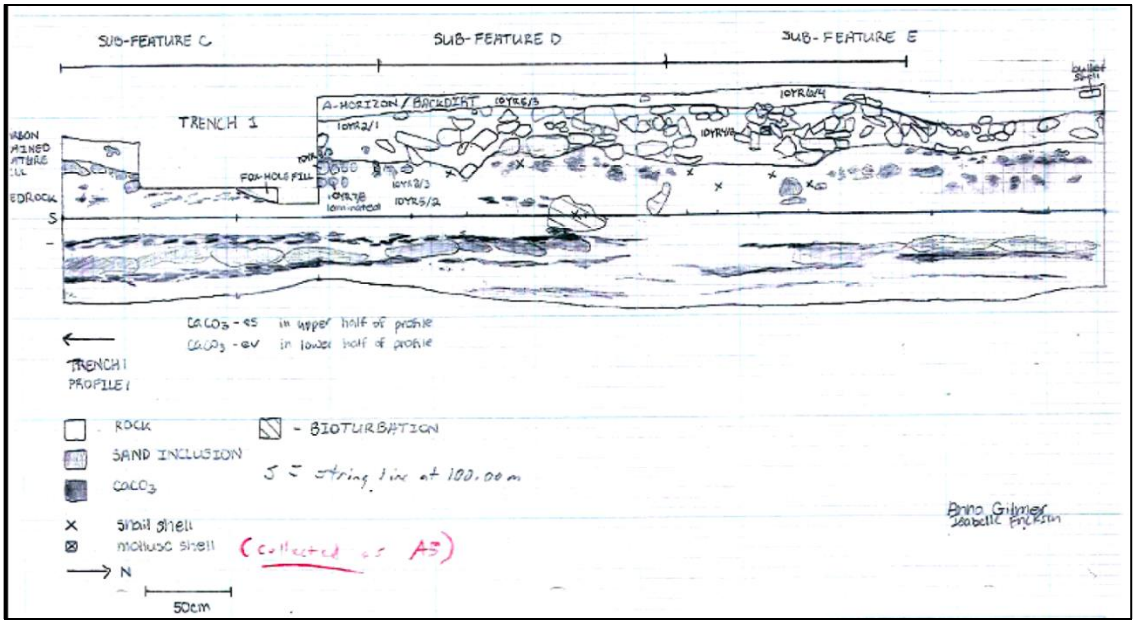


Figure 4.13. Field profile of features 2C-2E at 41CV594 (Thoms *et al*. 2013).

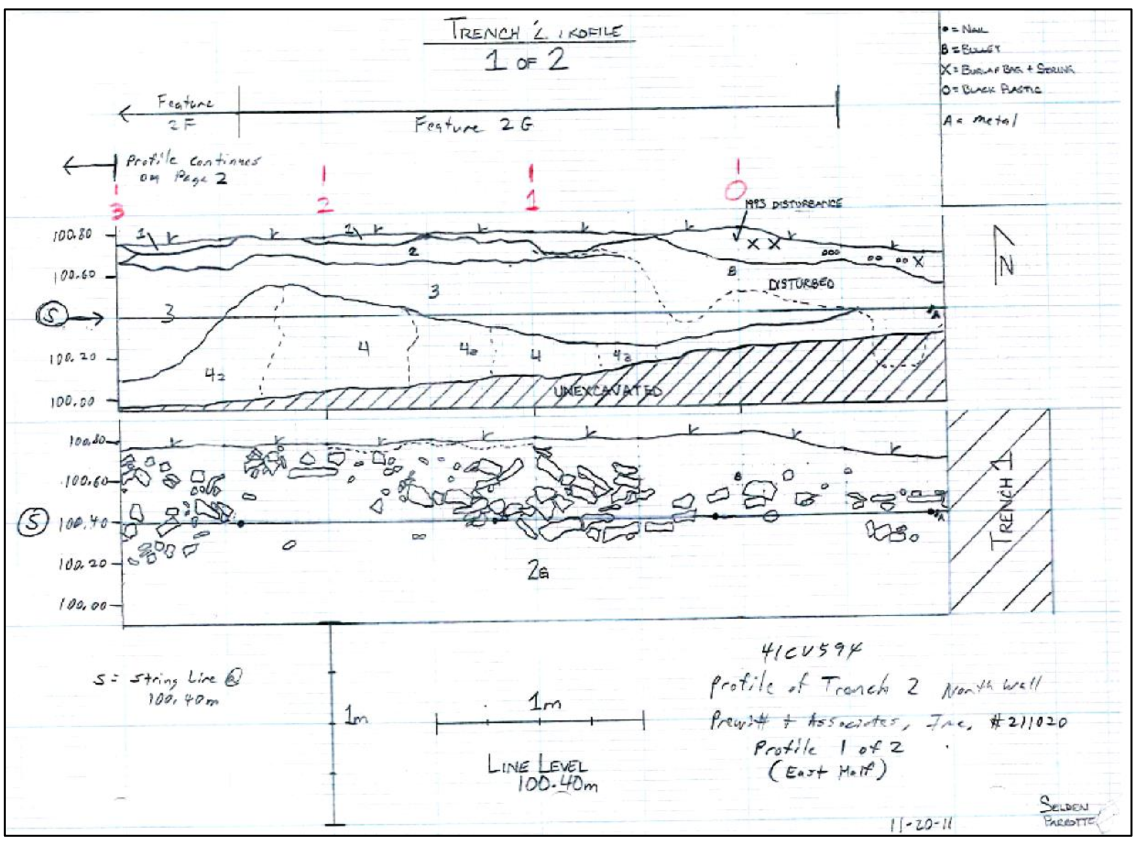


Figure 4.14. Field profile of Trench 2 at 41CV594 (Thoms *et al*. 2013).

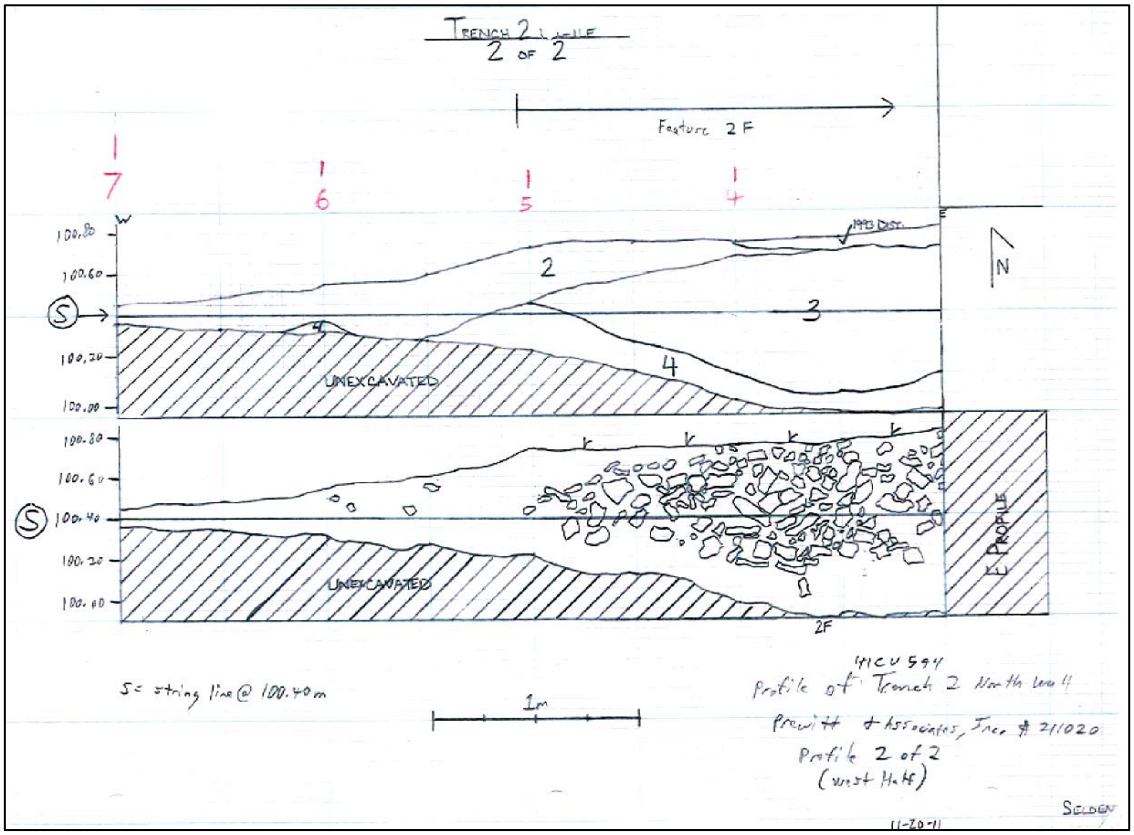


Figure 4.15. Profile of Trench 2 at 41CV594 (Thoms *et al*. 2013).


Figure 4.16. 41CV594 and surrounding area (image courtesy of Doug Boyd).

Figure 4.17. Images of (a) Test Pit 2 and (b-c) main trench at 41CV594.

41CV947 41CV947 (Figure 4.18-4.20) is located southwest of an unnamed tributary of Cowhouse Creek (Mehalchic *et al*. 1999:59). Previous testing of this site yielded 21 pieces of FCR, 28 flakes and 1 edge-modified flake (Mehalchic *et al*. 1999:60-61). Radiocarbon ages obtained during testing date the site to the Late Archaic with ages ranging from 1880 +/- 40 – 1370 +/-50 BP (Mehalchick *et al*. 1999:65). A total of six features were sampled for starch granule analysis from 41CV947 during the 2011 field season. Features 4, 6, 7, 8, and 9 had fine sandy loam sediments within the central pit, whereas Feature 5 had fine sandy loam sediments that were rich with organic material. Wood charcoal from plateau live oak, white group oak, and ash (*Fraxinus*) were recovered from the features. Furthermore, charred remains from two unidentified tuber fragments and a carbonized pecan (*Carya*) nut shell were also recovered in flotation samples (Leslie Bush, personal communication 2012).

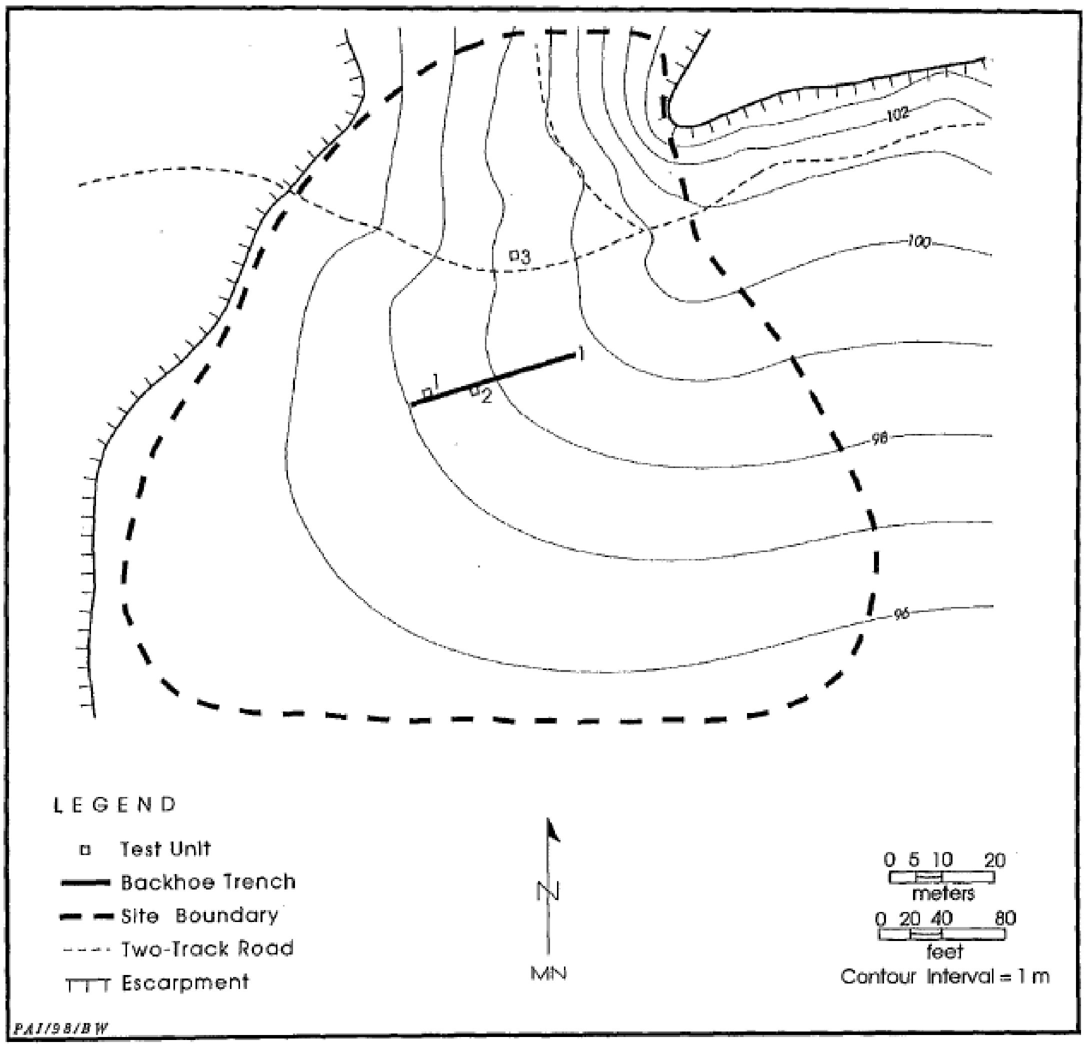


Figure 4.18. Site map of 41CV947 (Mehalchick *et al*. 1999:61 Figure 13).


Figure 4.19. 41CV947 and surrounding area (image courtesy of Doug Boyd).

Figure 4.20. (a) Feature 7, (b) Feature 5, and (c) overview of 41CV947.

41CV1104 Site 41CV1104 (Figure 4.21) is located in a road cut at the Two Year Old Creek water crossing. The site is located in clay loam sediments or silty clay of a T1 alluvial terrace of Cow House Creek. FCR from four earth oven features were sampled for starch granule analysis (Thoms *et al*. 2013). Two features were sampled in the west wall of the road cut. Feature 1 consisted of a small intact feature forming a shallow approximately 137 cm in diameter in the while Feature 2, also a shallow basin, was 125 cm in diameter. In the east wall of the road cut, Feature 3, partially destroyed during the construction of the road cut, was 50 cm below the surface and consisted of a flat lenticular earth oven 52 cm in diameter. Finally, Feature 4 was located about 90 cm below the surface of the east wall and formed a shallow basin 48 cm in diameter (Thoms *et al*. 2013). Only wood charcoal from plateau live oak and juniper (*Juniperus* sp.) were recovered from the features (Leslie Bush, personal communication 2012).

Figure 4.21. Features (a) 1 and 2, (b) Features 3 and 4, and (c) overview of 41CV1104.

41CV1553 A total of four features were excavated and samples for starch granules from 41CV1553 (Figures 4.22-4.23). All features were located within a fine sandy loam with limestone gravels. Previous testing at 41CV1553 yielded eleven charred bulb fragments and one tuber fragment. One of the bulb fragments was identified as wild onion/garlic (*Allium* sp.) and the tuber fragment was identified as scurfpea (*Pediomelum* sp.) (Leslie Bush, personal communication 2012). Wood charcoal recovered in flotation samples from the 2011 field season were identified to red group oak, unspecifiable oak, and juniper. Finally, a total of seven charred bulb scale fragments were recovered, two of which were identified as camas. The remaining bulb fragments could not be identified to a specific taxon (Leslie Bush, personal communication 2012).

Figure 4.22. 41CV1553 and surrounding area (image courtesy of Alston Thoms).

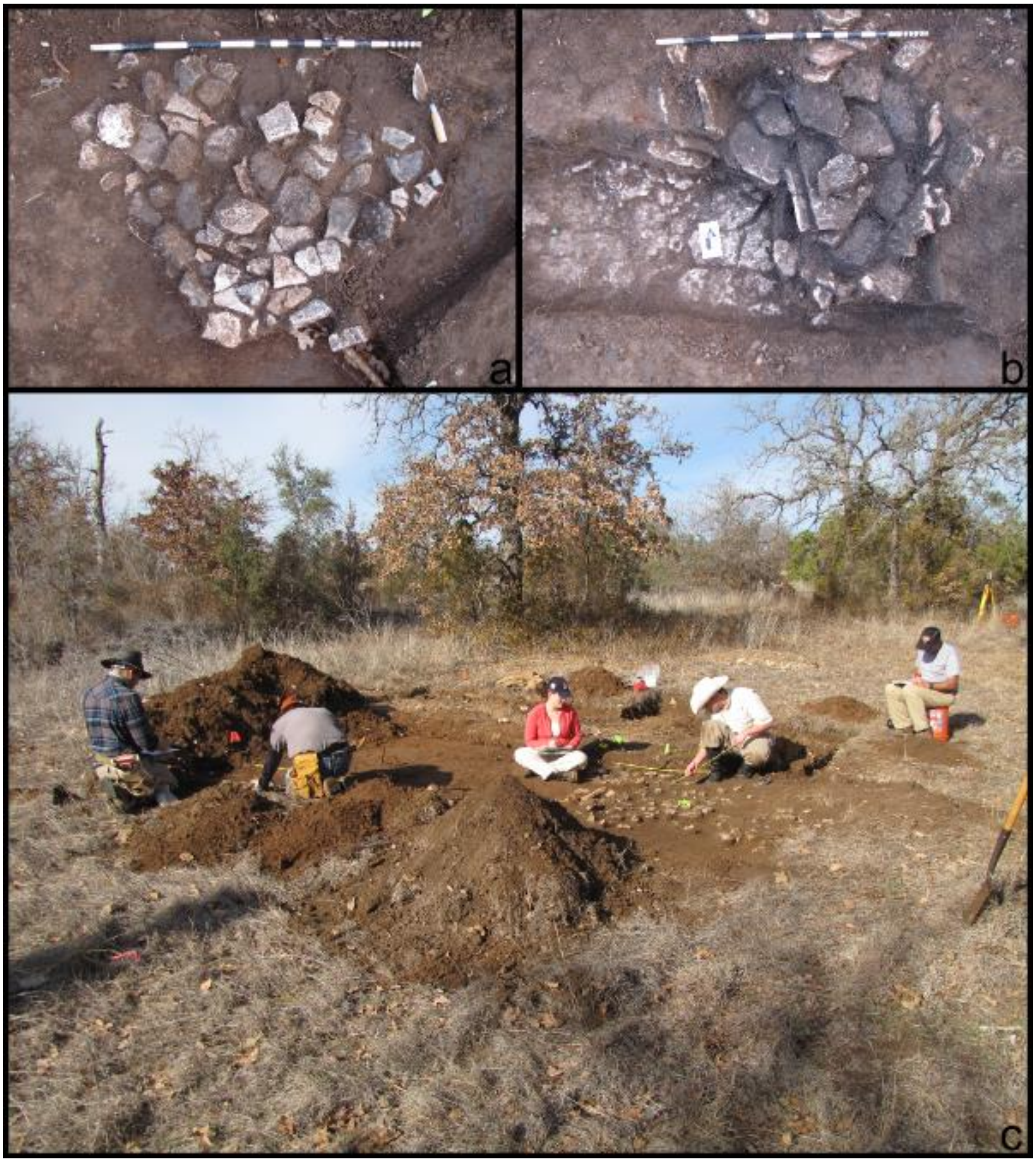


Figure 4.23. (a) Feature 8e, (b) Feature 6, and (c) overview of 8 at 41CV1553.

CHAPTER V

METHODS

This chapter presents the methods used in the Fort Hood case-study project (Thoms *et al*. 2011), focusing on the starch contamination control measures.

Reference Collection

Starch granules in the storage organs of thirteen wild plant foods—geophytes, hemicryptophytes, and succulents—were extracted and described for purposes of comparison with archaeological samples: (1) *Claytonia virginica* (eastern springbeauty); (2) *Smilax bona-nox* (greenbrier); (3) *Cooperia drummondii* (rain lily); (4) *Liatris mucronata* (narrow-leaf gay feather); (5) *Hypoxis hirsuta* (yellow star-grass); (6) *Nothoscordum bivalve* (false garlic); (7) *Habranthus tubispathus* (copper lily); (8) *Apios americana* (groundnut); (9) *Callirhoe involucrata* (winecup); (10) *Erythronium mesochoreum* (fawn lily; also known as dogtooth violet or trout lily); (11) *Pediomelum latestipulatum* (prairie turnip); (12) *Yucca baccata* (banana yucca); and (13) *Opuntia* sp. (prickly pear cactus). These species are among the wild plants known or suspected to have been important foods for the hunter-gatherers who occupied the Fort Hood landscape and vicinity in the distant past (Thoms 1994, 2004, 2008b, 2009b). Starch granules from two plants likely to have been used as packing material in earth ovens—*Quercus virginiana* (live oak leaves and acorns) and S*chizachyrium scoparium* (little bluestem grass seeds and stems)—were also extracted and described for purposes of comparison with archaeological samples. Since *Zea mays* (maize, aka corn) starch granules are common in many air samples, starch granules were also extracted from maize seeds for comparative purposes (Laurence *et al*. 2011). The above reference collection is on file at the Archaeological-Ecology Laboratory (AEL) at Texas A&M University.

Starch granules were extracted from all samples following procedures reported by Field (2006). Each specimen storage organ, leaf, or stem was bisected with a clean razor blade. For the plant-food storage organs, new toothpicks were used to scrape the inside of each storage organ. Two samples were taken from each storage organ, and the material on the toothpicks was smeared onto microscope slides and allowed to dehydrate. One sample was mounted with water for analysis and the other with Permount for curation purposes. For the live oak leaves and little bluestem grass stems, the interior of each sample was smeared directly onto microscope slides, allowed to dehydrate and then mounted separately with water and Permount.

Starch granules from maize, eastern springbeauty, false garlic, and rain lily storage organs and pollen were also observed under a scanning electron microscope (SEM). Starch from storage organs were smeared onto a carbon coated aluminum stub. To observe starch from pollen, the pollen from each species was sonicated and centrifuged to concentrate the recovered material. Once the material was concentrated, the material was transferred to an aluminum stub and allowed to dehydrate. All samples were vapor-coated with iodine-potassium-iodide (IKI) solution to allow better observation of starch with backscatter electrons (BSE) and during elemental analysis and mapping. Importantly, IKI solution only reacts with and coats on starch granules (Gott *et al*. 2006). After the samples were vapor-coated with IKI, they were coated with carbon to prevent charging of the samples during SEM observation. Observing starch granules under BSE confirms that the observed objects are starch granules, since the higher atomic mass of iodine, relative to the carbon background, produces more backscatter electrons thereby making the starch granules appear white against a black background (Petersen *et al*. 1983). Similarly, elemental analysis and mapping also indicates the presence of starch due to its ability to detect high concentrations of iodine and potassium that is the result of the reaction between IKI vapor and starch.

Curated Artifacts

The first stage of the ongoing project entitled "Geophyte Microfossil Investigations: Microscopic Assessments of Pre-Columbian Plant Use at Paluxy-Sand Sites, Fort Hood Military Reservation, Central Texas," Thoms *et al*. (2013) analyzed curated artifacts, sediment samples, and charred camas bulbs previously recovered from Fort Hood sites with well-preserved earth ovens. In all, nineteen artifacts were analyzed: (a) 5 groundstone tools; (b) 1 pitted stone; (c) 2 cores; (d) 1 hammerstone; and (e) 10 pieces of FCR from earth-oven heating elements.

All of the artifacts were first examined under a Wild M3Z Type-S microscope, at x6.5-x25 power, to identify potential residue deposits. Ideally, cooking residue shows up as dark-brown to black stains, sometimes tiny globs, on the surface or embedded in cracks and crevices. Residues were not observed on any of the samples. Since residues were not observed on the artifacts, two methods were employed to remove microfossils from the microcracks: (1) an initial method that entailed dislodging suspected residue from unwashed surfaces; and (2) a revised method wherein the area of the artifact to be sampled was rinsed with distilled prior to extracting residue.

The first method was a modified is a modified version of a pipette extraction method described by Fullagar (2006). Instead of using the tip of a pipette to dislodge microfossils from the surface of each sample, a sonicating toothbrush was employed to dislodge microfossils from microcracks on the surface in the samples' surfaces. For the groundstone tools, at least three surfaces were processed; including the ground face, the non-ground face, if such existed, and one broken edge, if present, as a "control" for post-use contamination. For the FCR samples, the upper and bottom sides were analyzed, as determined by a greater amount of calcium carbonate accumulation on the bottom sides and/or presence excavator-trowel marks on the upper surface. Once the residue was removed, the water containing it was transferred to 15 ml centrifuge tubes. They were then centrifuged at 2300 RPM for one minute, and the supernate was decanted. The remaining material was placed on a microscope slide where it was allowed to dehydrate under the cover of a sterile Petri dish so as to avoid airborne contamination. Once dehydrated, the samples were mounted in Permount for curation purposes (Field 2006).

After it was determined that most of the artifacts were probably contaminated by airborne starch granules or recent anthropogenic means, Thoms *et al*. (2010) adjusted the processing methods for the remaining artifacts by first gently washing them with distilled water as described by Laurence *et al*. (2011) and Messner (2011:57), and following up with the same steps described above. In one case, (Sample 9), adhering sediments were removed by means of a dry brushing rather than with water.

FCR from 41CV984 and 41CV1657

From site 41CV984, 50 FCR samples and their associated sediment, which either adhered to the bottom side of a given sample or was scraped from the sediment immediately underlying a given sample and clearly indicated by that rock's imprint upon removal, were collected (Thoms *et al*. 2013). As each FCR sample was removed from their respected features in the field, the tops of the samples were clearly marked with a pattern of scrapes from a trowel so as to distinguish them in the lab. Control samples were also taken to assess the amount of possible contamination at the site, including: (a) 4 sediment samples below level 9 at the B/T horizon; (b) 1 control sample (exposed bedrock); (c) 8 on-site (off feature) sediment samples; (d) 8 off-site sediment samples; and (e) 3 air samples. From 41CV1657, FCR samples and their associated sediment samples, along with 6 control samples (rocks), and 2 air samples were collected (Thoms *et al*. 2013). All samples were collected using powder-free latex gloves.

About 20 percent of the samples from Feature 4 at 41CV984 were processed and analyzed, including FCR (n=11) and associated sediment for each excavated level and several control samples. Approximately 30 percent of the recovered samples from 41CV1657 were process and analyzed, including FCR and associated sediment from Features 1-4 (n=21) and several control samples (Thoms *et al*. 2013). FCR from both 41CV984 and 41CV1657 were chosen based on their location within a feature or level (e.g. center and off-center FCR) so different locations within the features or levels were represented in the analysis (Thoms *et al*. 2013).

To process the FCR samples for microfossils, each sample was washed in distilled water to remove post-depositional contamination. A 1 cm^2 area of calcium carbonate ($CaCO_3$) was removed using sterile dental picks from the top and bottom surfaces of each sample and dissolved in glacial acetic acid (Figure 5.1), which required 1-3 weeks. The use of glacial acetic acid was used since it has a slow dissolve rate that does not adversely harm starch granules until they are exposed to the acid for at least one month. Once dissolved, the glacial acetic acid was removed by adding distilled water, centrifuging, and decanting three times. The remaining material was mounted slides with a 50:50 ratio of water and glycerin or in Permount for curation (Thoms *et al*. 2013).

Thoms *et al*. (2013) extracted microfossils from calcium carbonate deposits since those deposits began to form immediately after a given baking event, with decomposition of the packing material and normal soil illuviation. As per their working model, microfossils and other organic matter, along with minerals in the sediment, move down the profile and a portion thereof is deposited on the underlying FCR rocks and in sediment. As argued, the abundance of calcium carbonates protects the microfossils from consumption by soil micro-organism. Accordingly, microfossils embedded in the calcium carbonate deposits represent many different events during and, presumably, long after since the ovens were abandoned. To assess whether microfossils were embedded in crevices beneath the calcium carbonate deposits, Thoms *et al*. (2013) also sampled the surface of two pieces of FCR after removing the calcium-carbonate coat using the pipette extraction technique described by Fullagar (2006: 196). The slides were also mounted in 50:50 ratios of water and glycerin or in Permount (Thoms *et al*. 2013).

Three non-cultural rocks, two on-site and one off-site, were collected and processed as control samples from 41CV1657 while one on-site non-cultural rock was processed from 41CV984 (Thoms *et al*. 2013). These samples were processed by first washing each sample in distilled water to remove modern contamination. Both sides of each sample were processed by adding a drop of water to the sample locations, which were about 2 cm in diameter, and using a sonicating toothbrush to dislodge potential microfossils from the microcracks. The material was pipetted off and placed into 15-ml test tubes where they were centrifuged at 2300 revolutions per minute (RPM) to concentrate the material. The supernate was decanted and the remaining material was mounted on microscope slides with water.

Following suggestions in Loy and Barton (2006), the air at and near 41CV984 and 41CV1657 was sampled during our excavation work by leaving sterile 9-cm petri dishes, each containing a lens of distilled water, at ground level for several hours (Laurence *et al*. 2011). Three of the air samples, exposed for 2, 7, and 8.5 hours were taken onsite in the grasslands around 41CV984 and two of the samples, exposed for 8 hours, were taken off-site in a wooded area at 41CV1657. When the petri dishes were collected, the water was pipetted and placed in sterile 15-ml test tubes. Samples were centrifuged, the supernate decanted, and the remaining material, was placed directly on slides for analysis using Permount as the mounting medium so as to curate the slides.

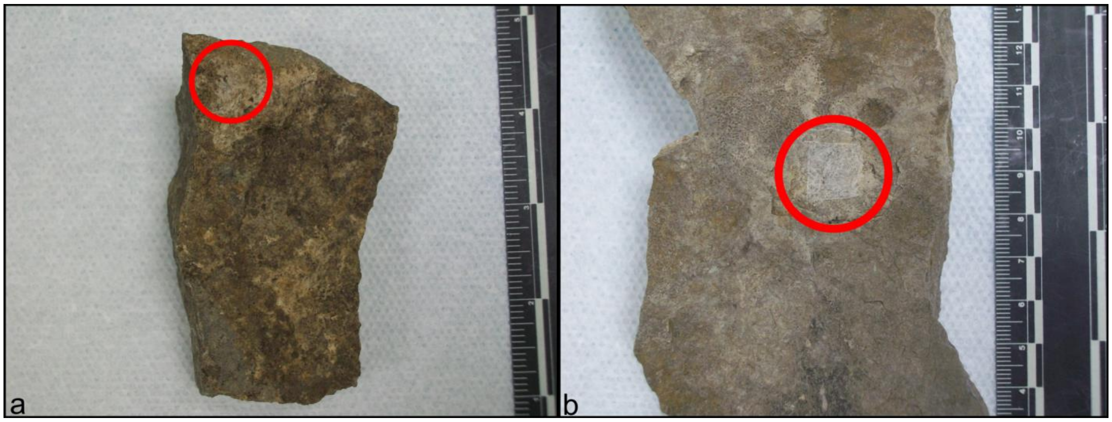


Figure 5.1. FCR samples after processing for microfossils: (a) 41CV984 and (b) 41CV1657 Feature 3A. Red areas indicate sampled locations (Figure courtesy of AEL, Thoms *et al*. 2013).

FCR from 41CV594, 41CV947, 41CV1104, and 41CV1553

FCR collected at site 41CV594, 41CV947, 41CV1104, and 41CV1553 were collected following the same field methods used at 41CV984 and 41CV1657. All artifacts were collected in situ using powder-free latex gloves and a trowel that was cleaned between each sample using rubbing alcohol. Once removed from the sediment matrix, all artifacts were immediately sealed in a sterile zip-lock bag along with their associated sediments. Air samples and off-site non-cultural rock control samples buried in sediments similar to those of the features were also taken at or near each site.

Calcium carbonate deposits were not readily visible on FCR from these sites. Therefore, once the pieces of FCR were washed with distilled or filtered water, they were processed using a sonicating toothbrush. An area of 26.4 cm^2 was sampled from the top and bottom of each artifact in an attempt to increase the number of recovered starch granules. In the rare cases when $CaCO_3$ deposits were available, all of the $CaCO_3$ within the delaminated 26.4 cm^2 area were sampled and dissolved in glacial acetic acid. Once the $CaCO_3$ was removed, the surface underneath the carbonates was sampled using a sonicating toothbrush. Off-site control samples were processed using the same methods as the artifacts. Importantly, all samples from each of these sites were processed under a clean bench with a 0.5 µm filter to minimize airborne starch contamination in the lab (Laurence *et al*. 2011). Fire-cracked-rock samples from all of these sites were chosen based on their location within their respected features so that multiple sampling locations were represented in the analysis.

The size of the sampling area was increased from 1 cm^2 to 26.4 cm^2 for two reasons. First, the relatively low recovery of starch granules recovered from individual FCR from 41CV984 and 41CV1657 prompted Thoms *et al*. (2013) to increase the sampling area in an attempt to increase the number of recovered starch granules, since other things being equal, the greater the surface area, the greater the number of accumulated starch granules. Second, if the model purposed by Thoms *et al*. (2011) is correct and starch granules become trapped in calcium carbonate deposits, then calcium carbonate deposits should have the greatest concentration of starch granules on a given artifact. Since the FCR from these sites lack large concentrations of calcium carbonate deposits (i.e. areas with high concentrations of starch granules), increasing the sampling area may compensate for the lack of concentrations. Finally, a clean bench was used during all stages of FCR processing because one became available for the AEL and Palynology Research Laboratory (PRL) at Texas A&M University.

A total of 20 pieces of FCR, including 4 $CaCO_3$ samples, 3 off-site control samples, and 3 air samples were analyzed from 41CV594. Eight pieces of FCR, 4 off-site samples, and 3 air samples were analyzed from 41CV947. Six pieces of FCR, 2 off-site samples, and 2 air samples were analyzed from 41CV1104. Finally, 13 pieces of FCR, including 4 $CaCO_3$ samples, 3 off-site samples, and 3 air samples were analyzed from 41CV1553.

Evaluation of Starch Contamination Control Methods

To evaluate the effectiveness of the contamination control methods employed at all stages of artifact recovery and processing, the recovered starch assemblages from each site were compared. These methods include using powder-free latex gloves to prevent transmission of starch granules from the hands to the artifacts, dry brushing or light washing to remove loosely adhering starch granules that may have been deposited as contamination, processing a controlled area to obtain starch concentration values, processing sides of groundstone artifacts (in the case of the curated samples) with freshly broken edges (sides that were not used to process plant material) to gauge contamination, the use of a sonicating toothbrush to dislodge starch granules housed in microcracks, processing $CaCO_3$ deposits since they provide a sheltered environment for starch granules, the use of air samples to control for airborne contamination, and the use of non-cultural rock samples to control for contamination in the past. Finally, artifacts collected from different rounds of field work were collected and processed using different methods as new challenges were encountered or new technologies became available. A comparison of contamination control methods is displayed in Table 5.1.

Table 5.1. Comparisons of methods used during artifact collection and processing.

Method	Curated Artifacts	41CV984	41CV1657	41CV594	41CV947	41CV1104	41CV1553
Collected with Powder-Free Gloves	No	Yes	Yes	Yes	Yes	Yes	Yes
Processed with Powder-Free Gloves	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dry Brushing	Some	No	No	No	No	No	No
Wash	Some	Yes	Yes	Yes	Yes	Yes	Yes
Use of a Clean Bench	No	No	No	Yes	Yes	Yes	Yes
Processed a Controlled Area	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Processed Broken Edge	Yes	No	No	No	No	No	No
Used Sonicating Toothbrush	Yes	No	No	Yes	Yes	Yes	Yes
Processed CaCO3	Some	Yes	Yes	Some	No	No	Some
Air Samples	No	Yes	Yes	Yes	Yes	Yes	Yes
Control Samples	No	Yes	Yes	Yes	Yes	Yes	Yes

Laboratory Space and Equipment

Two laboratories in the Department of Anthropology at Texas A&M University (AEL and PRL) were used in these experiments. Both labs were tested for airborne contamination as were materials used during various stages of starch granule analysis. To test for possible starch contamination, sterilized petri dishes with a thin layer of distilled water were placed in both labs for two consecutive periods of 48 hours. The water was pipetted out of the petri dishes into 15 ml test tubes and centrifuged to concentrate any trapped material. After the supernate was decanted, the remaining material was mounted on a slide with Permount for analysis.

Laboratory supplies tested for starch granules included unused sterile 15 ml and 50 ml test tubes, microscope slides, coverslips, zinc bromide, 400 ml and 1000 ml beakers, pipettes, sonicating toothbrush heads, powder-free gloves, one-dram vials, Permount, and distilled water. Slides and coverslips from open and unopened boxes were examined for starch using a polarized-light microscope. To test the distilled water (DI), a 50 ml test tube was rinsed with ethanol to remove potential contamination and allowed to dry. Once dry, 50 ml of DI water was added to the test tube, centrifuged and decanted. The remaining material was mounted on a previously cleaned microscope slide. Since microscope slides and coverslips were potential contamination sources, a slide and coverslip were rinsed with ethanol to remove potential contamination and allowed to dry before the material from the water was placed onto the slide. Once it was determined that the distilled water was free of starch, it was used in testing microscope slides and coverslips out of un-opened boxes.

CHAPTER VI

RESULTS

Reference Collection

There is a wide range of diversity in the morphological types of starch granules from each investigated species. Each sample is described below following terminology in Reichert's (1913) starch granule classification scheme. Table 6.1 presents size and morphological characteristics for each species. Brightfield and SEM micrographs of the reference samples are displayed in Figures 6.1 and 6.2.

Lily (Liliaceae) Family USOs Starch granules in the bulbs of four lily-family species in this reference collection are morphologically similar/indistinguishable: false garlic (*Nothoscordum bivalve*), rain lily (*Cooperia drummondii*), and copper lily (*Habranthus tubispathus* (copper lily). USOs from these lily-family plants generally exhibit lenticular or kidney-shaped morphologies, although elongated granules are common for granules smaller than five microns. Visible eccentric hila (i.e., visible under transmitted non-polarized light) are typical with y-shaped fissure. Lamellae, which appear as concentric rings, are characteristic of all starch granules from these species. Most granules have a diagnostic rounded protrusion near the hilum which separates starch from these species apart from any of the other investigated species.

Dogtooth Violet (Erythronium mesochoreum) Dogtooth violet (also known as fawn or trout lily) bulbs contain both simple and semicompound starch granules. Although dogtooth violet is a member of the lily family, its starch granules exhibit different characteristics and morphology than the above taxa. The simple granules are generally exhibit a visible eccentric hilum with inverted cone morphology. Visible lamellae (visible under polarized and brightfield illumination) are common, as are fissures radiating from the hilum. Semicompound granules have centric to eccentric hila, and are generally faceted on one surface. Visible lamellae are present but rare in semicompound granules.

Eastern Springbeauty (Claytonia virginica) Eastern springbeauty is a member of the Portulaceae family. Starch granules from tubers of this species have a wide range of morphological variation. The most common type is a round granule with two faceted sides converging with each other. Visible lamellae and hila are rare, although they are present on larger granules (20 µm and larger). When viewed under polarized light, the hilum is centric.

Narrow-leaf Gayfeather (Liatris mucronata) Narrow-leaf gayfeather is a member of the Asteraceae faimliy. Starch granules from the tap roots are polyhedral in shape. They have eccentric hila with individual or y-shaped fissures. Although compound starch granules are present, simple (single) granules are much more common. The region opposite the hilum appears to be constricted or “pinched” when compared to the rest of the granule.

Greenbrier (Smilax bona-nox) Greenbrier is a member of the Smilanaceae family. Most starch granules in the rhizomes (i.e., root nodes) are either round or faceted on one side but, here too, there is a wide range of morphological variability. Visible centric hila and lamellae are predominant on nearly all granules. Both simple (individual) and compound starch granules are common. This description of starch granules from greenbrier is consistent with that of Messner (2011).

Yellow-star Grass (Hypoxis hirsuta) Strach granules from corms of this Liliaceae family plant are common and occur as simple and cluster granules. Most granules are oval in shape or faceted along two or three sides. Visible hila are present and slightly eccentric, while visible lamellae are rare. The granules often have equatorial grooves, which sets them apart from the other investigated species.

Groundnut (Apios americana) Groundnut is a member of the Fabaceae family. Starch granules from tubers of this plant are unique when compared to those from the other investigated species. Visible lamellae are rare; eccentric hila are usually visible. Starch granules are elongated and irregular in morphology (they do not conform to a specific shape). They are diagnostically much longer than they are wide, which results from a lateral extension opposite the hilum that is comet-like in appearance. Y-shaped fissures are common. This description is similar to that of Messner (2011) and Richert (1913:219).

Winecup (Callirhoe involucrata) Starch granules from taproots of this Malvaceae plant have simple, compound, or semicompound forms. Simple granules have visible eccentric hila, single and y-shaped fissures, and are cone-shaped, although wedge-shaped granules also occur. Round granules with centric hila occur, but are not as common as eccentric granules. Compound and semicompound granules are faceted on one or more surfaces. Visible lamellae are common in all types of granules.

Prairie Turnip (Pediomelum latestipulatum) Starch granules in prairie turnip tubers (Fabaceae family) have eccentric hila with transverse clefts, fissures radiating from the hilum, visible lamellae, and are faceted on at least one side. Simple and semicompound granules are common, with simple forms prevailing. Granules often have a rough, pock-marked surface. These descriptions are consistent with Messner (2011) except that Messner describes the granules as having non-visible lamellae.

Banana Yucca (Yucca baccata) Yucca is a member of the Agavaceae family. Starch granules from the flower pods, stalks, and leaves are characterized by their polyhedral shape. Visible hila are centric to slightly eccentric and are located within a round depression, which has the appearance of a volcano crater. Visible lamellae are rare. Y-shaped and single fissures are common.

Prickly Pear (Opuntia sp.) Prickly pear is a member of the Cactaceae family. Starch granules from the pads, seeds, and tunas have a wide range of morphologies. Smaller starch granules (~ 5µm) are hexagonal in polar view and have centric hila with visible lamellae. Starch granules larger than 5µm have a wide range of morphologies ranging from rounded, faceted on all sides, to irregular that have eccentric hila and y-shaped fissures.

Live Oak (Quercus virginiana) Live oak (Fagaceae family) starch granules from acorns and leaves are most commonly spindle-shaped with a transverse cleft. The hilum is visible in granules that do not have a transverse cleft. Lamellae are common. Compound starch granules also occur in live oak but are not as common as spindle-shaped granules.

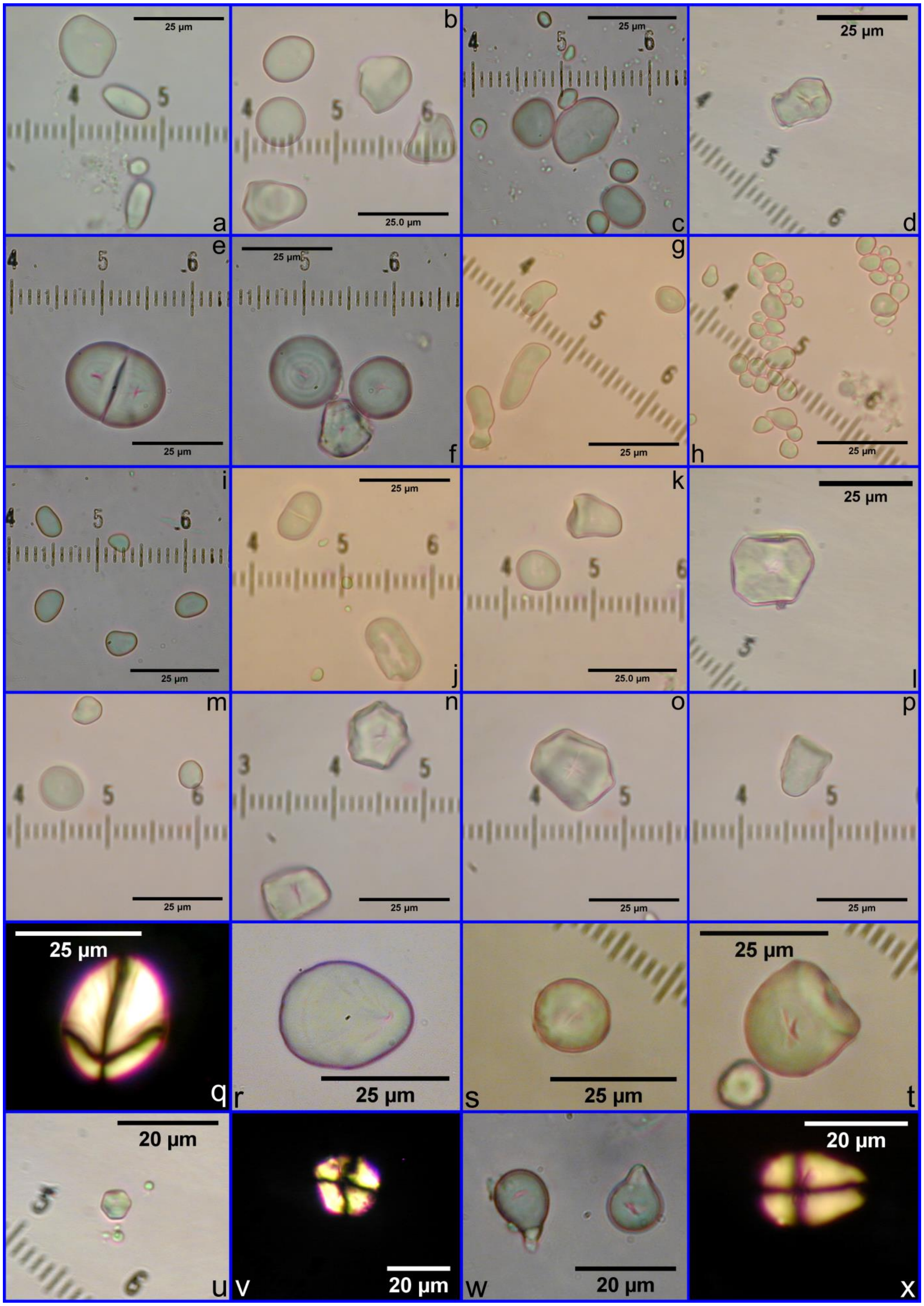
Little Bluestem Grass (Schizachyrium scoparium) Starch granules in little bluestem grass (Poaceae family) stems and seeds granules have more or less centric hila and are often spherical to slightly ovoid or faceted on all sides. Fissures radiating from the hilum are common and visible lamellae are sometimes present. Compound and semicompound granules occur, but are not as common as simple granules.

Maize (Zea mays) Starch granules from maize (Poaceae family) seeds have a wide range of variation. Although polyhedral granules predominate, round and ovoid granules are also common. Visible hila with y-shaped fissures are predominant and visible lamellae are rare.

Table 6.1. Summary descriptions of starch reference collection.

Scientific Name	Common Name	Size of Starch Granules	Description of Starch in Storage Organ
Habranthus tubispathus	Copper lily	2.5 - 25 µm	compound to simple granules, elongated, lenticular and kidney-shaped granules, visible hilum, x-shaped to single fissures, visible lamellae (Figure 6.1a)
Claytonia virginica	Eastern springbeauty	5 - 25 µm	round to faceted, presence of fissure radiating out of hilum, eccentric hilum, visible lamellae is rare (Figure 6.1b)
Nothoscordum bivalve	False garlic	5 - 40 µm	visible lamellae, lenticular and kidney-shaped, visible hilum, eccentric hilum, various shapes of fissures (Figure 6.1c)
Liatris mucronata	Narrow-leaf gay feather	10 - 25 µm	polyhedral shaped, visible hilum, eccentric hilum, y-shaped to single fissures, compound and simple granules (Figure 6.1d)
Smilax bona-nox	Greenbrier	5 - 25 µm	visible lamellae, centric hilum, round to polyhedral shaped (generally faceted on one or two surfaces), compound and single granules, y-shaped fissures (Figure 6.1e-f)
Cooperia drummondii	Rain lily	5 - 25 µm	elongated, faceted, lenticular and kidney-shaped granules, eccentric hilum, visible lamellae, compound to simple granules (Figure 6.1i)
Apios americana	Groundnut	5 - 25 µm	eccentric hilum, irregular shape (generally long and thin), visible lamellae are rare, y-shaped fissures are common (Figure 6.1g-h)
Hypoxis hirsuta	Yellow-star grass	2.5 - 25 µm	visible hilum, eccentric hilum, presence of fissures, elongated and faceted, compound to single granules (Figure 6.1j-k)
Yucca baccata	Banana yucca	10 - 25 µm	centric to slightly eccentric hilum, visible lamellae are rare, polyhedral granules (Figure 6.1l)
Callirhoe involucrata	Winecup	5 - 25 µm	simple, compound, and semicompound granules, visible eccentric hilum, single and y-shaped fissures, cone and wedge-shaped, round and faceted granules are also present (Figure 6.1w-x)
Erythronium mesochoreum	Dogtooth violet	5 - 50 µm	simple and semicompound granules, visible eccentric hilum, inverted cone morphology, visible lamellae, fissures are common (Figure 6.1q-r)
Pediomelum latestipulatum	Prairie turnip	2.5 - 25 µm	visible eccentric hila, transverse cleft, fissures, visible lamellae, faceted on one or more side, simple and compound granules, have rough, pock-marked surface (Figure 6.1s-t)
Opuntia sp.	Prickly pear cactus	5 - 25 µm	simple granules, small granules are hexogonal in shape, centric hila, visible lamellae, large granules are hexogonal, rounded, and irregular, centric hila, and y-shaped fissures (Figure 6.1u-v)
Zea mays	Maize	5 - 25 µm	round, ovoid, and polyhedral shaped granules, visible hilum, centric to eccentric hilum, y-shaped fissures (Figure 6.1m-p)

Figure 6.1 Modern starch granules from: (a) copper lily, (b) eastern springbeauty, (c) false garlic, (d) narrow-leaf gay feather, (e-j) greenbrier, (g-h) groundnut, (i) rain lily, (j-k) yellow-star grass, (l) yucca, (m-p) maize, (q-r) dogtooth violet, (s-t) prairie turnip, (u-v) prickly pear, and (w-x) winecup. Micrographs a-p, r-t, u, and w are under brighfield light whereas micrographs q, v, and x are under cross-polarized light.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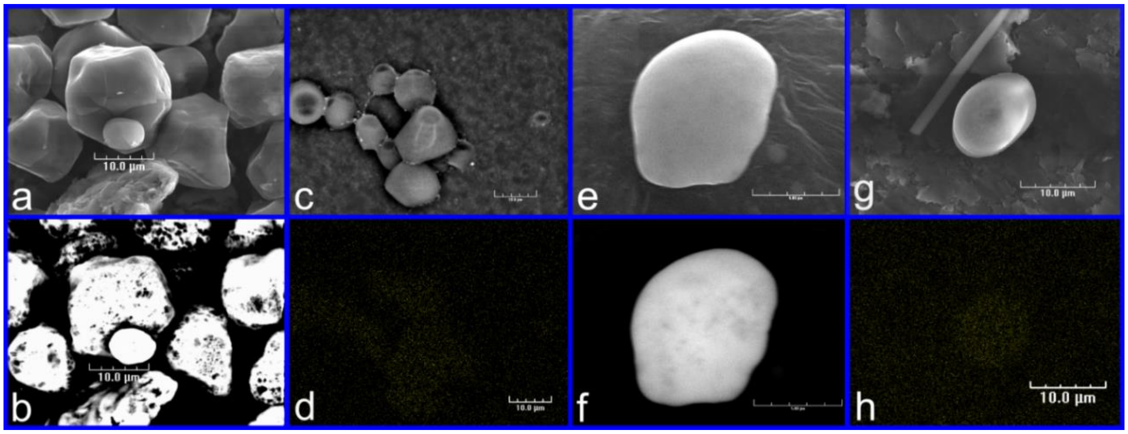


Figure 6.2 Scanning electron micrographs of: (a-b) maize, (c-d) eastern springbeauty, (e-f) false garlic, and (g-h) rain lily. Micrographs a, c, e, and g were taken using SE while micrographs b and f were taken using BSE. Micrographs d and h are an elemental map of potassium and iodine, demonstrating that starch can be differentiated from other material by vapor coating samples with IKI solution. The bottom row micrographs are the same starch granules as those from the top row. Micrographs a-b were acquired 2700x magnification and operated at 15kV and a working distance (WD) of 15mm. Micrographs c-d were acquired at 1900x magnification operating at 15kV and a WD of 15 mm. Micrographs e-f were acquired at 8000x magnification operating at 25kV and a WD of 15 mm. Micrographs g-h were acquired at 3500x magnification operating at 15kV and a WD of 15 mm. Note the raphide in g.

Laboratory Space

All of the tools and chemicals used in processing artifacts were consistently starch-free with the exception of the powder-free gloves. The gloves used in the Archaeological-Ecology and Palynology Laboratory at Texas A&M University tested positive for maize starch (See Figure 3.8 in Chapter 6).

The Maize Dilemma

The fact that maize starch can be recovered from powder-free gloves proves to be a very formidable obstacle when conducting starch research. Furthermore, maize starch has a wide range of morphological variation (Figures 6.3-6.4), thus making it difficult to distinguish between maize and other taxa (Figure 6.4). When looking at the starch granules recovered from a maize seed in Figure 6.4c compared to the copper lily (*Habranthus tubispathus*) starch granules in Figure 6.4a as indicated by the black arrows, starch granules from both taxa have lenticular granules with visible lamellae, y-shaped fissures, and eccentric hila. Furthermore, when comparing some maize starch granules (Figre 6.4c) to that of winecup (*Callirhoe involucrata*) (Figure 6.4b) as indicated by the red arrows, both types of starch granules have eccentric hila, y-shaped fissures, visible lamellae, and have a cone-shaped protuberance opposite of the hilum. If individual starch granules of these types were recovered from an artifact, it would be difficult to identify them to a specific taxon. For instance, if one starch granule such as that displayed in Figure 6.4a was recovered, it could possible belong to copper lily or maize. However, if multiple starch granules were recovered of this type and no diagnostic starch granules were recovered, then it would most likely belong to copper lily as the majority of maize starch granules are faceted as opposed to lenticular.

Finally, air samples taken by Laurence *et al*. (2011) captured maize starch outdoors in urban and rural settings, as well as those taken in indoors in laboratory settings. The fact that maize starch is on supposedly powder-free gloves and in the atmosphere suggests that maize starch granules can contaminate archaeological samples during all stages of sample collection and processing, thereby complicating interpretations of starch granule assemblages especially in regions of the world where maize was cultivated.

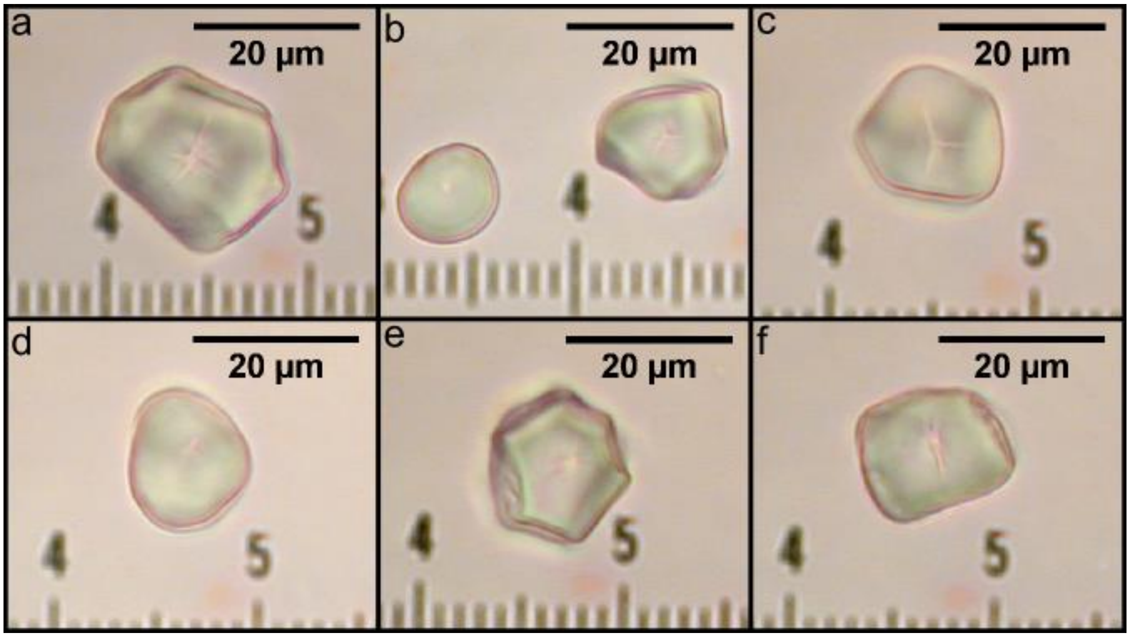


Figure 6.3. Selected variation of maize starch granules. Note the differences in the number of facets, overall "roundness" and "sharpness" of corners between the granules.

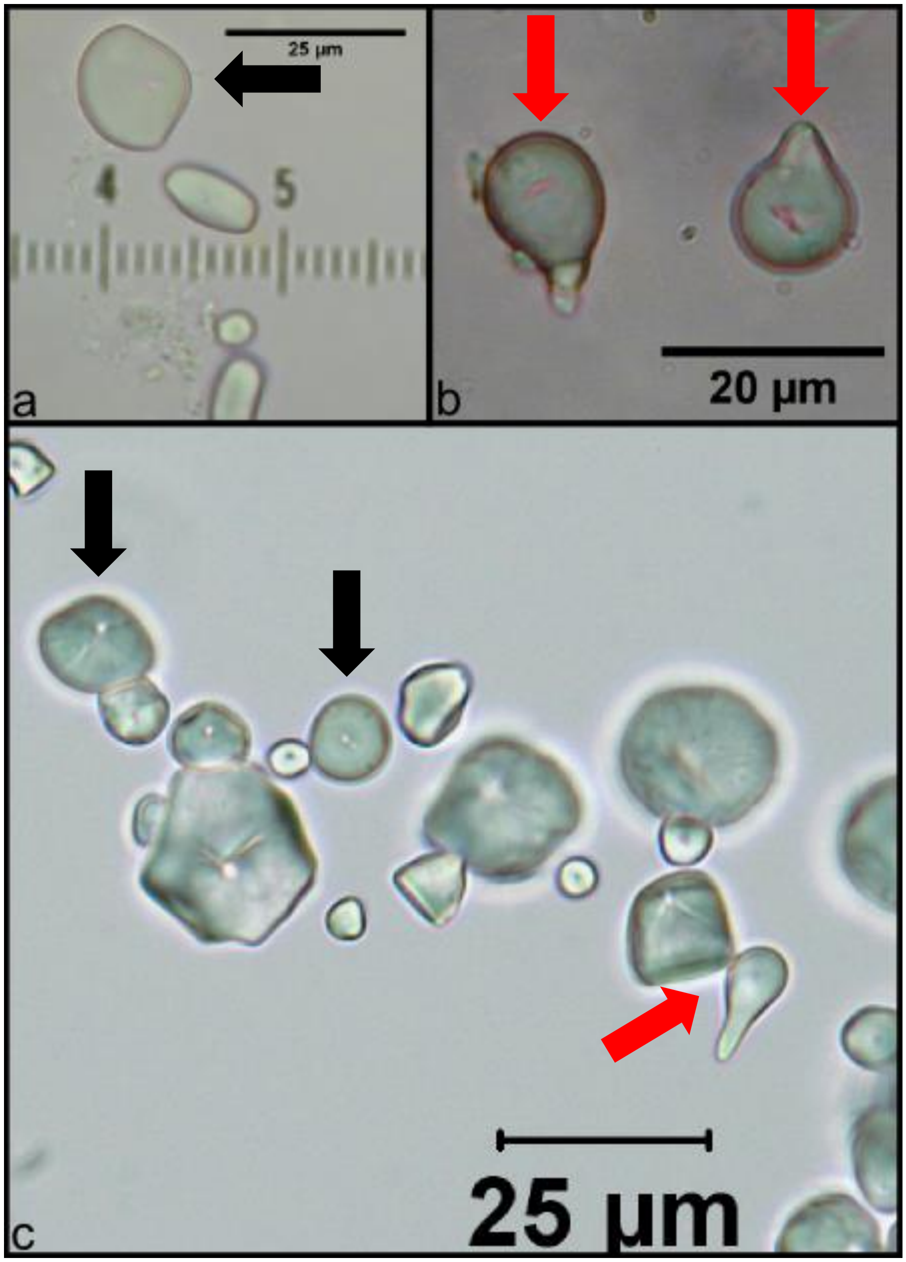


Figure 6.4. Starch granules recovered from maize kernel. Black arrows show similarities between (a) copper lily and (c) maize starch granules whereas red arrows show similarities between (b) winecup and (c) maize granules.

Curated Artifacts

Fourteen of the 19 processed artifacts yielded starch granules (Table 6.2). These artifacts were processed and analyzed to determine the ubiquity of identifiable and gelatinize starch granules on curated artifacts from Fort Hood, and no identifications were made apart from the recovery of maize starch granules from multiple artifacts. Along with displaying the presence/absence of identifiable, maize, and gelatinized starch, Table 6.2 also displays the artifact number, site, type (tool class), and side of the artifact where starch granules were recovered. As discussed in the Methods chapter, 5 of the analyzed artifacts yielded modified starch granules, including clusters of gelatinized starch granules consistent with those left behind in a fingerprint after someone has handled modern processed maize products (Figure 6.5). Thoms *et al*. (2013) suspect these artifacts were contaminated sometime during excavation, laboratory processing, or curation preparation.

Table 6.2. Curated artifacts and sediment samples processed and analyzed for microfossils. Note: standard processing technique refers to the use of a sonicating toothbrush to remove potential residues.

Artifact #	Acc #	Site	Artifact Type	Identifiable Starch Present	Maize Starch Present	Gelatinized Starch Present	Side of artifact with microfossils
1	1-0595-118-01	41CV595	pitted-groundstone (may actually be FCR)	yes	yes	yes	all
2	036-3067	41CV0595	mano	yes	no	yes	all
3	035-001	01-1553	groundstone fragment	yes	no	no	all
4	FCR Sample 3 Feature 10	41CV1049	FCR	yes	no	no	all
5	FCR Sample 1 Feature 8D	41CV1553	FCR	yes	no	no	all
6	FCR Sample 1 Feature 10	41CV1049	FCR	yes	yes	no	all
7	FCR Sample 2 Feature 10	41CV1049	FCR	yes	yes	no	all
8	063-001 Feature 9	01-1049	groundstone or hammerstone	yes	yes	no	used surfaces only
9	FCR Sample 1 Feature 8A	41CV1553	FCR	no	no	no	none
10	FCR Sample 2 Feature 8B	41CV1553	FCR	no	no	no	none
11	FCR Sample B Feature 8C	41CV1553	FCR	no	no	no	3 sides
12	070-001	01-1553	groundstone (mano)	yes	yes	no	3 sides
13	036-3064	41CV0595	groundstone (mano)	no	no	no	1 side
14	073-003	01-1049	Hammerstone	no	no	no	rounded end
15	064-002	01-1049	core	yes	no	no	battered surface
16	075-002	01-1049	core	yes	no	no	1 side
17	FCR Sample C Feature 8C	41CV1553	FCR	yes	yes	yes	all
18	FCR Sample 2 Feature 8A	41CV1553	FCR	yes	yes	no	all
19	FCR Sample 2 Feature 8D	41CV1553	FCR	yes	yes	no	2 sides

Thoms *et al*. (2013) also recovered what might be archaeologically relevant starch granules, although assessment of this assertion requires substantial re-sampling and new analyses. Unidentifiable starch granules, with characteristics consistent with grinding or milling activities as described by (Babott 2003), were recovered from several of the groundstone tools. Potentially archaeologically relevant starch granules are: (a) one lily-like granule on a FCR fragment; (b) two unknown type A granules from a groundstone/ hammerstone and mano; (c) three non-diagnostic faceted granules form a groundstone/hammerstone and FCR; (d) one unidentified geophyte-type granule on a mano; and (e) prickly pear-like starch granules on a mano and two pieces of FCR (Figure 6.6) (Thoms *et al*. 2013).

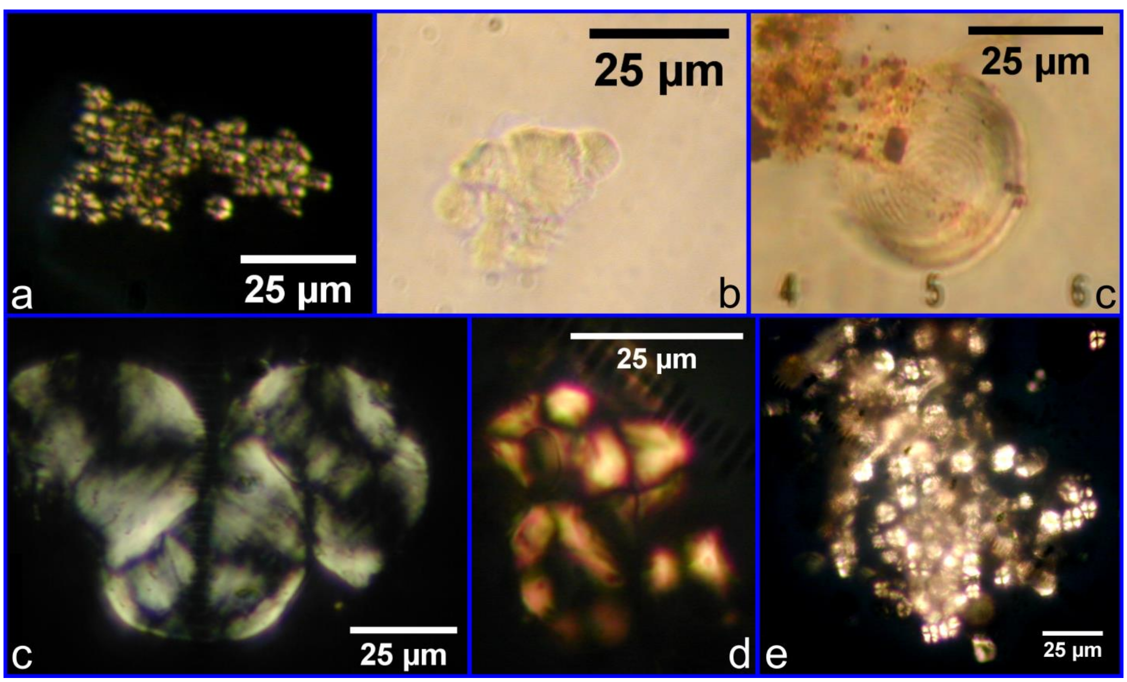


Figure 6.5. Starch granule contamination from processed foods: (a-b) curated artifact 1 (groundstone), (c-d) feature fill sample FLOT-16, and (e) fingerprints of author (ARL) after eating corn chips (Thoms *et al*. 2013).

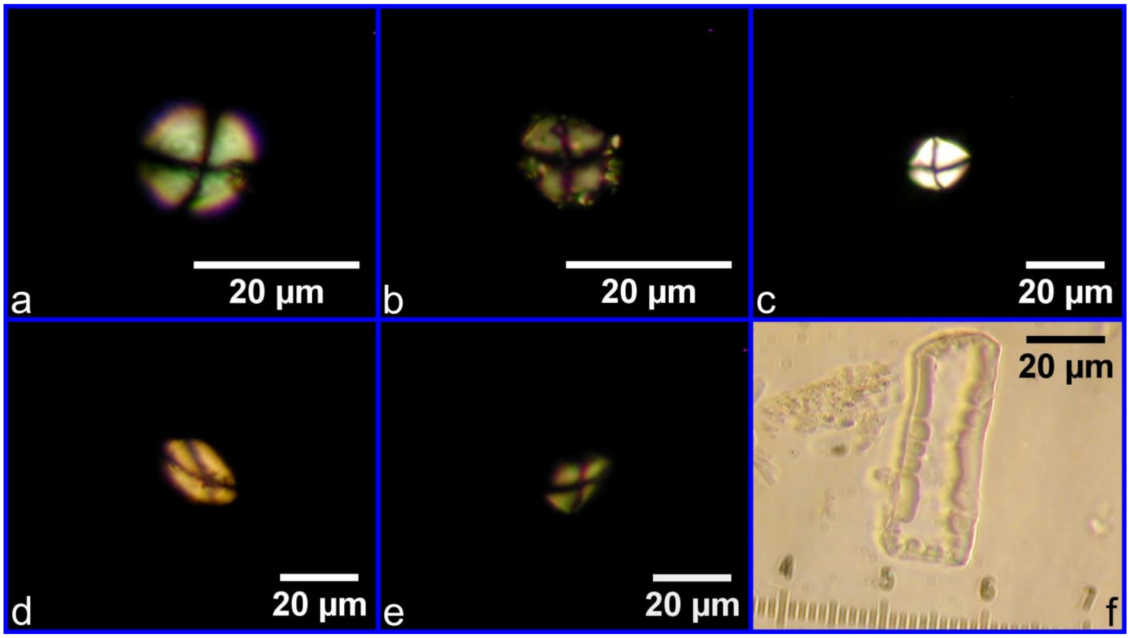


Figure 6.6. Microfossils recovered from curated artifacts: (a) lily-like starch granule from artifact 7 (FCR), (b) prickly pear-like starch granule from artifact 19 (FCR), (c) unknown type A starch granule from artifact 8 (groundstone or hammerstone), (d) unidentified geophyte starch granule from artifact 12 (groundstone), (e) non-diagnostic starch granule from artifact 18 (FCR), and (f) possible groundnut phytolith from artifact 11 (FCR) (Thoms *et al*. 2013).

Samples from Sites Excavated during 2010-2012 Field Seasons

FCR from 27 earth ovens at 6 sites were analyzed for microfossils with an emphasis on starch granules as part of the archaeological case study at Fort Hood. The total numbers of starch granules recovered from each fire-cracked-rock (FCR), rock control sample (RCS, and air control sample (ACS) are presented in this section. The total numbers of recovered starch granules separated by the tops and bottoms of each piece of FCR can be found in Appendix A. Although presented out of numerical order, the results from 41CV984 and 41CV1657 are presented first since the samples collected from these sites were processed differently than the other sites due to the presence of $CaCO_3$ deposits and lack of access to a clean bench.

41CV984

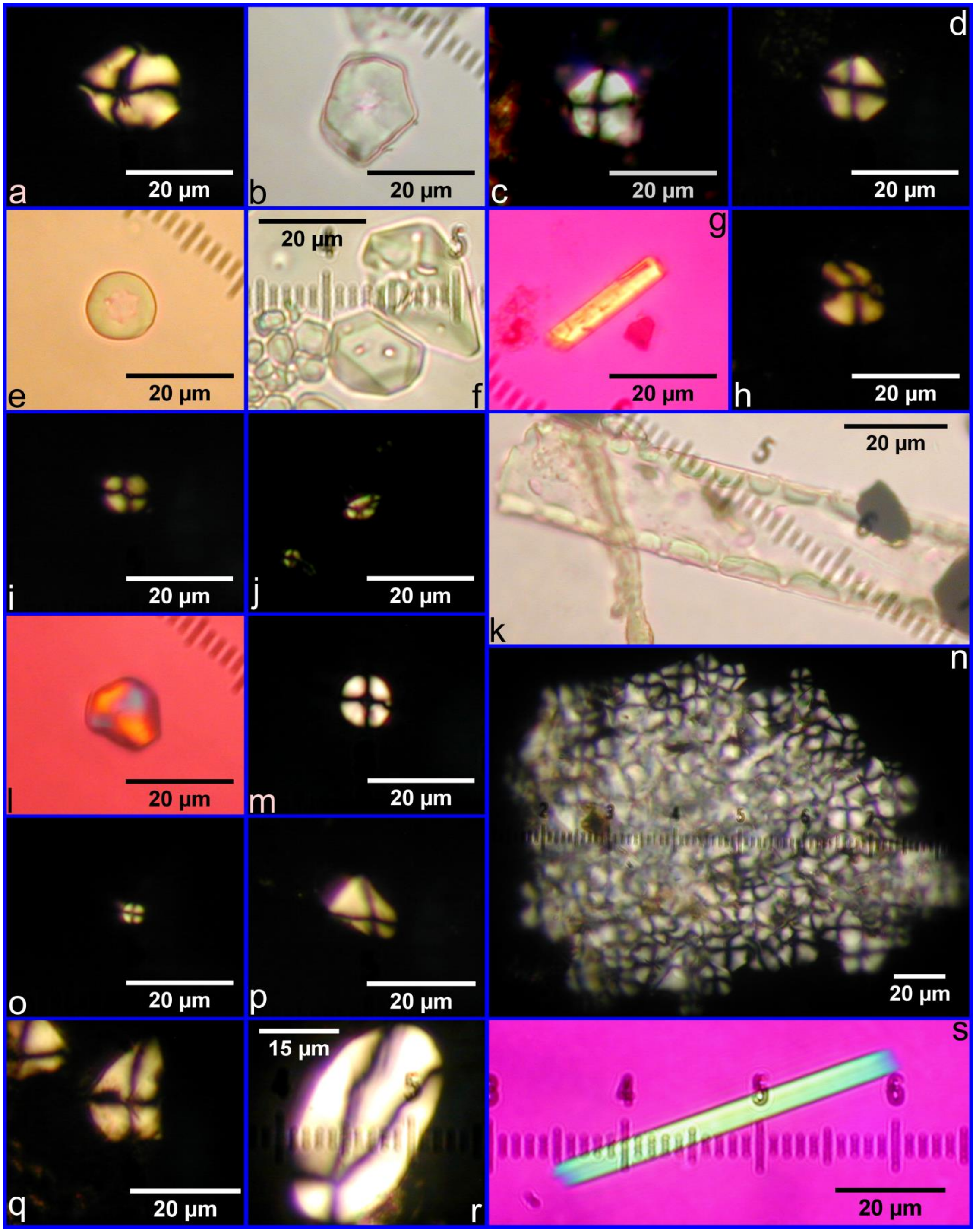
Fourteen pieces of FCR and their associated sediments were processed and analyzed from Feature 4—an earth-oven mound—at 41CV984, along with one control sample and three air samples (Table 6.3). Figure 6.7 illustrates examples of microfossils including starch, phytoliths, and raphides to demonstrate that a wide range of microfossils were recovered from FCR from Feature 4 at 41CV984 while Figure 6.8 illustrates examples of starch granules from control and air samples for the site. A total of 16 classifications of starch were recovered from the FCR (Table 6.3). Of these, only six taxa could be identified including maize (*Zea mays*), cf. *Yucca*, Liliaceae, *Quercus* sp., *Opuntia* sp., and cf. *Liatris*. Since maize agriculture was not practiced in Central Texas during the Archaic Period (Collins 2004), the recovered maize starch granules were most likely introduced into the samples as contamination, probably from the latex gloves. The remaining classifications; unidentified tuber, the large and small round granules, large and small faceted granules, Unknown Types A and B, unidentifiable, and gelatinized starch granules cannot be identified to a specific taxa and are therefore not considered as important taxa for comparison as their origins cannot be determined (i.e. archaeological or contamination). Finally, identifiable cf. *Yucca*, Liliaceae, *Quercus* sp., and *Opuntia* sp. starch granules were recovered from the ACS whereas maize and Liliaceae granules were recovered from the RCS (Table 6.3). Non-diagnostic/non-identifiable starch was also recovered from control samples.

When compared to all of the features analyzed for starch granules as part of the Paluxy Sand Geophyte Project, 41CV984 yielded significantly more starch granules. Of particular interest is Sample 44 from the lowest level of the feature which yielded over 5,000 starch granules. Among those, 1162 cf. *Yucca*, 531 Liliaceae, 1266 *Opuntia* sp., and 90 cf. *Liatris* starch granules were recovered. Also, 70 unidentified tuber starch granules were recovered, although since their origin cannot be determined, it is difficult to assign meaning to these granules especially since tuber starch granules were recovered in lab air samples (Table 6.3). No other sample analyzed for this study yielded such large numbers of starch granules.

Table 6.3. Starch granules recovered from 41CV984.

Artifact and Level	Sample Type	*Zea mays*	cf. *Yucca*	Lilia-ceae	*Quercus* sp.	*Opu-ntia sp.*	cf. *Li-atris*	UnID Tuber	Faceted > 5 µm	Small Faceted (<5µm)	Round >5 µm	Small Round (< 5 µm)	Clusters of granules	UnK A	UnK B	UnID /Deg-raded	Gel
8 - 2	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 - 3	FCR	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0
17 - 4	FCR	0	7	1	1	0	0	0	0	101	1	3	0	0	0	0	0
23 - 5	FCR	0	4	0	0	7	0	0	3	0	3	0	0	0	0	2	0
29 - 6	FCR	0	0	0	0	1	0	1	2	0	0	3	0	0	0	1	0
35 - 6	FCR	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 7	FCR	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0
37 - 7	FCR	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0
38 - 7	FCR	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 - 9	FCR	0	1162	531	4	1266	90	70	1200	528	0	46	11	69	1	80	12
44 Pipette - 9	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 - 9	FCR	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Bedrock	RCS	0	5	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Air Sample 1	ACS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Air Sample 2	ACS	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0

Figure 6.7. Microfossils recovered from FCR samples at 41CV984: (a) yucca-like starch granule from sample 36, (b) yucca-like starch granule from sample 38, (c-d) prickly pear-like starch granules from sample 44, (e) prickly pear phytolith from sediments below sample 17, (f) unidentified phytoliths from sample 29, (g) prickly pear calcium oxalate crystal from sample 38, (h) lily-like starch granule from sample 44, (i) oak-like starch granule from sample 44, (j) oak-like starch granule from sample 17, (k) oak phytolith from sediments below sample 17, (l) gayfeather-like starch granule from sample 53, (m) non-diagnostic round starch granule from sample 23, (n) cluster of starch granules from sample 44, (o) non-diagnostic faceted starch granule from sample 17, (p) unknown type A starch granule from sample 44, (q) unknown type B starch granule from sample 44, (r) unidentified geophyte starch granule from sample 29, and (s) raphide bundle from sample 29. Micrographs a, c-d, h-j, and m-r are under cross-polarized light, micrographs b, e-f, and k are under brightfield illumination, and micrographs g, l, and s are under ¼ λ polarized light (Thoms *et al*. 2013).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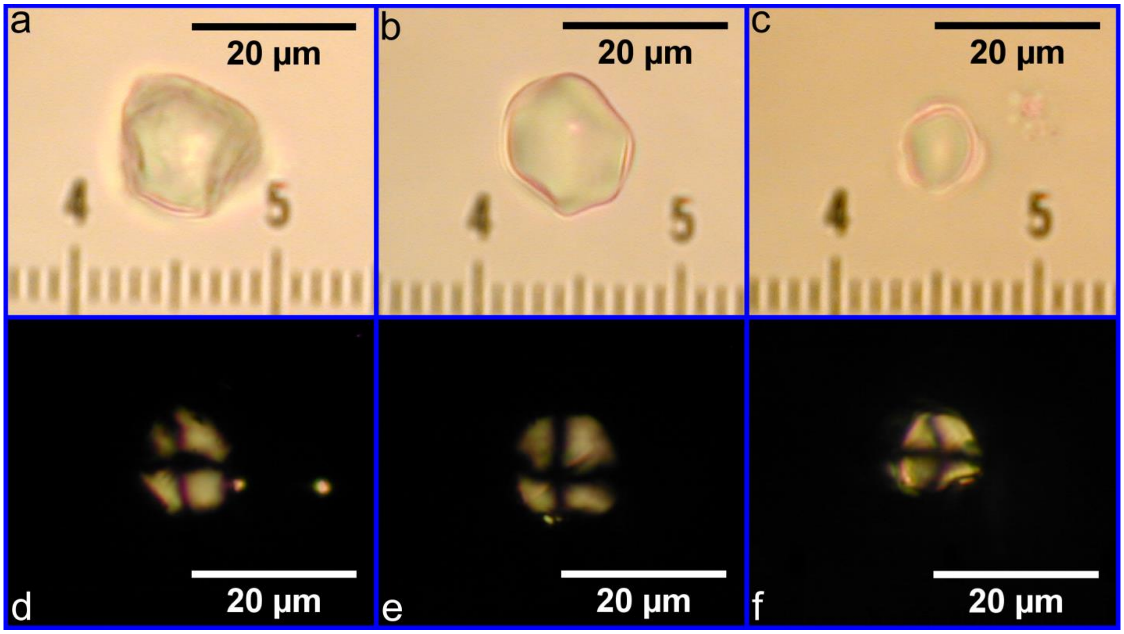


Figure 6.8. Starch granules from 41CV984 control samples (a) yucca-like starch granule from bedrock sample, (b) prickly pear-like starch granule from bedrock sample, (c) oak-like starch granule from bedrock sample, (d) yucca-like starch granule from air sample 2, (e) lily-like starch granule from air sample 2, and (f) unidentified starch granule from air sample 2. Micrographs 1-c are under brightfield illumination whereas d-f are under cross-polarized light (Thoms *et al*. 2013).

To determine where the majority of the starch granules were recovered from FCR and RCS (i.e. top vs. bottom of the samples), five comparisons were made between the tops and bottoms for all FCR and RCS samples including; Recovered Starch, Total without Maize, Total without Maize and Faceted, Total Unidentifiable and Gelatinized, and Total Identifiable without Maize or Faceted. The first column "Recovered Starch," displays the total number of starch granules recovered from the FCR. The second column, "Total without Maize," displays the total number of recovered starch granules without counting maize starch since that is a modern contaminant. Next, "Total without Maize and Faceted" displays the total number of recovered starch granules minus maize and non-diagnostic faceted starch since maize is a modern contaminant and non-diagnostic faceted starch could actually be maize, although it is unknown if this is actually the case. The "Total Unidentifiable and Gelatinized" column displays the total number of starch granules that cannot be identified to a specific taxon. Finally, the last column, "Total Identifiable without Maize or Faceted," displays the total number of starch granules that can be identified or possibly identified to a specific taxon, excluding the known and possible contamination starch granules. Unidentifiable and gelatinized starch granules were excluded from this category since it is unknown if they represent modern contaminants such as maize, ancient starch, or both.

Based on the results displayed in Figures 6.9-6.11, a greater number of starch granules were recovered on the top of the FCR rather than the bottom at 41CV984. Since most of starch granules were recovered from one sample, Sample 44, two sets of comparisons were made. The first set displays the total number of starch granules recovered for that site, including Sample 44. Sample 44 is unique in that it yielded 5054 individual starch granules as well as 11 clusters with concentrations of starch granules too dense to count. Given that this sample is an outlier, it was excluded from the second set of comparisons. In both sets of comparisons, the majority of starch granules were recovered from the top of the FCR, with the exception of the recovered unidentifiable and gelatinized starch granules. Finally, only 8 starch granules were recovered from the single RCS analyzed form 41CV984, all of which were recovered from the bottom of the sample (Figure 6.11).

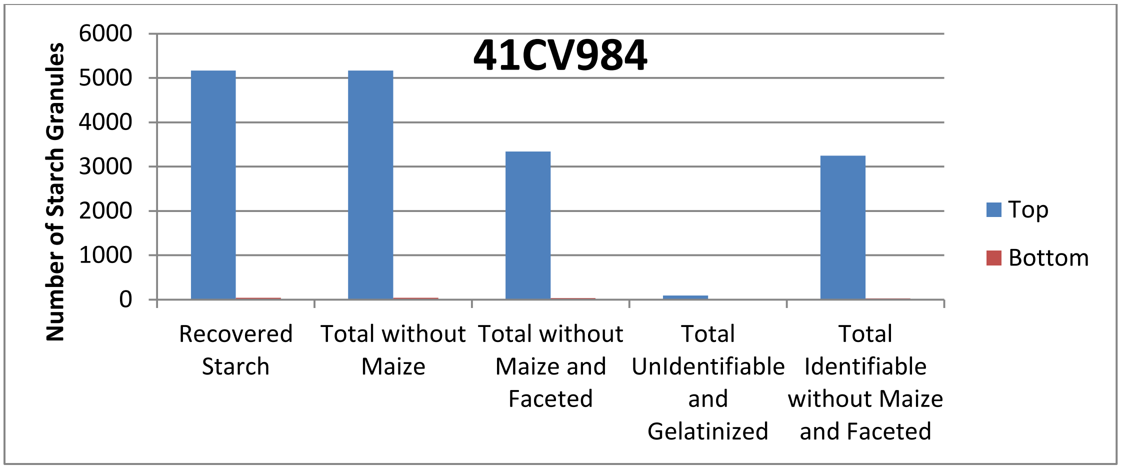


Figure 6.9. Number of starch granules recovered from top and bottom of FCR at 41CV984.

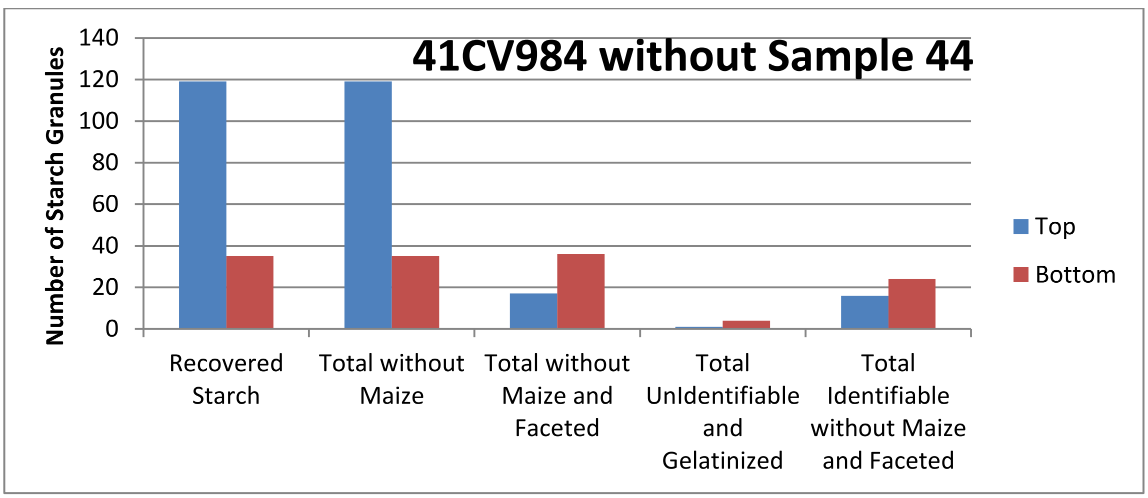


Figure 6.10. Number of starch granules recovered from top and bottom of FCR at 41CV984 without Sample 44.

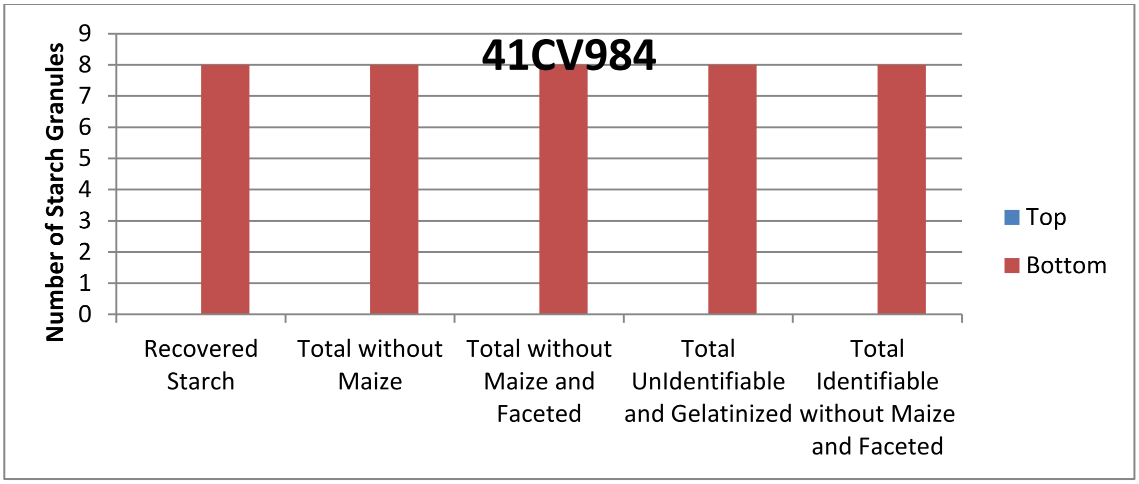


Figure 6.11. Number of starch granules recovered from top and bottom of RCS from 41CV984.

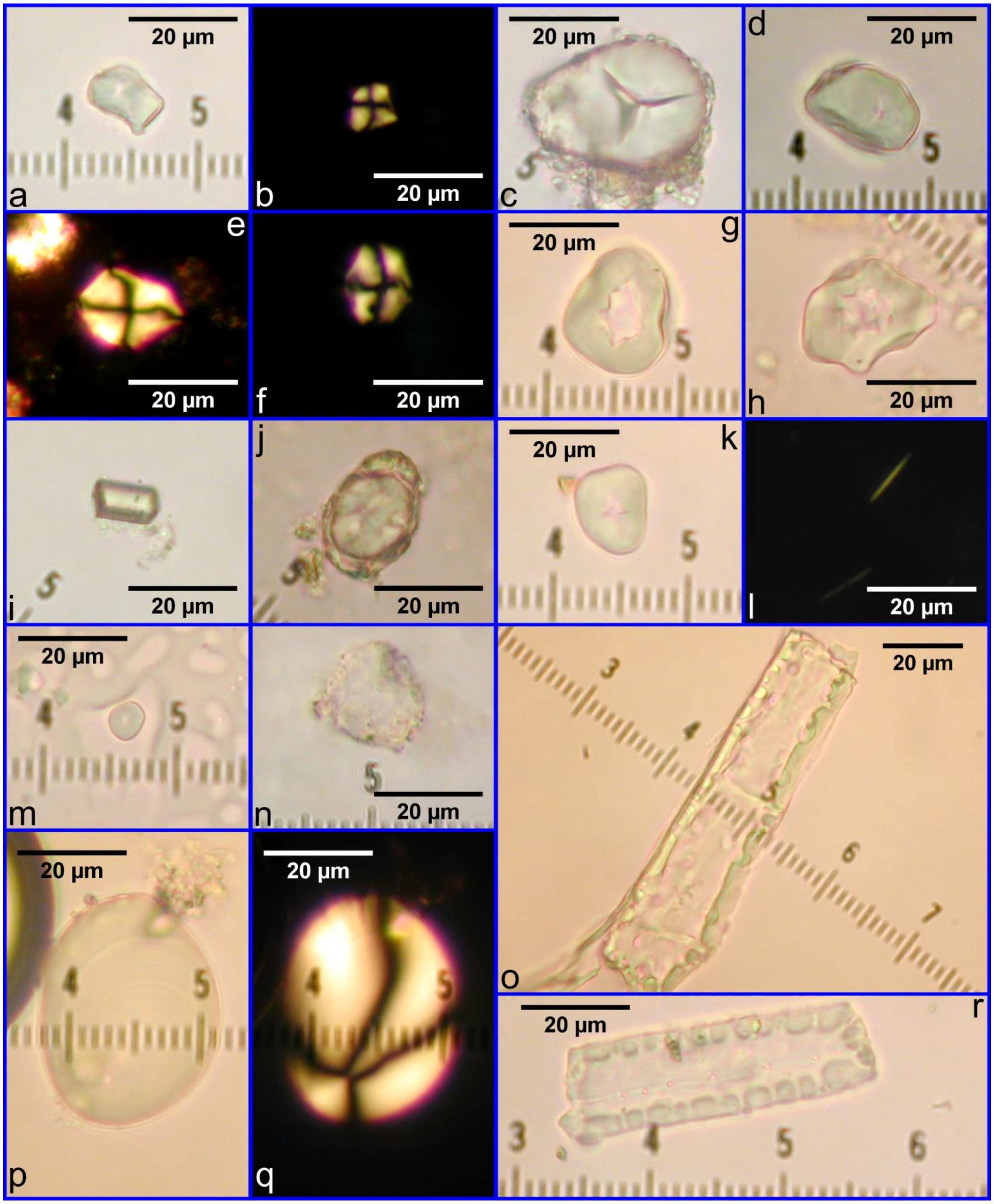
41CV1657 (Gully Mouth)

Twenty-one pieces of FCR and associated sediment samples (sediment that was directly below and in contact with the FCR) were processed and analyzed from one large and three smaller earth ovens at 41CV1657, along with 2 control and 2 air samples (Table 6.4). Microfossils were recovered from all sample types including starch granules, phytoliths, and raphides, although the phytoliths and raphides were not identified (Figures 6.12-6.-13). A summary of the results can be found in Table 6.4 while a more detailed listing (i.e. starch recovered from the top vs. bottom of the samples) can be found in Appendix A. Notably, maize, cf. *Yucca*, Liliaceae, *Quercus* sp., *Opuntia* sp., cf. *Liatris*, and cf. *Callirhoe* were recovered from FCR along with other non-diagnostic, non-identifiable, and gelatinized starch granules. The cf. *Callirhoe* starch granule recovered from Sample BD is the only cf. *Callirhoe* starch granule recovered in this study. Regarding the control samples, maize, cf. *Yucca*, Liliaceae, *Opuntia* sp., and cf. *Liatris* starch granules were recovered from the RCS whereas a single *Opuntia* sp. starch granule was the only identifiable/diagnostic starch granule recovered from the ACS. It does need to be pointed out however, that the high numbers of small faceted starch granules recovered from air sample 4 most likely belong to the Poaceae family (grass). This sample was mounted in Permount, however, and the high refractive index of Permount obscures the features of starch granules smaller than 5 μm in size, thereby making identification tentative. Finally, when observing where the starch granules were recovered from individual pieces of FCR and RCS, the majority of starch granules were recovered from the bottoms of both types of samples (Figures 6.14-6.15).

Table 6.4. Starch granules recovered from 41CV1657.

Artifact	Site and Feature	Sample Type	*Zea mays*	cf. *Yucca*	Liliaceae	*Quercus* sp.	*Opuntia sp.*	cf. *Liatris*	cf. *Callirhoe*	Compound	Faceted > 5 µm	Small Faceted (<5µm)	Round >5 µm	Small Round (< 5 µm)	UnID/ Degraded	Gel
A	41CV1657 - 3	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	41CV1657 F3	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	41CV1657 F 3	FCR	0	2	0	0	0	0	0	0	0	0	0	0	0	0
O	41CV1657 F3A	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Q	41CV1657 F3A	FCR	0	0	0	0	0	1	0	0	0	0	0	0	0	0
V	41CV1657 F3	FCR	5	0	1	0	0	0	0	0	0	0	0	0	1	0
X	41CV1657 F3	FCR	0	0	0	0	0	0	0	1	0	0	0	0	0	0
AG	41CV1657 F1	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AJ	41CV1657 F1	FCR	0	2	0	1	0	0	0	0	0	0	0	1	0	1
AT	41CV1657 F4	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0	0
AW	41CV1657 F4	FCR	0	0	0	0	0	0	0	0	1	0	0	0	0	0
BA	41CV1657 F4	FCR	0	0	0	0	1	0	0	0	1	0	0	0	1	0
BB	41CV1657 F4	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BC	41CV1657 F4	FCR	1	0	0	0	1	0	0	0	1	0	0	0	0	0
BC Pipette	41CV1657 F4	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BD	41CV1657 F2	FCR	0	0	0	0	0	0	1	0	0	0	0	0	0	0
BE	41CV1657 F2	FCR	0	0	0	0	3	0	0	0	1	1	0	0	4	0
BF	41CV1657 F2	FCR	0	0	0	0	0	0	0	0	0	0	1	0	0	0
BJ	41CV1657F 2	FCR	0	2	1	0	0	0	0	0	0	0	0	0	2	0
BK	41CV1657 F2	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	41CV1657	RCS	1	0	0	0	0	0	0	0	0	0	0	0	0	1
AR	41CV1657	RCS	1	1	1	0	1	2	0	0	0	0	0	0	1	0
Off Site Sample 1	41CV1657	RCS	0	1	1	0	2	0	0	0	0	0	0	0	0	0
Off Site Sample 2 Profile 3	41CV1657	RCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Air Sample 1	41CV1657	ACS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Air Sample 2	41CV1657	ACS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Air Sample 3	41CV1657	ACS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Air Sample 4	41CV1657	ACS	0	0	0	0	0	0	0	0	0	100	0	0	0	0
Air Sample 5	41CV1657	ACS	0	0	0	0	1	0	0	0	0	1	0	0	1	0

Figure 6.12. Microfossils recovered from FCR samples from 41CV1657: (a) possible gayfeather starch granule from sample AR (on-site off-feature control sample), (b) unknown B starch granule from sample X, (c) possible winecup starch granule from sample BD, (d) possible yucca starch from sample AR (on-site off-feature control sample), (e) possible prickly pear starch granule from sample BE, (f) possible prickly pear starch granule from sample BJ, (g) prickly pear phytolith from sample V, (h) prickly pear phytolith from sample AJ, (i) prickly pear calcium oxalate crystal from sample BD, (j) heavily modified lily starch granule from sample Q, (k) lily starch granule from sample V, (l) raphides from sample X, (m) oak-like starch granule from sample BJ, (n) gelatinized starch granule from sample AJ, (o) oak phytolith from sample AJ, (p-q) unidentified geophyte starch granule from sample BC, and (r) unidentified phytolith from sample V. Micrographs a, c-d, g-k, m-p, and r are under brightfield illumination whereas b, e-f, l and q are under cross-polarized light.



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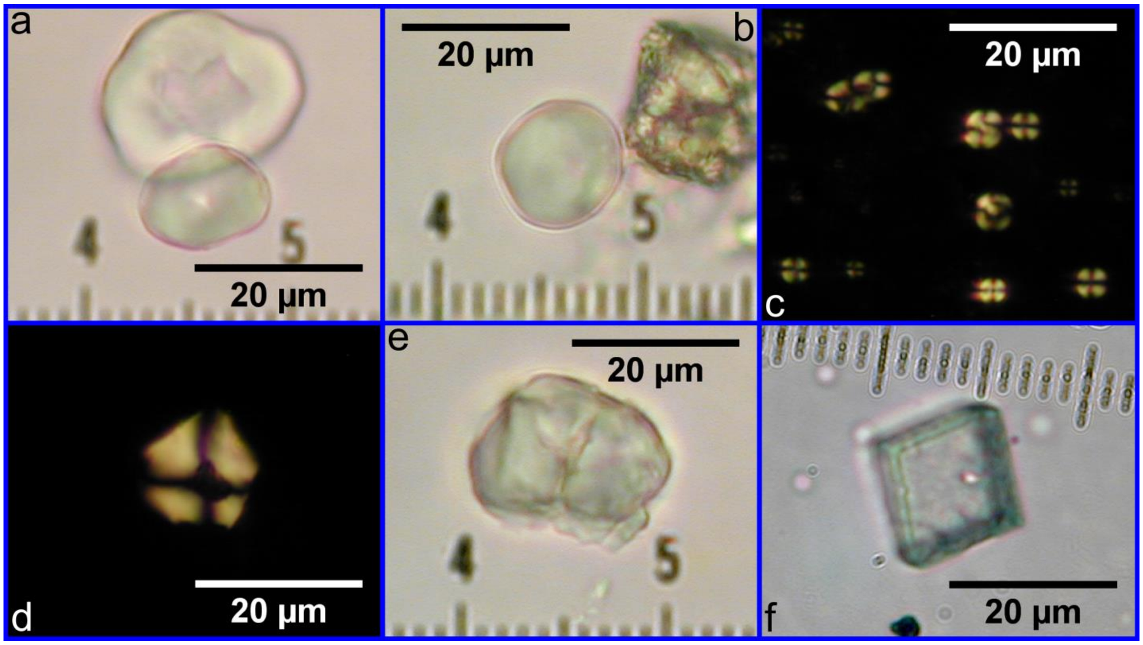

Figure 6.13. Microfossils recovered from 41CV1657 control samples: (a) possible prickly pear starch granule and phytolith from off-site sample 1, (b) lily starch granule from off-site sample 1, (c) non-diagnostic round starch granules from air sample 4, (d) possible prickly-pear starch granule from air sample 4, (e) unidentifiable starch granule from air sample 5, and (f) non-diagnostic calcium oxalate crystal from air sample 5. Micrographs a-b and e-f are under brightfield illumination whereas c-d are under cross-polarized light.

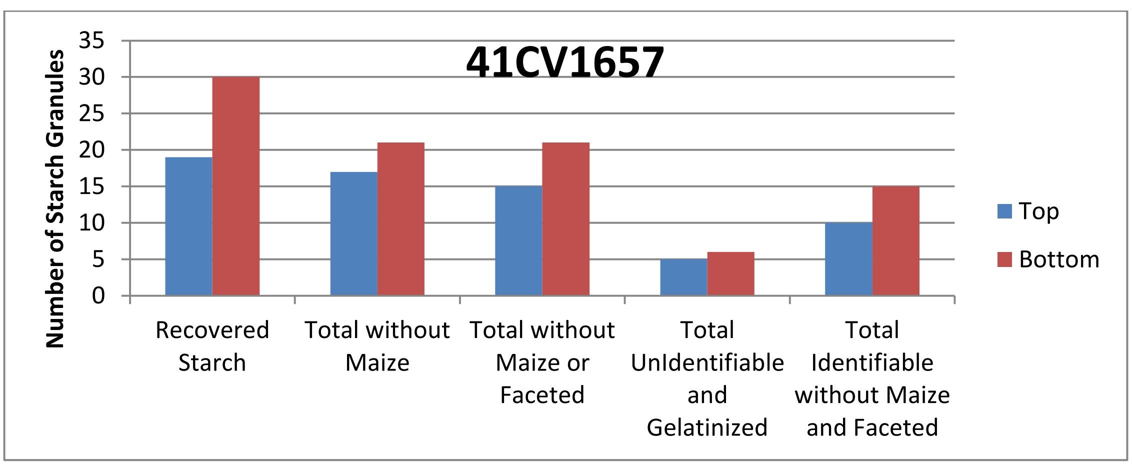

Figure 6.14. Number of starch granules recovered from top and bottom of FCR 41CV1657.

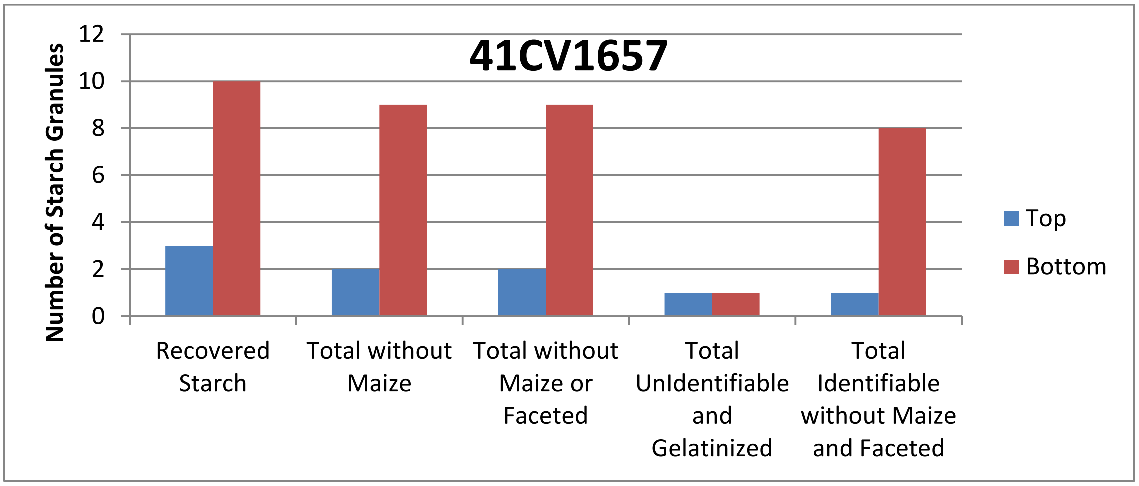

Figure 6.15. Number of starch granules recovered from top and bottom of RCS 41CV1657.

41CV594

Twenty pieces of FCR from seven distinct earth ovens (Features 2A-2G), a test pit, and disturbed context were sample for starch granule analysis along with three RCS and three ACS. At least one FCR sample was analyzed for starch from each feature and/or sampling location. A summary of the results of the starch granule analysis are listed in Table 6.5 and a detailed listing can be found in Appendix A. Only three identifiable and diagnostic taxa were recovered from FCR at 41CV594 including maize, Liliaceae, and Poaceae along with non-diagnostic and unidentifiable starch granules (Table 6.5). Interestingly, over 260 Poaceae starch granules along with clusters of an indeterminate number of starch granules, most likely Poaceae, were recovered from Sample M-10 in a basin-shaped earth oven. Maize and Liliaceae starch granules were also recovered from both RCS and ACS along with non-diagnostic and unidentifiable starch granules. Gelatinized starch was also recovered in RCS samples. Figure 6.25 illustrates examples of starch granules recovered from 41CV594, while Figure 6.26 illustrates examples of starch granules recovered from the control samples. Finally, the majority of starch granules were recovered from the bottom of the FCR, while one identifiable and diagnostic starch granule was recovered from the top and one from the bottom of the RCS (Figures 6.16-6.17).

Table 6.5. Starch granules recovered from 41CV594.

Artifact	Site and Feature	Sample Type	# of rec-overed starch	*Zea mays*	Lilia-ceae	Poa-ceae	Face-ted > 5 µm	Small Faceted (<5µm)	Clus-ters of gra-nules	UnK A	UnID/ Deg	Gel
M-2	41CV594	FCR	1	0	0	0	0	0	0	0	0	1
M-3	41CV594	FCR	7	0	0	0	0	0	0	0	5	2
M-9	41CV594 - Test Pit	FCR	3	0	0	2	1	0	0	0	0	0
M-10	41CV594 - Test Pit	FCR	497	1	0	262	0	0	129	0	0	105
M-10 $CaCo_3$	41CV594 - Test Pit	FCR	3	1	0	0	0	0	0	0	1	1
M-14	41CV594	FCR	1	0	0	0	0	0	0	0	1	0
M-15	41CV594	FCR	23	23	0	0	0	0	0	0	0	0
M-17	41CV594	FCR	4	0	0	0	0	0	0	0	1	3
M-18	41CV594	FCR	9	0	2	0	1	0	0	0	2	4
M-28	41CV594 F 2C	FCR	0	0	0	0	0	0	0	0	0	0
M-29	41CV594 F 2C	FCR	3	0	0	0	1	0	0	1	0	1
M-46	41CV594 F 2A	FCR	8	5	0	0	1	0	0	0	2	0
M-56	41CV594 F2B	FCR	3	2	0	0	0	0	0	0	1	0
M-61	41CV594 F 2F	FCR	0	0	0	0	0	0	0	0	0	0
M-61 CaCO3	41CV594 F 2F	FCR	0	0	0	0	0	0	0	0	0	0
M-67	41CV594 F 2C	FCR	3	1	0	0	0	0	0	0	0	2
M-68	41CV594 F 2C	FCR	1	0	0	0	0	0	0	0	1	0
M-68 CaCO3	41CV594 F 2C	FCR	0	0	0	0	0	0	0	0	0	0
M-69	41CV594 F 2C	FCR	1	1	0	0	0	0	0	0	0	0
M-69 $CaCO_3$	41CV594 F 2C	FCR	1	0	0	0	0	0	0	0	1	0
M-71	41CV594 F 2G	FCR	1	0	0	0	1	0	0	0	0	0
M-75	41CV594 F2D	FCR	2	0	0	1	0	0	0	0	0	1
M-77	41CV594 Trench 1	FCR	13	10	0	0	0	0	0	0	3	0
M-86	41CV594 F 2E	FCR	8	2	0	0	2	2	0	0	2	0
Off Site 1	41CV594	RCS	3	2	0	0	0	0	0	0	0	1
Off Site 2	41CV594	RCS	2	0	0	0	0	0	0	0	1	0
Off Site 4	41CV594	RCS	2	1	0	0	0	0	0	0	0	1
Air Sample 1	41CV594	ACS	0	0	0	0	0	0	0	0	0	0
Air Sample 2	41CV594	ACS	1	1	0	0	0	0	0	0	0	0
Air Sample 3	41CV594	ACS	0	0	0	0	0	0	0	0	0	0

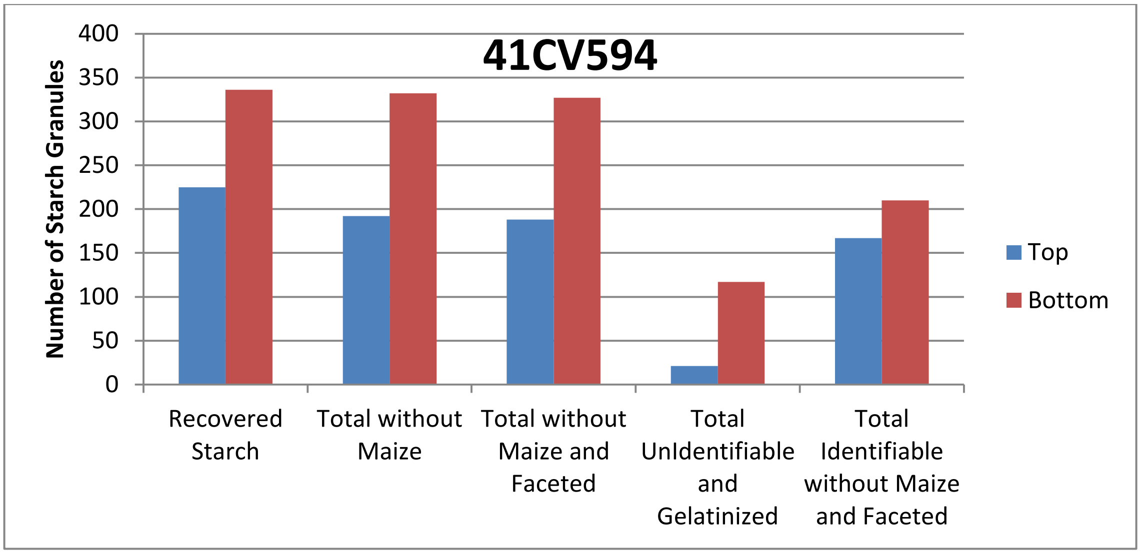

Figure 6.16. Number of starch granules recovered from top and bottom of FCR 41CV594.

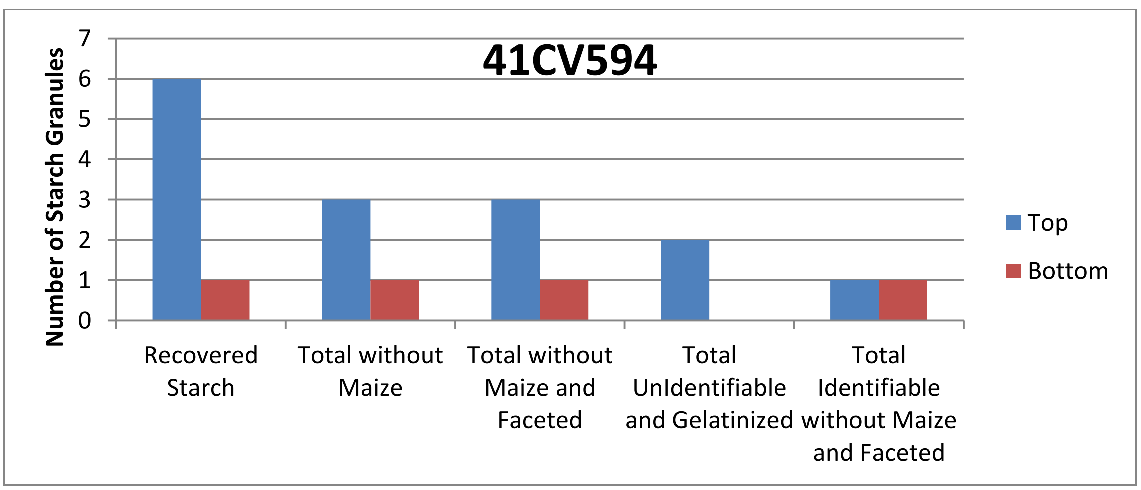

Figure 6.17. Number of starch granules recovered from top and bottom of RCS 41CV594.

41CV947

Six features were sampled for starch granule analysis from 41CV947. At least one FCR sample was analyzed for microfossils. A summary of the results of the starch granule analysis are listed in Table 6.6 and a detailed listing can be found in Appendix A. Notably, common bean (Fabaceae) starch granules, including a cluster of over 100 common bean starch granules were the only diagnostic starch granules recovered from any of the FCR, all of which came from one piece of FCR, M-61. Non-diagnostic, unidentifiable, and gelatinized starch granules were also recovered from the FCR. With regard to the RCS and ACS, maize and common bean starch granules were the only diagnostic starch granules, although unidentifiable and gelatinized starch was also recovered from RCS samples. Figure 6.25 illustrates examples of starch granules recovered from 41CV947, while Figure 6.26 illustrates examples of starch granules recovered from the non-cultural rock and air control samples.

Regarding whether recovered starch granules came from the top or bottom surface, the majority of starch granules from the FCR came from the bottom surface (Figure 6.18). However, the most of the identifiable and diagnostic starch granules came from a cluster of over 100 common bean starch granules, most of which did not show signs of modification from human activities. Those that were modified were undergoing hydrolysis. As this was an outlier and probably the result of contamination during excavation (see discussion in Chapter 7 for more details), a second comparison was made with sample M-61 removed from the analysis. With that sample removed, only one identifiable and diagnostic starch granule was recovered from the top and one was recovered from the bottom (Figure 6.19). Finally, five identifiable and diagnostic starch granules recovered from the RCS, all of which came from the bottom surface (Figure 6.20).

Table 6.6. Starch granules recovered from 41CV947.

Artifact and Level	Site and Feature	Sample Type	*Zea mays*	Common Bean	Faceted > 5 µm	Clusters of granules	UnK F	UnK G	UnID/ Degr-aded	Gel
M-6	41CV947 F6	FCR	0	0	0	0	0	0	0	0
M-9	41CV947 F8	FCR	0	0	1	0	0	1	1	0
M-14	41CV947 F5	FCR	0	0	1	0	1	0	1	0
M-25	41CV947 F9	FCR	0	0	0	0	0	0	2	0
M-45	41CV947 F5	FCR	0	0	0	0	0	0	3	0
M-30	41CV947 F5	FCR	0	0	1	0	0	0	3	1
M-61	41CV947 F7	FCR	0	2	1	1	0	0	0	1
Off Site	41CV947	RCS	0	0	0	0	0	0	0	0
Off Site1	41CV947	RCS	0	0	0	0	0	0	1	0
Off Site 2	41CV947	RCS	7	1	0	0	0	0	1	0
Off Site 3	41CV947	RCS	2	0	0	0	0	0	5	1
Air Sample 2	41CV947	ACS	1	0	0	0	0	0	0	0
Air Sample 3	41CV947	ACS	1	1	0	0	0	0	0	0

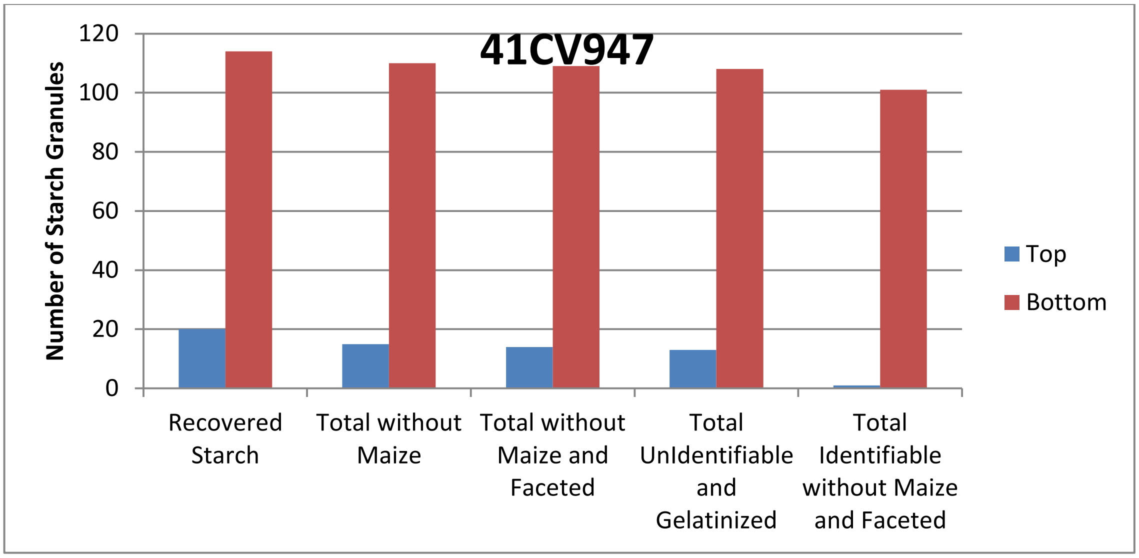

Figure 6.18. Number of starch granules recovered from top and bottom of FCR 41CV947.

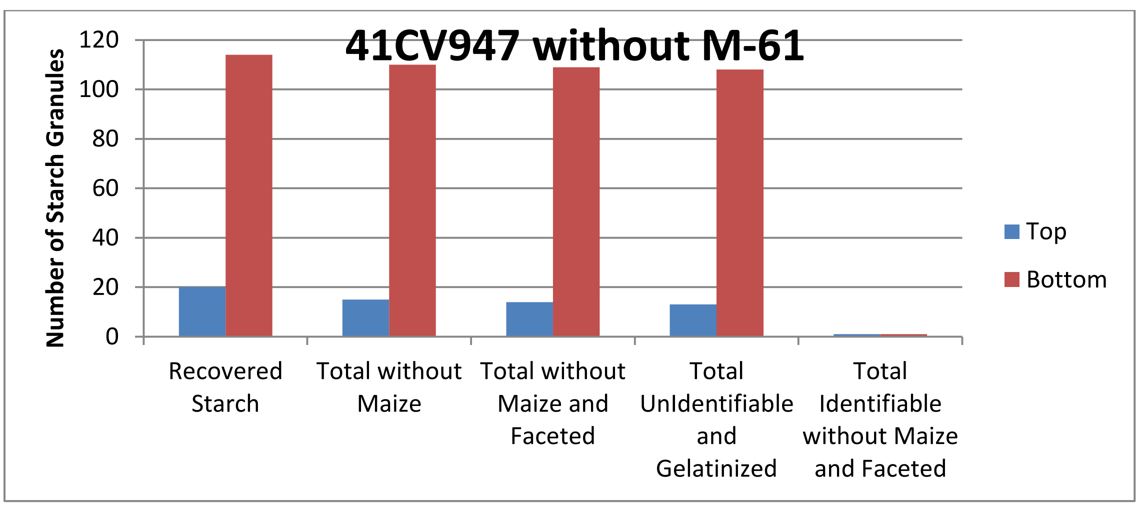

Figure 6.19. Number of starch granules recovered from top and bottom of FCR without M-61 41CV947.

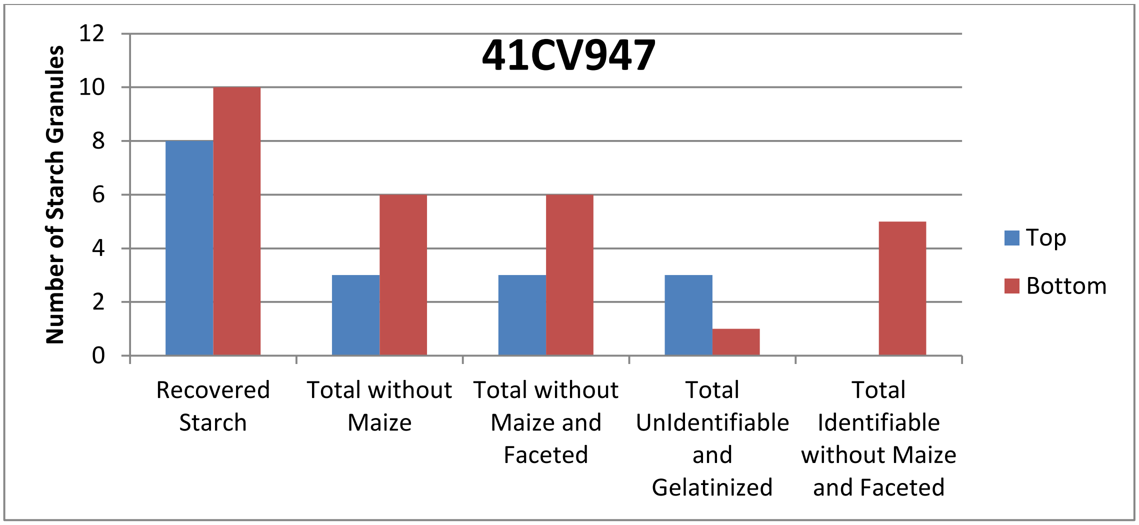

Figure 6.20. Number of starch granules recovered from top and bottom of RCS 41CV947.

41CV1104

Four features from 41CV1104 were sampled for starch granule analysis. A total of 6 pieces of FCR where at least one piece of FCR from every feature was analyzed, 2 RCS and 2 ACS samples were analyzed for starch. The simplified results of the starch granule analysis are listed in Table 6.7 and a detailed listing can be found in Appendix A. Maize, Liliaceae, and common bean were the only taxa represented by identifiable starch granules from the FCR, although un-identifiable and gelatinized starch was also recovered (Table 6.7). For the control samples, maize, unidentifiable, and gelatinized starch granules were recovered from the RCS whereas maize and common bean starch granules were recovered from the ACS. Figure 6.25 illustrates examples of starch granules recovered from 41CV1104, while Figure 6.26 illustrates examples of starch granules recovered from the non-cultural rock and air control samples. Finally, the bottoms of both the FCR and RCS yielded more starch granules, although only three total identifiable and diagnostic granules were recovered from the FCR and only one was recovered from the RCS (Figure 6.21-6.22).

Table 6.7. Starch granules recovered from 41CV1104.

Artifact and Level	Site and Feature	Sample Type	*Zea mays*	Liliaceae	Common Bean	UnID/ Degraded	Gelatinized
M-2	41CV1104 F-3	FCR	1	0	0	1	0
M-3	41CV1104 F-3	FCR	1	0	1	0	0
M-4	41CV1104 F-4	FCR	8	2	0	3	2
M-7	41CV1104 F-2	FCR	0	0	0	0	0
M-8	41CV1104 F-2	FCR	2	0	0	0	0
M-10	41CV1104 F-1	FCR	1	0	0	1	0
Off-Site 2	41CV1104	RCS	0	0	0	0	0
Off-Site 6	41CV1104	RCS	1	0	0	1	3
Air Sample 2	41CV1104	ACS	1	0	0	0	0
Air Sample 3	41CV1104	ACS	1	0	1	0	0

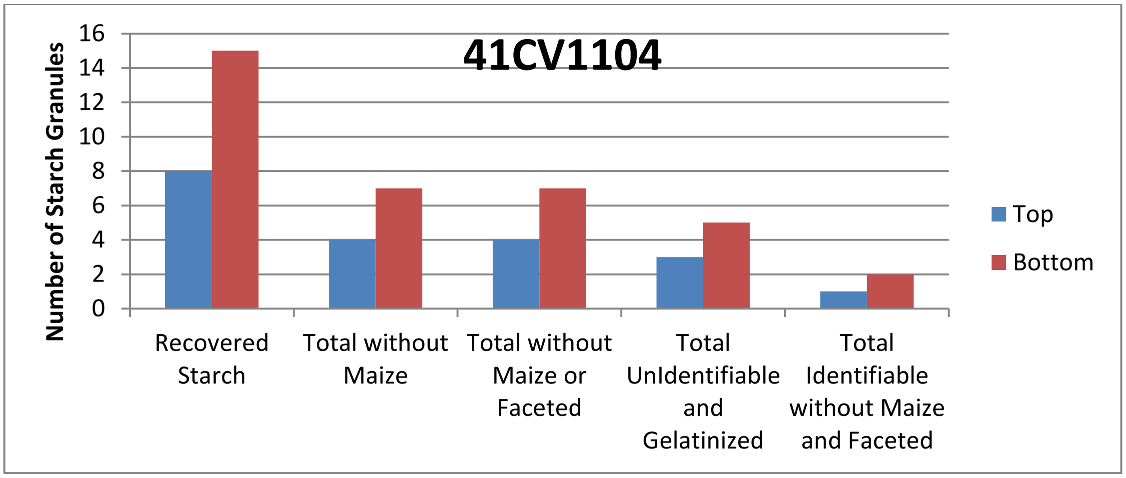

Figure 6.21. Number of starch granules recovered from top and bottom of FCR 41CV1104.

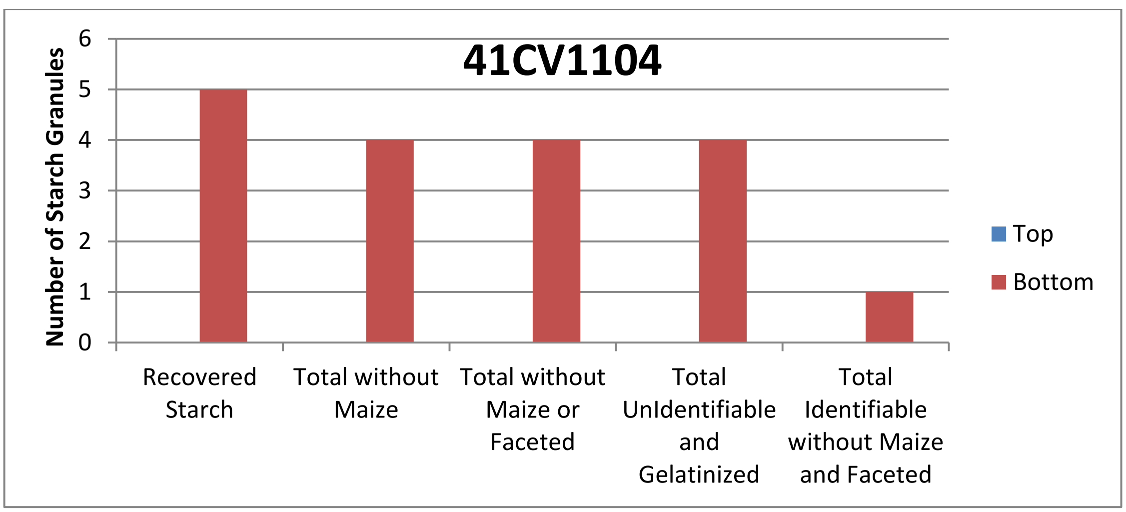

Figure 6.22. Number of starch granules recovered from top and bottom of RCS 41CV1104.

41CV1553

FCR from four features at 41CV1553 were sampled for starch granules. A total of 13 pieces of FCR, 3 RCS, and 3 ACS were analyzed for starch granules. The simplified results of the starch granule analysis are listed in Table 6.8 and a detailed listing can be found in Appendix A. A total of seven identifiable/diagnostic taxa were recovered from the FCR including maize, Fabaceae (common bean), *Quercus* sp. *Opuntia* sp., cf. *Apios*, cf. *Liatris*, and cf. *Clatonia* (springbeauty). Interestingly, the cf. *Claytonia* starch granule recovered from M-8 was the only starch granule recovered from this taxon during the Paluxy Sand Geophyte Project. Since only starch granule from cf. *Claytonia* was recovered, it is difficult to ascribe meaning to just one starch granule. Non-diagnostic, unidentifiable, and gelatinized starch was also recovered from the FCR. Only one non-diagnostic and one unidentifiable starch granule were recovered from the RCS, whereas maize, *Opuntia* sp., and cf. *Apios* along with non-diagnostic and unidentifiable starch granules were recovered from the ACS samples. Figure 6.25 illustrates examples of starch granules recovered from 41CV1553, while Figure 6.26 illustrates examples of starch granules recovered from the non-cultural rock and air control samples. Finally, most of the identifiable and diagnostic starch granules recovered from the FCR was recovered from the bottoms of the FCR (Figure 6.23). No identifiable and diagnostic starch granules were recovered from the RCS (Figure 6.24).

Table 6.8. Starch granules recovered from 41CV1553.

Artifact and Level	Site and Feature	Sample Type	*Zea mays*	Fabaceae	*Quercus* sp.	*Opuntia sp.*	cf. *Apios*	cf. *Liatris*	cf. *Claytonia*	Faceted > 5 µm	Small Faceted (<5µm)	Ovid	UnID /Deg	Gel
M-2	41CV1553 F-8E	FCR	0	0	0	0	0	0	0	0	0	0	1	1
M-3	41CV1553 F-8E	FCR	0	0	0	0	0	0	0	1	0	0	0	1
M-3 CaCO3	41CV1553 F-8E	FCR	1	0	0	0	0	0	0	0	0	0	0	0
M-4	41CV1553 F-8E	FCR	0	1	0	0	3	0	0	0	0	0	3	3
M-4 CaCO3	41CV1553 F-8E	FCR	0	0	1	0	0	0	0	0	0	0	0	1
M-5	41CV1553 F-8E	FCR	0	0	0	0	0	0	0	0	0	0	2	0
M-6	41CV1553 F-8E	FCR	0	0	0	0	0	0	0	0	0	0	0	0
M-7	41CV1553 F-8F	FCR	0	0	0	0	0	0	0	1	0	0	0	1
M-8	41CV1553 F-8	FCR	0	0	0	0	0	1	1	1	0	0	0	4
M-9	41CV1553 F-6	FCR	0	0	0	0	0	0	0	0	0	0	3	0
M-12	41CV1553 F-6	FCR	0	0	0	0	0	0	0	0	0	0	1	0
M-16	41CV1553 F-6	FCR	0	0	0	0	0	0	0	0	0	0	0	0
M-17	41CV1553 F-6	FCR	1	0	0	0	0	0	0	0	0	0	0	4
M-17 CaCO3	41CV1553 F-6	FCR	1	0	0	0	0	0	0	3	0	0	0	0
M-18	41CV1553 F-6	FCR	0	0	0	0	0	0	0	0	0	0	1	0
M-18 CaCO3	41CV1553 F-6	FCR	0	0	0	0	0	0	0	0	0	0	1	1
M-19	41CV1553 F-6	FCR	0	0	0	0	0	0	0	0	0	0	0	2
Bedrock 1	41CV1553 F-6	RCS	0	0	0	0	0	0	0	1	0	0	0	2
Off-Site 1	41CV1553	RCS	0	0	0	0	0	0	0	0	0	0	1	0
Off-Site 3	41CV1553	RCS	0	0	0	0	0	0	0	0	0	0	0	0
Air Sample 1	41CV1553	ACS	0	0	0	0	1	0	0	0	1	4	1	0
Air Sample 2	41CV1553	ACS	1	0	0	1	0	0	0	0	0	0	0	1
Air Sample 3	41CV1553	ACS	0	0	0	0	0	0	0	0	0	0	0	0

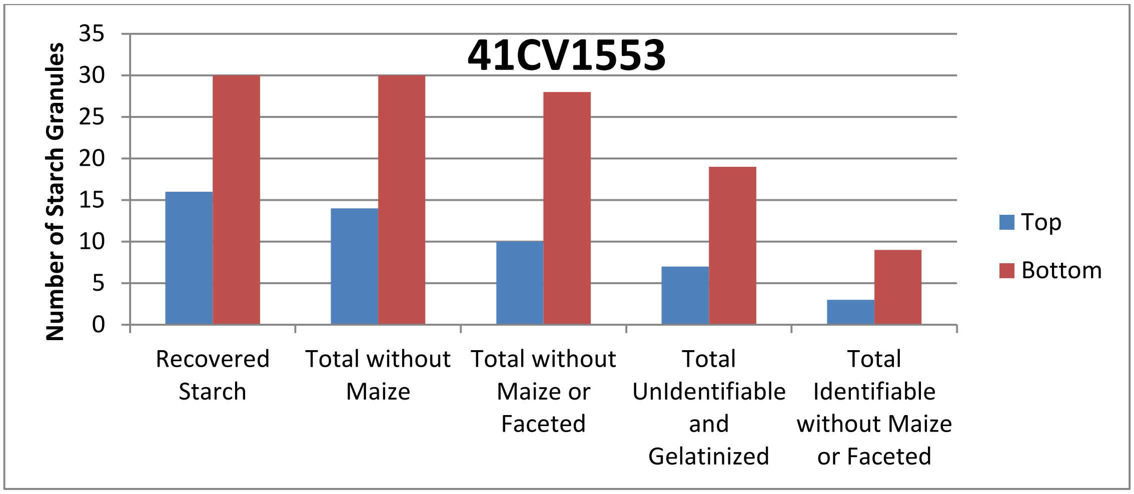

Figure 6.23. Number of starch granules recovered from top and bottom of FCR from 41CV1553.

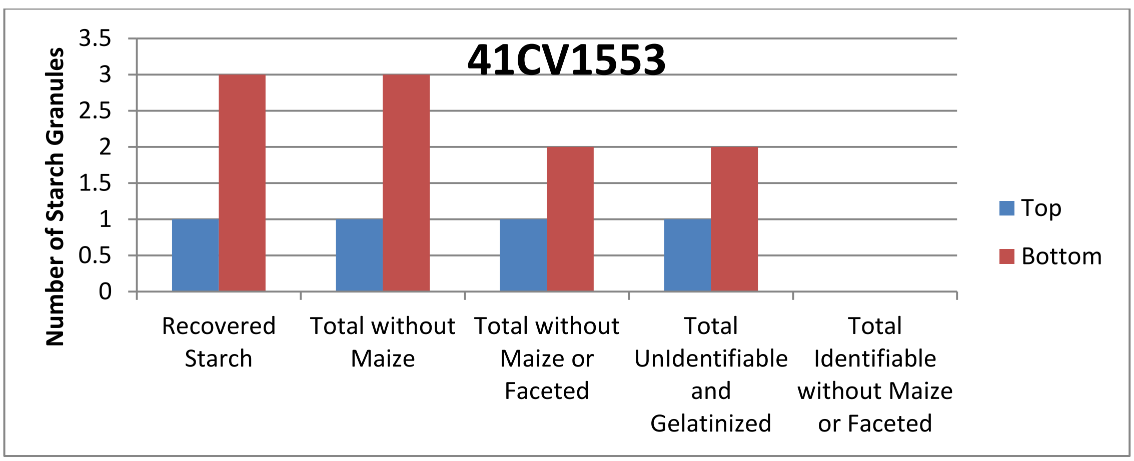

Figure 6.24. Number of starch granules recovered from top and bottom of FCR from 41CV1553.

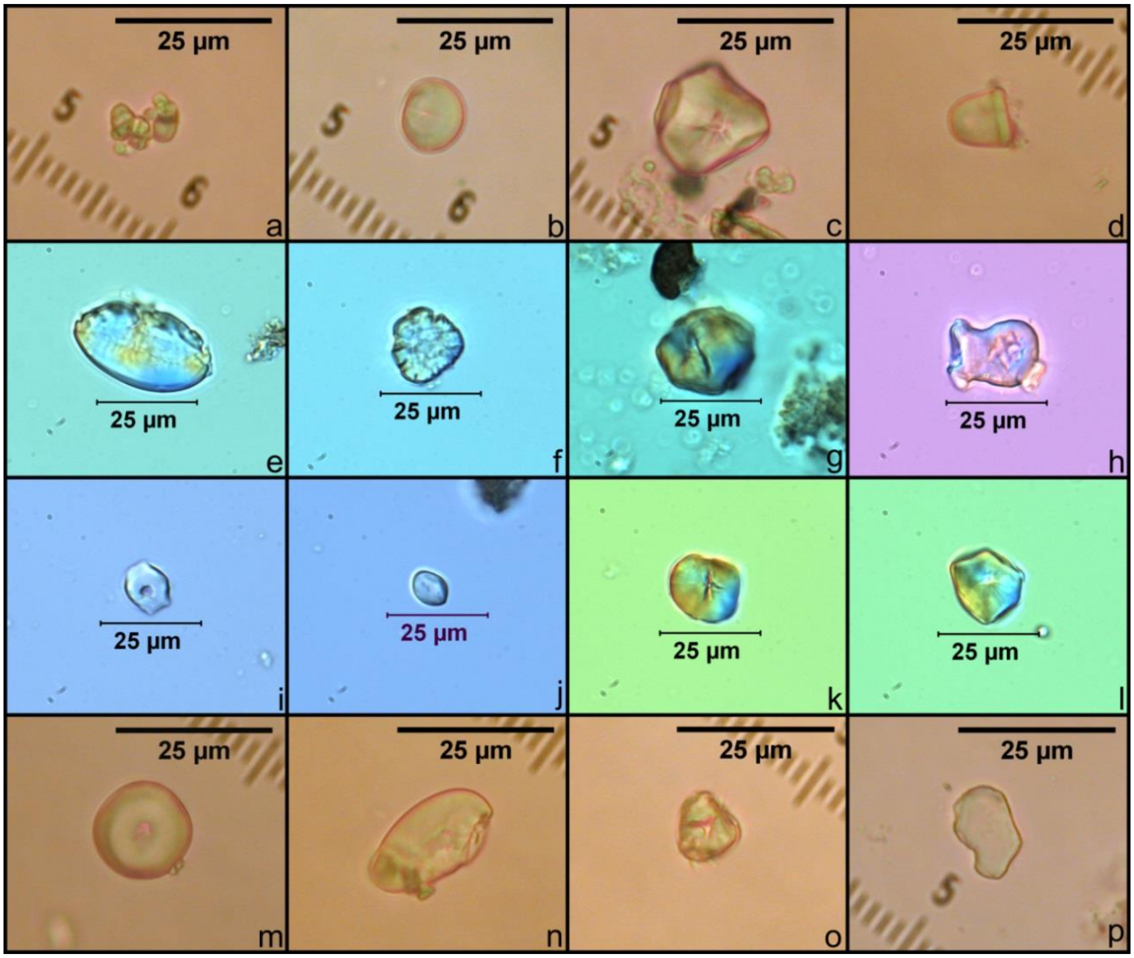

Figure 6.25. Starch granules recovered from (a-d) 41CV594, (e-i) 41CV947, (j-l) 41CV1104, and (m-p) 41CV1553 artifacts. Starch granules identified as (a) grass, (b and k) lily, (c, g, and l) maize, (d) unknown type A, (e, j, and n) common bean, (f) gelatinized starch, (h) unknown type F, (i) unknown type G, (m) eastern springbeauty, (o) narrow-leaf gayfeather, and (p) cf. groundnut. Micrographs a-d and m-p are under brighfield illumination whereas e-l are under ¼ λ polarized light.

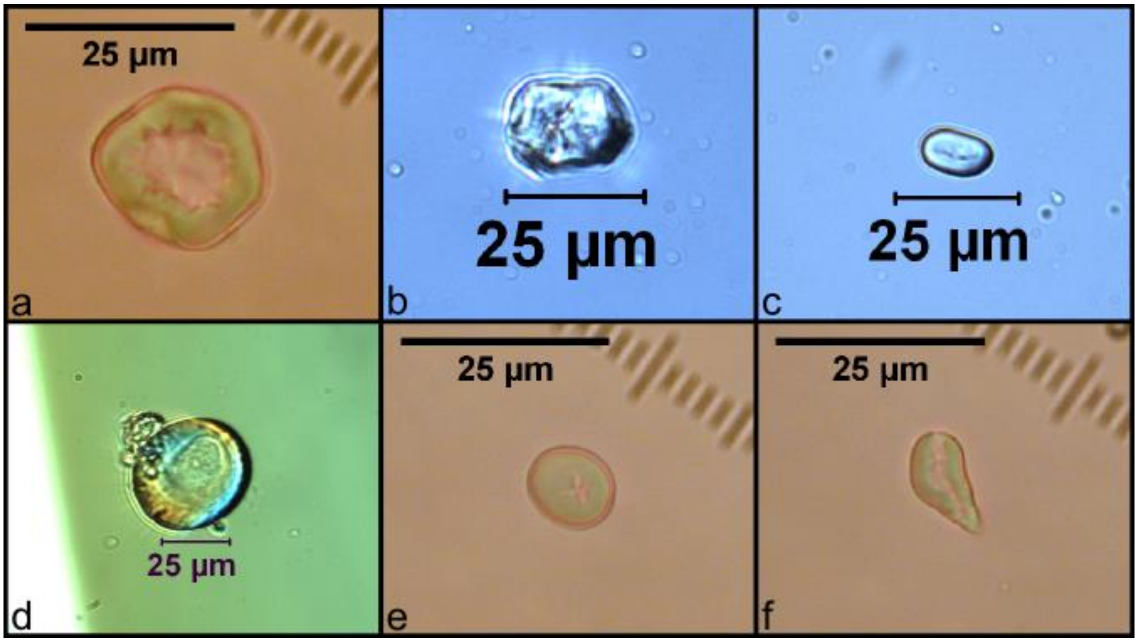

Figure 6.26. Selected starch granules recovered from 41CV594, 41CV947, 41CV1104, and 41CV1553 control samples. Starch granules include: (a and d) unidentifiable, (b) maize, (c) common bean, (e) non-diagnostic ovoid, and (f) cf. *Apios* (groundnut).

Effectiveness of Field Collection and Handling Techniques

To evaluate the effectiveness of the field collection and artifact handling techniques a comparison was made between the curated artifacts that were collected and handled without the use of powder-free latex gloves and were left exposed to the atmosphere for a year or more with artifacts that were collected using a clean trowel and powder-free latex gloves, and were sealed in a sterile bag immediately after collection. While it is difficult to tease out archaeological starch from modern starch when non-domesticated plant species are involved, a notable difference between the curated artifacts and those collected and handled with the above methods is the presence of clusters of gelatinized starch granules (Thoms *et al*. 2013). Clusters of gelatinized starch were recovered on several curated artifacts and sediment samples that are very similar to clusters of starch granules obtained from the author's fingerprints after handling starch-rich corn chips (Figure 6.5). Such clusters of gelatinized starch granules are absent from subsequent samples collected in the field. The absence of clusters on artifacts collected using contamination control measures suggests that contamination from the excavators' hands may have been minimized.

Effectiveness of Clean Bench

To evaluate the effectiveness of the clean bench, the recovered starch assemblages from artifacts processed under this devise and artifacts processed without a clean bench were compared to starch granules recovered in air samples taken in the lab. Numerous types of starch granules were recovered from air samples taken in both the Archaeological-Ecology Laboratory (AEL) and the Palynology Research Laboratory (PRL) (Figure 6.27). Starch granules a-b and e-o in Figure 6.27 most likely came from maize, thereby rendering them an unreliable measurement of airborne contamination given that their presence could be attributed to contact with "powder-free" gloves rather than as part of the starch rain. Apart from maize, one cf. groundnut (*Apios americana*) and one unidentifiable starch granule was recovered in an AEL air sample (Figure 6.27c and d) while one wheat starch granule was recovered in a PRL air sample (Figure 6.27p). Wheat starch granules were not recovered from any of the artifacts regardless of whether the clean bench was used in processing. However, cf. groundnut starch granules were recovered from artifacts processed under the clean bench. Air samples taken within the clean bench only yielded maize starch granules, which most likely came from the gloves worn while handling the samples under the clean bench.

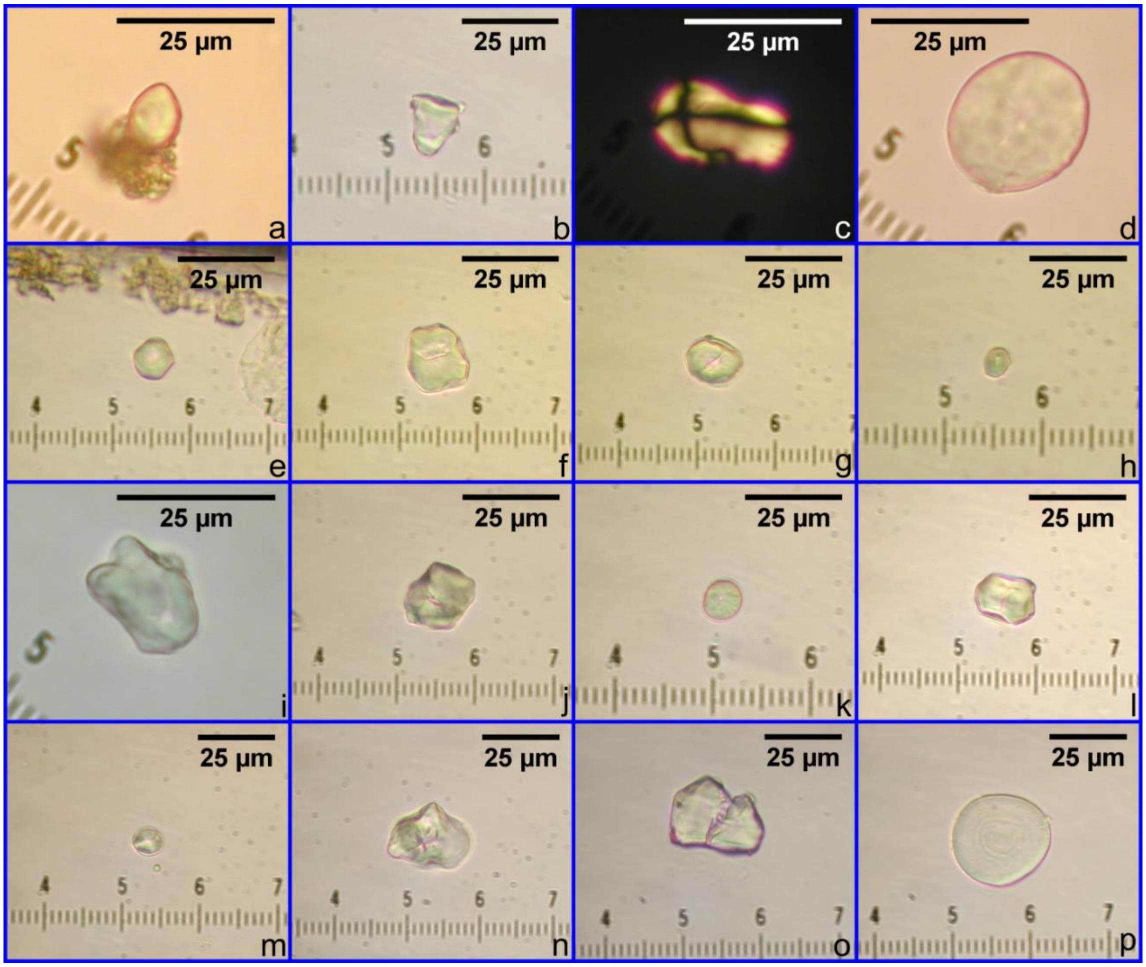

Figure 6.27. Starch granules recovered from air samples taken in (a-h) the AEL and (i-p) PRL at Texas A&M University. Micrographs a-b and d-p are under brightfield illumination while micrograph c is under cross-polarized light.

Statistical Analysis

Mann Whitney U tests were run on all of the artifacts and control samples to determine if they can be statistically separated. When comparing the number of

Statistical Analysis

Mann Whitney U tests were run on all of the artifacts and control samples to determine if they can be statistically separated. When comparing the number of recovered taxa and number of starch granules between the FCR and rock control samples (RCS) from all sites, no significant differences are observed (Table 6.9). All sites were combined for this analysis due to the relatively small number of FCR samples from individual sites. When comparing the difference between the numbers of starch granules recovered from the top and bottom of the FCR, clear differences are observed. Finally, when comparing the differences between the percentages of starch granules recovered from the tops and bottoms of FCR vs. RCS, no significant differences are observed. This suggests that starch granules were accumulated on the tops and bottoms of FCR and RCS in similar proportions.

Table 6.9. Mann Whitney U Test comparing recovered number of taxa, number of recovered starch granules, percent of starch granules recovered from the top of samples and number of starch granules recovered from bottom of samples.

Ranks

	Sample Type	N	Mean Rank	Sum of Ranks
Total Number of Taxa	1	86	53.98	4642.00
	2	21	54.10	1136.00
	Total	107		
Number of recovered starch	1	86	54.16	4657.50
	2	21	53.36	1120.50
	Total	107		
Percent Recovered from Top	1	86	55.13	4741.50
	2	21	49.36	1036.50
	Total	107		
Percent Recovered from Bottom	1	86	53.87	4632.50
	2	21	54.55	1145.50
	Total	107		

Test Statistics[a]

	Total Number of Taxa	Number of recovered starch	Percent Recovered from Top	Percent Recovered from Bottom
Mann-Whitney U	901.000	889.500	805.500	891.500
Wilcoxon W	4642.000	1120.500	1036.500	4632.500
Z	-.016	-.107	-.806	-.093
Asymp. Sig. (2-tailed)	.987	.915	.420	.926

a. Grouping Variable: Sample Type

Top vs. Bottoms of FCR and RCS

When the identifiable and diagnostic starch granules from all of the sites are combined, the majority of starch granules were recovered from the top of the FCR (Figure 6.28). However, given that Sample 44 from 41CV948 was an outlier with over

5054 starch granules, once it was excluded from the total, the majority of identifiable and diagnostic starch granules were recovered from the bottoms of the FCR (Figure 6.29). Similarly, when the total identifiable and diagnostic starch granules recovered from the RCS at each site were combined, the majority of starch granules were recovered from the bottom (Figure 6.30).

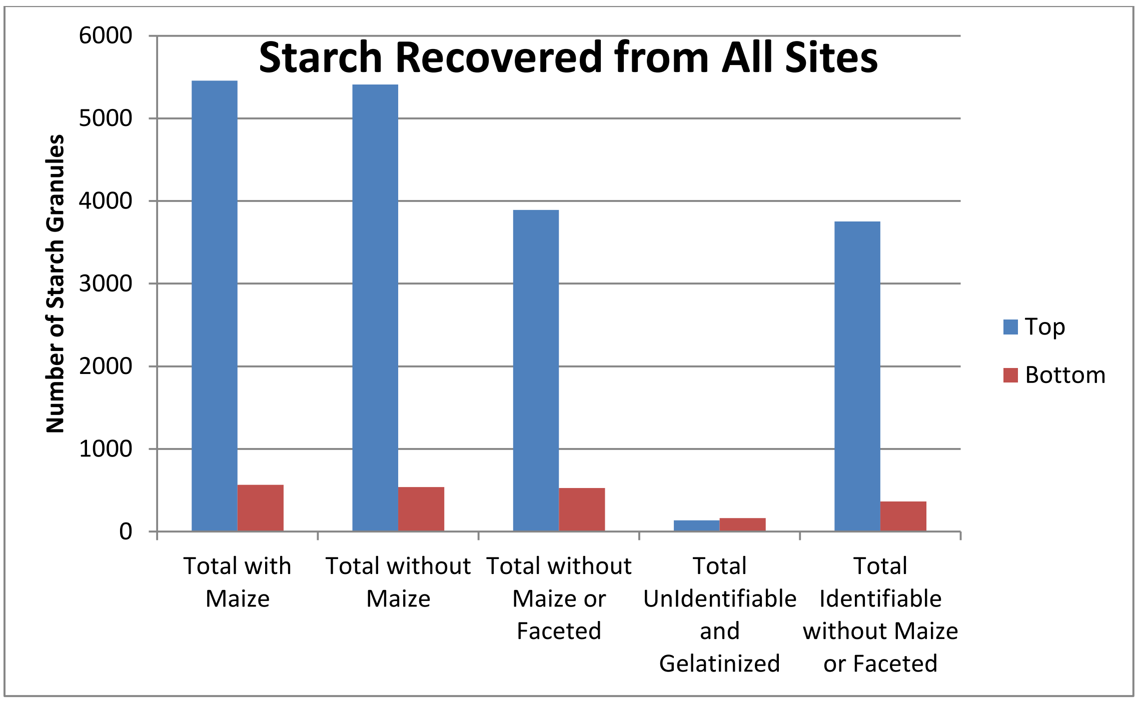

Figure 6.28. Comparison between the numbers of starch granules recovered from the tops and bottoms of the FCR from all sites.

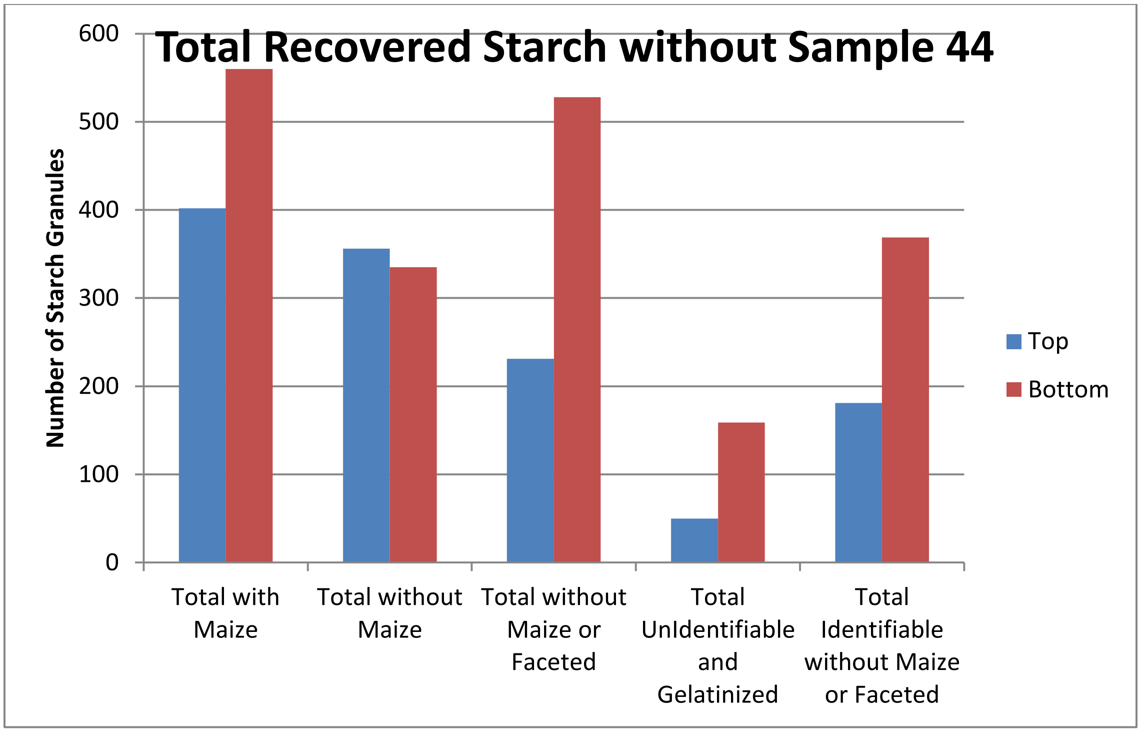

Figure 6.29. Comparison between numbers of starch granules recovered from the tops and bottoms of FCR without Sample 44 from 41CV984.

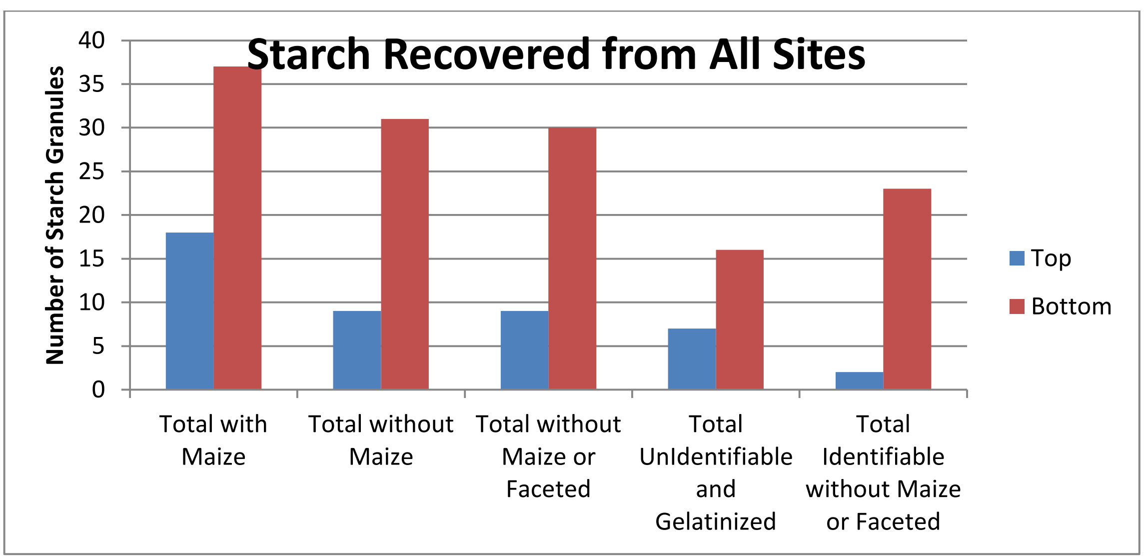

Figure 6.30. Comparison between the numbers of starch granules recovered from the tops and bottoms of the RCS from all sites.

Differences between FCR and Control Samples

Many taxa were recovered from both the artifacts and control samples (Table 6.10). Out of the 25 recovered taxa, 11 were unique to the FCR. Of those, 3 categories consist of non-diagnostic starch granules that could very well belong to other identified or unidentified taxa (compound, round > 5µm, and round < 5µm) and clusters of granules where the number of starch granules were clustered too tightly together for any individual granules to be identified, such as those in Figure 6.7n. The four unknown starch types (Unknown A, B, F, and G) were unique to the FCR, although in the case of Unknowns B, F, and G only one starch granule from each category was recovered. Unknown A was unique to the FCR, although that starch "type" is found in several different species, including maize and live oak, and cannot be considered diagnostic. Furthermore, compound starch granules were only recovered from the FCR, but compound starch granules can also be found in many different species and therefore cannot be considered diagnostic. Starch granules from cf. *Callirohoe*, cf. *Claytonia* were unique to FCR, although like Unknown types B, F, and G, only one starch granule from these taxa was recovered from the FCR. Finally, unidentified tuber starch granules were only recovered from the FCR. The significance of these results will be discussed in the following chapter.

Table 6.10. Starch taxa recovered from FCR, RCS, and ACS.

Taxon	FCR	RCS	ACS
Maize	x	x	x
cf. *Yucca*	x	x	
Liliaceae	x	x	x
Common Bean	x	x	x
***Quercus* sp.**	x	x	
Opuntia sp.	x	x	x
cf. *Apios*	x		x
cf. *Liatris*	x	x	
cf. *Callirhoe*	x		
cf. *Claytonia*	x		
Poaceae	x		x
UnID Tuber	x		
Compound	x		
Faceted > 5 µm	x	x	
Small Faceted (<5µm)	x		
Round >5 µm	x		
Small Round (< 5 µm)	x		
Ovid			x
Clusters of granules	x		
Unknown A	x		
Unknown B	x		
Unknown F	x		
Unknown G	x		
Un-identifiable/Degraded	x	x	x
Gelatinized	x	x	

Summary

This chapter presented the results of the different analyses performed in this study as well as displaying the reference collection used at the AEL at Texas A&M University. Starch granule contamination recovered from the curated artifacts demonstrates the importance of using contamination control measures when microfossil analysis is to be conducted. Of all of the features analyzed for starch granules, only one feature, Feature 4 from 41CV984 yielded very high concentrations of starch granules. From that feature, 97% of the total recovered starch came from one piece of FCR. Both RCS and ACS samples yielded starch granules from taxa similar to those recovered from the FCR, and the starch granule assemblages from the FCR could not be statistically separated from the starch granule assemblages recovered from the RCS. However, there are 11 taxa unique to the FCR, although only two of which can be identified to a specific taxa as the others are either non-diagnostic or unknown types where only one starch granule from each type was recovered.

Two interesting patters were observed. First, the prevalence of maize starch granules on all FCR and RCS and in ACS samples suggests that maize starch is a significant contaminant. Since maize agriculture was not practiced in Central Texas, and was therefore considered contamination as it is unlikely that maize was cooked in the investigated earth ovens (Collins 2004). Second, when observing where on FCR and RCS starch granules accumulated, the majority of starch was recovered from the bottoms of the samples. This is consistent with the model purposed by Thoms *et al*. (2013) where water moving through a sediment profile will deposit material on the bottom of rocks. The following chapter will discuss these results in greater detail and as well as their implications for archaeological starch granule research.

CHAPTER VII

DISCUSSION

The results of this study have important implications for future starch research. The following chapter will discuss the data presented in previous chapters and put it into a much broader archaeological context. Before the recovered starch assemblages recovered from the artifacts from Fort Hood can be analyzed, several issues regarding starch contamination first needs to be discussed.

Field Control Methods

Collecting artifacts using a clean trowel while wearing powder-free latex gloves proved to be an effective method of reducing contamination from excavators, but it may not prevent it. Clusters of gelatinized starch like those recovered from the curated samples were not recovered from the artifacts collected using these contamination control methods. The only exception lies with the latex gloves themselves that were actually a source of contamination. Furthermore, the non-cultural rocks and air control samples were successful in their ability to gauge the non-cultural starch contamination occurring at the sites in that they collected contamination from the environment. While the control samples identified potential sources of contamination, it still remains unclear as to what taxa can be eliminated as contamination and what can be considered archaeological. This topic will be discussed in greater detail later in this chapter. Finally, while this contamination control measure was not employed in this study, excavators should wash their hands prior to collecting samples for starch granule analysis even if they are going to wear powder-free latex gloves. This step may limit the number of starch granules transferred from the hand to the outside of the powder-free gloves when the gloves are put on prior to sampling.

Laboratory Contamination Control Methods

All of the laboratory control methods used in this study proved to be effective in minimizing contamination. Washing artifacts prior to sampling removed much of the simulated airborne contamination, i.e. maize starch. Furthermore, most of the culturally relevant starch (Irish potato) remained adhering to the simulated groundstone. These results are very encouraging, and suggest that loosely adhering starch granules that are deposited on artifacts via airborne contamination can be largely removed without removing archaeological starch.

While washing artifacts in the lab helped to remove modern airborne contamination from both the field and lab, the use of the clean bench with a 0.5 µm filter eliminated airborne starch contamination in the lab. Air samples taken within the clean bench did not yield starch granules. This suggests that if all processing and handling of artifacts is done under a clean bench, airborne contamination can effectively be eliminated within the lab.

Unfortunately, the supposedly powder-free gloves proved to be a source of contamination within the lab, including the clean bench, as well as in the field. Periodic testing of the gloves used in the lab yielded maize starch granules. This undermines both washing artifacts prior to processing as well as the use of a clean bench. So long as the gloves have starch adhering to their surface, this starch will continue to contaminate artifacts and appear to apart of the starch assemblage.

Starch Recovered from Curated Fort Hood Artifacts

Unfortunately, the curated artifacts were most likely contaminated due to handling of the artifacts during excavation and post-excavation analyses and curation, as indicated by the presence of clusters of gelatinized starch similar to that recovered from the author's fingerprints after eating corn chips. Furthermore, the artifacts were exposed to the atmosphere for extended periods of time during excavation and analysis, thereby accumulating airborne starch contamination. For these reasons, no attempt was made at interpreting the starch granule assemblages recovered from these artifacts as it was difficult to tease out archaeological starch from modern contamination. While culturally significant data was not obtained from the curated artifacts, they do provide a cautionary tale as to the prevalence of starch contamination during all stages of artifact recovery, analysis, and curation.

Starch Recovered from non-Curated Fort Hood FCR

Overall, the number of recovered starch granules from FCR was fairly low. Out of all of the sites, 41CV984 yielded the numbers of starch granules hoped to be recovered from earth ovens where hundreds of kilograms of plant foods were cooked, thereby releasing thousands of starch granules into the local environment (Thoms *et al*. 2013). Even with the high recovery from 41CV984, 99% of the recovered starch was recovered from one artifact (Sample 44). Apart from Sample 44, only Sample 23 from 41CV984 yielded significant numbers of starch granules. The term "significant" here is arbitrarily defined as 10 or more starch granules that can be identified to a specific taxon that is not maize or non-domesticated grass. Ten starch granules was chosen as the significant value since it is greater than the number of starch granules recovered from the control samples excluding maize and non-domesticated grass. Maize and non-domesticated grass is considered non-significant since maize is clearly a contaminant and grass starch is airborne in very high numbers (Schäppi *et al*. 1999). It is unknown if the grass starch is culturally relevant from the use of grass as packing material or contamination. Finally, non-identifiable/gelatinized and non-diagnostic starch was removed from consideration in the counts since the origin of these classifications cannot be determined either in terms of the specific taxon or pathway to the FCR (i.e. contamination or cultural). While some researchers argue that the presence of gelatinized starch is an indication of cultural processes (Babot 2003; Henry *et al*. 2009; Perry 2004; Perry 2005), natural processes can cause starch to gelatinize (Collins and Copeland 2011), and gelatinized starch is airborne (Laurence *et al*. 2011). Therefore, gelatinized starch cannot be assumed to be cultural in origin, especially when it is recovered in low numbers.

There are at least three mechanisms that might account for low recovery rates. First, it is possible that starch-rich plants were not cooked in any of the earth ovens apart from 41CV984, and therefore starch granules would not occur in any significant numbers. For instance, if inulin-rich plants such as onions were cooked in the ovens, as was the case with several of the features investigated in this study (41CV594, 41CV984, and 41CV1553) then starch granules related to the cooking event(s) would not be recovered. Based on the macrobotanical analysis (Leslie Bush, personal communication 2012), camas and wild onion bulbs accounted for 18% of the total recovered charred bulb and tuber fragments from all sites and 57% of the total identifiable charred bulbs and tubers. Given that camas and wild onions made up the majority of the identifiable charred bulb fragments, it seems likely that starch-rich plants were baked either less frequently or in smaller quantities thereby suggesting that few starch granules should be recovered from the features.

Second, there could be different preservation issues influencing starch survival at each sites that are yet unknown. Starch taphonomy remains a largely unexplored research area and the reasons why starch granules preserve at all are yet unknown (Haslam 2004). Experiments aimed at measuring microbial activity in soil demonstrate that there is a significant increase in microbial activity when starch is added to soil (Martínez-Trinidad *et al*. 2010). Therefore, it is possible that starch-rich plants were cooked in all of the earth ovens, but the starch granules did not survive on the FCR due to the increased microbial activity generated by the influx of starch granules into the local environment. Unknown factors at 41CV984 may have allowed greater numbers of starch granules to survive over time compared to the other sites. Finally, FCR from 41CV984 also had the highest concentration of $CaCO_3$ deposits than FCR from other sites. The more pronounced presence of $CaCO_3$ on the FCR suggests that water was moving through the feature, carrying small particles from the local environment, including starch granules released from plants during cooking episodes, and deposited them on the FCR (Thoms *et al*. 2013). As the $CaCO_3$ built up on the FCR, starch granules may have become trapped within these deposits and may have been protected from microbial activity (Thoms *et al*. 2013).

Comparison of FCR to Control Samples

The Mann Whitney U tests comparing the starch recovered from the FCR to those recovered from the rock control samples (RCS) showed that there were no significant differences between the number of starch granules and the number of taxa recovered from each site. These results were surprising considering the amount of starch granules that should be present in an earth oven when starch-rich plant foods are cooked, one would expect there to be significantly more starch on the FCR than the RCS. So why then were there no significant differences?

First, the lack of statistical difference between the number of taxa recovered from the FCR and ACS could be due to the fact that starch-rich plant foods baked in earth ovens are also growing in the natural environment. Therefore, starch granules from wild edible starch-rich plants are expected to enter the archaeological record both as food and contamination and should consequently be recovered from both FCR and control samples. Second, a lack of preservation due to microbial activity could be responsible for the paucity of starch granules recovered from the FCR. Only one site, 41CV984, yielded significant numbers of starch granules and a charred starch-rich bulb. Third, overall small samples sizes and sampling areas may have prevented statistical differences. Therefore, increasing both the number of samples and the sampling area in the future may reveal significant differences between starch granule assemblages between FCR and RCS.

In this study, less than 10% of the total FCR from each earth oven was analyzed for starch granules. Furthermore, a total of 2 cm^2 (including top and bottom) was analyzed from FCR at 41CV984 and 41CV1657 while a total of 52.8 cm^2 (including top and bottom) was analyzed from FCR at 41CV594, 41CV947, 41CV1104, and 41CV1553. The overall low recovery of starch granules from each site is probably a reflection of low numbers of FCR analyzed per earth oven. Furthermore, an estimated 5-70% of the total surface area was analyzed per piece of FCR or RCS. The reason for using delineated areas was so that concentration values could be calculated for statistical comparison. Had greater surface areas been analyzed for starch granules, however, then it is likely that greater quantities of starch granules would have been recovered from each piece of FCR. Perhaps sonicating the entire FCR sample, as described by Pearsall *et al*. (2004), after washing the sample and using mathematical formulas to calculate the surface area is more effective at recovering starch granules than spot sampling. Apart from increasing the sampling area, future work should also focus on "intensive" sampling of one earth oven at a time where at least 30% of FCR from each earth oven is analyzed for starch granules. By intensively sampling one feature, we will gain a better understanding of the intra-oven distribution of starch granules along with increasing the number of granules recovered per oven.

Finally, since inulin-rich plants, such as wild onions, were cooked in the earth ovens then few starch granules may be expected to be recovered from the FCR. Investigations into the number and types of charred bulbs recovered from earth ovens across Fort Hood suggest that usually only inulin-rich or starch-rich plants were cooked in a given earth oven, or at least during any given cooking episode (Boyd, Ringstaff and Mehalchick 2004:179-186). If this trend is correct, then starch granules are not expected to be recovered from single-use earth ovens that yielded camas or wild onion bulbs. However, multi-use ovens may represent cooking episodes of both inulin and starch-rich plants.

In this investigation the earth oven feature at 41CV984 yielded both starch-rich (false garlic) and inulin-rich bulbs (camas and wild onions). While this finding seems contrary to other earth ovens investigated at Fort Hood, this feature was used for over 1,000 years. Therefore, the presence of starch and inulin-rich bulbs may represent different cooking episodes rather than one event. Cooking inulin and starch-rich plants separately may be supported by different cooking requirements needed to render starch and inulin more nutritious, such as different cooking times (Wandsnider 1997). Cooking experiments by Thoms *et al*. (2013) support this notion as starch-rich plants, including false garlic were fully cooked after baking for 20 hours in an earth oven, whereas inulin-rich plants, including camas and wild onion were not fully cooked until 40 hours of baking. While the camas cooked in the 40 hour experimental earth oven burned due to a deficit of moisture within the oven, Thoms (1989) demonstrates the need to cook camas for 40 hours through experimental work and ethnographic case studies.

Although there were no significant differences between the FCR and RCS with respect to the number of recovered starch granules and taxa, there are a few observational differences that need to be explored. First, there are a few taxa excluding the non-diagnostic types that were only recovered from the FCR (Table 7.1). When comparing the FCR to the RCS, starch granules from cf. *Apios*, cf. *Callirhoe*, cf. *Claytonia*, Poaceae, and unidentified tuber were only recovered from the FCR. With the exception of Poaceae and unidentified tuber, these taxa only occurred in very small quantities.

Laurence *et al*. (2011) caution that the presence of a few starch granules may not be archeological in origin, as it can be the result of airborne contamination in the past or present. In fact, one of the taxa that did not occur on the RCS, cf. *Apios*, was recovered in an air sample. Furthermore, the presence of Poaceae may not be unique to the FCR. Both the ACS and RCS yielded small non-diagnostic starch granules (classified as "faceted < 5 μm") that could have been from Poaceae (grass). The high refractive index of Permount, the mounting medium used for samples from 41CV984 and 41CV1657 makes it difficult to identify features on starch granules smaller than 5 μm. One of the air samples from 41CV1657 had over 100 starch granules that were faceted and less than 5 μm. While these starch granules were most likely Poaceae, the features were distorted by the Permount and therefore cannot be securely identified as such. Even if the starch granules recovered in air sample were not Poaceae, the sheer number of Poaceae starch that is airborne (Schäppi 1999) precludes it from being considered unique for the FCR. It does need to be pointed out however, that grass is commonly used as packing material for earth ovens (Thoms *et al*. 2013). Therefore it is possible that the Poaceae starch granules are the result of ancient cooking episodes.

The unidentified tuber starch granules, however, do appear to be unique to FCR and they occur in high concentrations. While the taxon or taxa cannot be identified, it is unlikely that these starch granules originated from a domesticated species such as Irish potato since the size of these starch granules are too small to consistently originate from a domesticated potato such as those recovered from the author's fingerprint (see Figure 3.1). Had the tuber starch granules come from a domesticated species, then many of the recovered starch granules should have been over 30 µm rather than all of them being 15 µm or less.

Finally, none of the non-diagnostic starch granules were considered as distinguishing taxa. These categories were excluded from this analysis because individual species have a wide range of starch types many of which are non-diagnostic, and therefore the non-diagnostic starch recovered from the samples could potentially belong to the identified taxa or different taxa altogether. In sum, no individual taxa can be considered unique to the FCR samples based on ubiquity alone and therefore indicative of past human action rather than contamination. Since all of the recovered taxa were growing in the environment around the sites, the presence of one starch granule from cf. *Apios*, cf. *Callirhoe*, and cf. *Claytonia* on the FCR could be from contamination or ancient plant use (Laurence *et al*. 2011).

Table 7.1. Number of starch granules from identified taxa in ACS, FCR, and RCS.

	ACS	FCR	RCS
Maize	5	65	14
cf. Yucca	0	1188	7
Liliaceae	1	536	4
Fabaceae	1	3	1
Quercus.sp.	0	7	2
Opuntia.sp.	2	1281	4
cf. Apios	1	3	0
cf.Liatris	0	92	2
cf. Callirhoe	0	1	0
cf. Claytonia	0	1	0
Poaceae	0	265	0
UnID Tuber	0	72	0

While none of the identified taxa can be considered unique to the FCR, there are clear numerical differences between the numbers of starch granules recovered from the FCR compared to the RCS. Excluding maize and Poaceae, there were significantly more cf. *Yucca*, Liliaceae, cf. *Liatris*, and cf. *Opunita* starch granules recovered from the FCR (Table 7.1). This suggests that while individual taxa cannot be considered unique to FCR, there are taxa that occur in much greater frequency, although the majority of the recovered starch granules were recovered from a single FCR, Sample 44 from 41CV984. As it was alluded to above, it is possible that the burned-rock feature at 41CV984 may have been the only feature in this investigation in which starch-rich plants were cooked. If this is the case, then large quantities of starch granules are only expected to be recovered from that feature.

Apart from the higher numbers of cf. *Yucca*, Liliaceae, cf. *Liatris*, and cf. *Opunita*, clusters of starch granules were only recovered from the FCR (Figure 7.1). Clusters were only recovered from three pieces of FCR, including Sample 44 from 41CV984 that yielded over 5000 starch granules. The starch granules from Sample M-10 from 41CV594 belong to the Poaceae family, and many of the starch granules were gelatinized. These clusters, however, were very similar to the small faceted starch granules recovered from processed corn chips (Figure 7.1d). Given the size and modification of starch recovered from M-10, it is difficult to distinguish between non-domesticated Poaceae and maize starch granules, thereby making it difficult to determine whether or not the starch granules are archaeological in origin. While it is difficult to identify the vast majority of the individual starch granules in the cluster recovered from Sample M-61 from 41CV947 due to the high concentration of starch, starch granules belonging to the Fabaceae family (common bean) are present in the cluster. Most of the starch granules were not gelatinized. Starch often gelatinizes during cooking episodes where the water in the storage organs is heated in excess of 50^{o} C, although the amount of time for gelatinization to occur varies by species (Gott *et al*. 2006:45). This does not mean, however, that all starch gelatinizes during cooking episodes due to a variety of reasons (Eliasson and Karlsson, 1983; Lin *et al*. 1997; Şumnu *et al*. 1999). Given that the majority of visible starch granules were not gelatinized or partially gelatinized (i.e. modified) after during cooking episodes, it is unknown if the starch granules were deposited on the FCR during a cooking episode or were contamination, possibly from a trowel that cut through a Fabaceae root during excavation. The bean starch granules are unlikely to have originated in modern processed foods since the starch granules were largely unmodified.

Starch-rich plants were observed growing over all of the investigated sites, including narrow-leaf gayfeather and members of the lily (Lilieaceae) and bean (Fabaceae) families, thereby providing root systems capable of producing contamination if cut during excavation. Finally, the majority of starch granules clustered together in sample 44 from 41CV984 was also largely non-gelatinized. These clustered granules exhibit a wide range of morphological diversity suggesting that they most likely came from different taxa. However, given that charred remains of starch-rich lily-family bulbs were recovered from the burned-rock feature, it seems likely that the starch granules are archaeological in origin rather than contamination. Furthermore, unidentified tuber starch granules were recovered in high numbers (70) from this feature. Given that the size of these starch granules were 15 µm or less, contamination from processed foods such as potato chips can be ruled out as domesticated potato starch granules can be well over 30 µm and it is very unlikely that only small starch granules were transferred from an excavator's hands to the artifact.

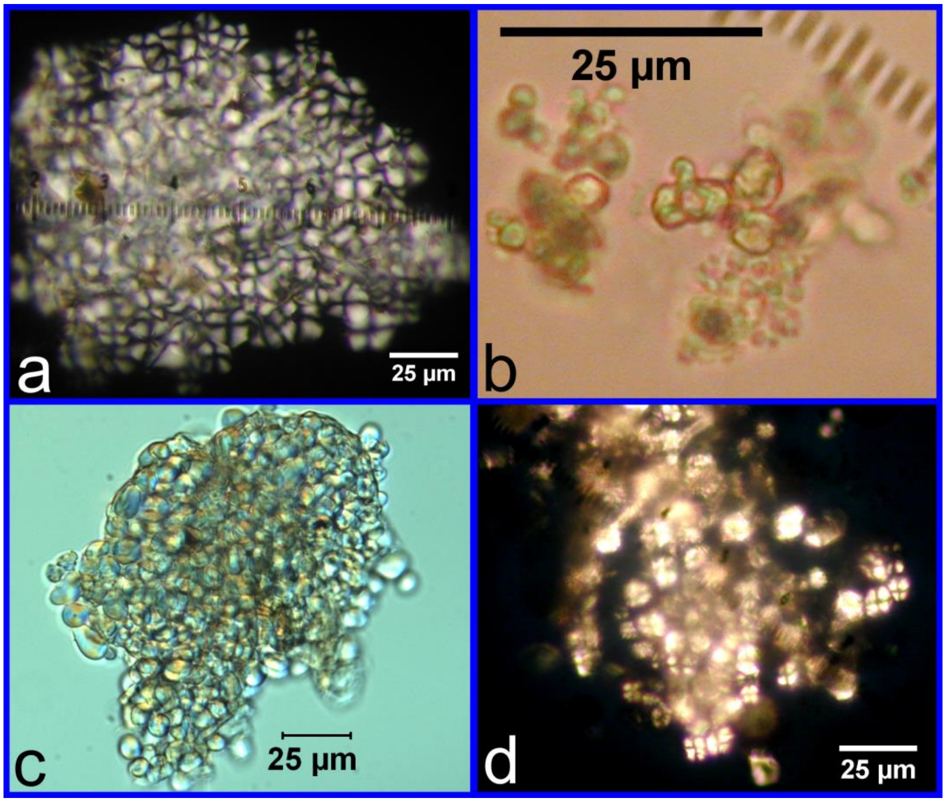

Figure 7.1. Clusters of starch granules recovered from (a) burned-rock midden at 41CV984, (b) basin-shaped oven at 41CV594, (c) flat oven at 41CV947, and (d) corn chips.

The clusters of starch granules were rare, as were FCR containing more than 10 non-maize, identifiable starch granules. Given the basin shape of the features and the fact that water flows to the lowest point, the expectation going into this study was that FCR in the center of the earth ovens should have the greatest concentration of starch granules (Thoms *et al*. 2013). The FCR with the starch clusters yielded the highest quantities of starch granules. Of these three FCR samples, Sample 44 from 41CV984 and Sample M-10 from 41CV594 were located near the center of an earth oven, although neither can be considered to have originated at the center of the oven (Figure 7.2).

Finally, M-61 from 41CV947 was located along the edge of the feature. Given that the FCR with the greatest number of starch granules, excluding the clusters, originated near the center of the features, the model proposed by Thoms *et al*. (2013) suggesting that starch granules may be recovered in highest densities in the center of earth ovens may be correct. Finally, the majority of identified charred bulbs recovered from all investigated ovens came from inulin-rich plants. Therefore, additional data from earth ovens where it is known that starch-rich plants were cooked is needed to verify this hypothesis since starch-rich plants may have only been cooked at 41CV984.

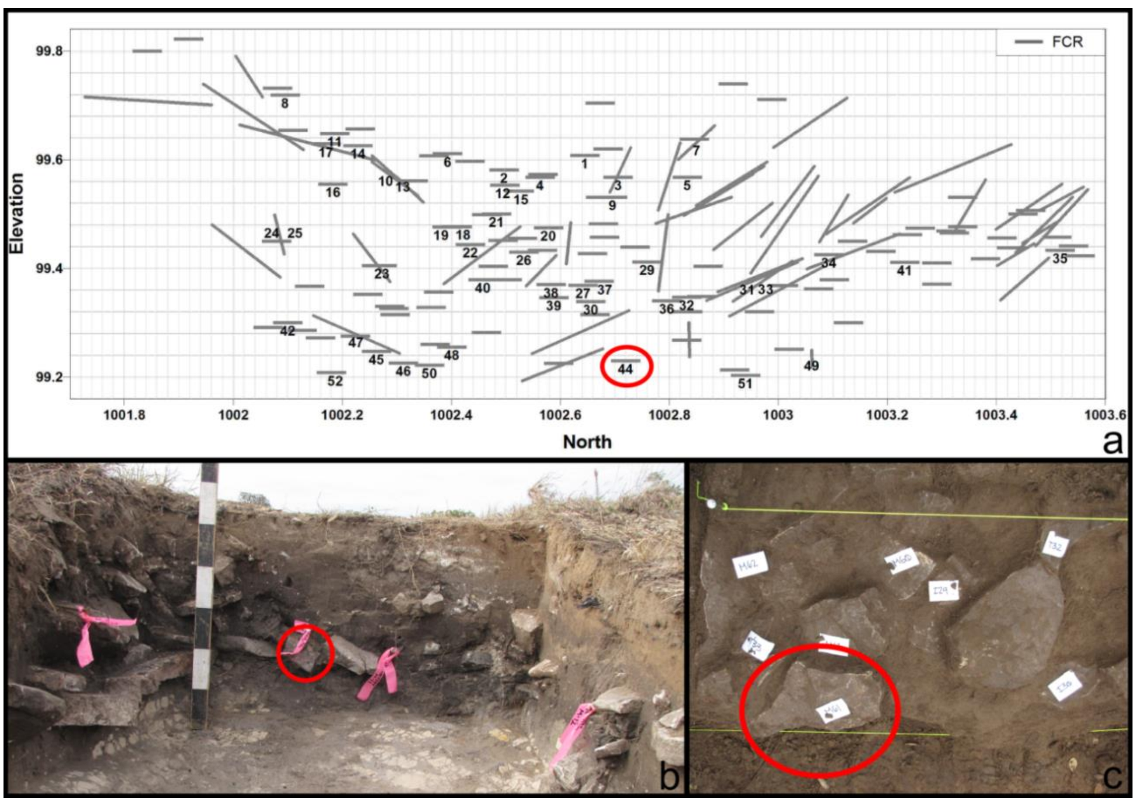

Figure 7.2. Location of artifacts with starch clusters within the feature of origin: (a) sample 44 from 41CV984, (b) M-10 from 41CV594, and (c) M-61 from 41CV947.

Thus far, air control samples (ACS) have not been discussed in any great detail. The most formidable problem associated with the air samples is whether or not taxa recovered in air samples should be eliminated for consideration as archaeological starch, even if those taxa are also recovered from FCR. The problem with simply eliminating taxa resides in the fact that non-domesticated species such as greenbrier, winecup, and false garlic grow near the sites, both today and in the past were also potential or known food resources (Havard 1895; Thoms 2009). For instance, Liliaceae starch was recovered from two FCR samples and one ACS at 41CV984. Furthermore, charred Liliaceae bulbs were also recovered from the feature. Had Liliaceae bulbs not been recovered, Liliaceae as a taxon might have been removed as a potential food resource based on its recovery in the ACS although Liliaceae USOs were clearly baked in this particular earth oven. Therefore, the recovery of a starch type in an air sample does not preclude it as a food resource.

In situations where a taxon is recovered both in air samples and FCR, but no charred remains are recovered, then quantitative analysis may be used to differentiate archaeological starch from contamination. For instance, very high concentrations of cf. *Yucca* (1162 starch granules), cf. *Opuntia* (1266 starch granules), and cf. *Liatris* (90 starch granules) starch granules were recovered from Sample 44 at 41CV984, much higher concentrations than were recovered in air samples. Although charred remains from these taxa were not recovered, the high concentration of these starch granules, many of which exhibit signs of modification, suggests that they were related to ancient cooking episodes rather than contamination. In the case of the Fabaceae starch granules, however, only four granules were recovered from three different FCR from three different features whereas two Fabaceae starch granules were recovered in two ACS. It is possible that storage organs from Fabaceae were cooked in those earth ovens, but the low concentration of recovered Fabaceae starch granules can be explained both by cultural use and airborne contamination. In sum, while the air samples provided information regarding the types of modern airborne contaminates at Fort Hood, the contaminates belonging to non-domesticated taxa that were growing near the sites in the past and present, many of which were potential food resources. Therefore, it is unknown at this time if the non-domesticated taxa that were recovered both on the FCR and ACS represent contamination, food, or both.

Non-domesticated food resources are not the only source of ambiguity in determining if recovered starch granules are cultural or non-cultural in origin. Starch-rich packing material can also prove to be difficult to tease out. Experimental earth ovens built as part of the ongoing Pauxly Sands Project at Fort Hood used little bluestem grass (*Schizachyrium scoparium*) and oak (*Quercus*) packing material (Thoms *et al*. 2013). Grass is one of the most prolific airborne starch producers on the planet (Schäppi *et al*. 1999). Given that there is an estimated 10,000 grass starch granules/m^3 in the atmosphere during the grass pollinating season, starch granules from this taxon could have been deposited in ancient earth ovens during the ovens' construction and after cooking evens as the FCR are exposed to the atmosphere while the rocks were cooling down or left exposed on the surface. Similarly, if grass was used as a packing material, then large quantities of grass starch are expected to be part of the archaeological starch assemblage, thereby making it difficult to determine whether or not grass starch granules recovered from FCR are from the packing material or atmosphere. Experimental earth ovens constructed by Thoms *et al*. (2013) illustrates this point. Little bluestem grass stems and live oak leaves were used as packing material for these ovens. Starch granules from both grass and oak were recovered from the FCR whereas starch granules from grass were also recovered from an air sample taken during the duration of the baking experiments (Thoms *et al*. 2013). In these experiments, as it may be for the earth ovens sampled at Fort Hood, grass starch granules recovered from samples may represent both packing material and contamination.

Top vs. Bottom of Samples

The majority of starch granules were recovered from the bottom of both FCR and RCS samples when Sample 44 from 41CV984 was removed from the analysis. Furthermore, greater numbers of starch granules were recovered from the bottoms of FCR and RCS samples. This follows the Thoms *et al*. (2013) model where starch granules suspended in water will accumulate on the bottoms of FCR much in the same way as calcium carbonate ($CaCO_3$) deposits. Although FCR and RCS from most of the sites had very little $CaCO_3$ deposits, $CaCO_3$ deposits were greatest on the bottoms of the FCR and RCS from 41CV984 and 41CV1657. Since waterborne particles of $CaCO_3$ were deposited in greater numbers on the bottom of the samples from these sites, waterborne starch granules were also expected to accumulate on the bottoms of the samples as well (Thoms *et al*. 2013). With regard to Sample 44, over 99% of the starch granules were recovered from the top surface. It is unknown why the vast majority of starch granules were recovered from the top surface, although it is possible the high concentrations of less permeable clay particles in the burned-rock midden may have prevented the majority of starch granules from accumulating on the bottom surface. When Sample 44 was removed from the analysis, the majority of identifiable starch granules excluding maize and faceted starch granules recovered from 41CV984 was recovered from bottom rather than the top, whereas only 30% of the total FCR yielded more starch from the top, 40% from the bottom, and 30% had the same amount of starch recovered from the top and bottom. This suggests that while more total starch granules were recovered from the top surface of FCR from this feature, most of FCR had more starch granules on the bottom surface and most of the identifiable starch granules excluding maize and faceted were recovered from the bottom surface. Based on these results, the model proposed by Thoms *et al*. (2013) where more starch should be recovered from the bottom surfaces seems to hold true for the investigated features.

Cultural or Contamination?

Starch contamination is clearly a significant obstacle when conducting archaeological starch granule research. Given that contamination from air fall, direct contact with the excavator (gloves and fingerprints), and contact with starch-rich roots during excavation was observed during all sampling, collection, and processing stages, it is difficult to isolate starch that is both ancient in origin (i.e. not modern) and related to human activities rather than some form of contamination. This study demonstrates the difficulty of teasing out cultural vs. non-cultural starch when non-domesticated species are the staple plant resource. If non-domesticated taxa were utilized by ancient people and growing locally both in the past and present, the recovery of those taxa would be expected in both archaeological and control samples. Unfortunately, the condition of the starch granules, i.e. modified vs. unmodified, does not reflect whether or not recovered starch is cultural or non-cultural in origin as modified starch is airborne and starch can gelatinize by means of natural processes (Collins and Copeland 2011; Laurence *et al*. 2011).

Based on the available evidence, only starch granules recovered from the burned-rock midden (Feature 4) at 41CV984 can be considered with confidence to be indicative of past human cooking activities. First, although Liliaceae, cf. *Yucca*, cf. *Opuntia*, and cf. *Liatris* starch granules were recovered from the RCS as well as the FCR, the sheer number of Liliaceae (531), cf. *Yucca* (1162), cf. *Opuntia* (1266), and cf. *Liatris* (90) starch granules compared to the one Liliaceae, one cf. *Yucca*, two cf. *Opuntia*, and no cf. *Liatris* starch granules recovered from RCS samples suggests that plants from this family were cooked in the oven. The significant numerical difference alone between Sample 44 and any of the control samples suggests that higher numbers of starch granules were deposited in that feature, as is expected from cooking episodes (Thoms *et al*. 2013). Second, charred macrobotanical remains of starch-rich bulbs were recovered from the oven, namely those belonging to the Liliaceae family. The multiple lines of evidence provided by both the charred Liliaceae bulbs and starch granules suggests that starch-rich foods, at least from this taxon, were indeed cooked in this oven.

Furthermore, Feature 4 yielded a greater number of represented taxa than any of the other features or sample types. Feature had radiocarbon dates ranging from ~2750-1910 BP, indicating that it was used multiple times over a 800 year time period (Leslie Bush, personal communication 2010). The hundreds of kilograms of starch-rich plants that were cooked in the ovens through time may have increased the chances of starch survival by adding more starch to the oven over time.

It is possible that starch-rich foods could have been cooked in the earth ovens at the other sites, however, ancient and/or modern contamination can also account for the recovered starch assemblages. Although the starch granules recovered from the other five sites cannot be classified as archaeological in origin, it does not mean that plant foods were not cooked in these earth ovens. Inulin-rich plants are common throughout Fort Hood (Boyd *et al*. 2004). Features from half of the investigated sites (41CV594, 41CV984, and 41CV1553) yielded charred camas and/or wild onion (57% of the total identified charred bulb/tuber remains), both of which are inulin-rich plants (Leslie Bush, personal communication 2012). The fact that starch recovered from the FCR and RCS could not be differentiated may be due to the possibility that inulin-rich plants were cooked in the features as opposed to starch-rich plants. If this is the case, as suggested by the presence of charred camas and wild onion, then recovered starch granule assemblages are expected to be different between FCR and RCS.

Finally, sample size and lack of $CaCO_3$ deposits may be factors as well. Heavy concentrations of $CaCO_3$ were only found on FCR from 41CV984 and 41CV1657. Of those two sites, only 41CV984 yielded significant quantities of starch granules and/or charred macrobotanical remains from starch-rich taxa. As previously discussed, $CaCO_3$ deposits may provide a protected setting for starch granules. While 41CV594 and 41CV947 yielded charred unidentified tuber remains, starch granules belonging to tubers were not recovered. It is possible that tubers were inadvertently charred and added to the features' sediment matrix as the ovens backfilled after cooking episodes while the FCR was still hot, or the lack of $CaCO_3$ deposits may have prevented starch granule preservation. Finally, the sample size in terms of the number of sampled FCR and the sampling area on individual FCR may not be large enough to detect differences between FCR and RCS samples. It is possible that larger sample sizes than those used in this study are needed to address this issue.

The Maize Dilemma

Perhaps the most important "discovery" was the sheer amount of maize starch granules that can enter into the archaeological record from modern contamination sources. There is no archaeological evidence that maize agriculture was practiced in greater Central Texas, including at Fort Hood (Collins 2004). Maize starch, however, comprised 19.75% of FCR, 31.25% of ACS, and 40% of RCS total starch assemblages (Table 7.2). Maize starch was overwhelmingly dominant despite the fact that maize was not a part of the hunter-gatherer diet in Central Texas.

Table 7.2. Percent of identified taxa from ACS, FCR, and RCS.

	ACS	FCR	RCS
Maize	31.25	19.75	40
cf. Yucca	0	13.58	20
Liliaceae	6.25	6.17	20
Fabaceae	6.25	2.47	6.67
Quercus sp.	0	4.94	13.33
Opuntia sp.	12.5	8.64	20
cf. Apios	6.25	1.23	0
cf. Liatris	0	3.7	6.67
cf. Callirhoe	0	1.23	0
cf. Claytonia	0	1.23	0
Poaceae	0	3.7	0

If maize was not cooked in the earth ovens, then where did the maize come from? The most parsimonious answer is that the author inadvertently added maize to the sample by using supposedly powder-free latex gloves to handle and process the artifacts. Even though the gloves are made “powder-free” (without the use of maize starch during the manufacturing process), the gloves are still made in the same factories as their powdered counterparts (Cassandra McDonough, personal communication 2011). Maize starch airborne within the factories settled on the “powder-free” gloves and their boxes prior to being sealed and shipped, thereby contaminating the gloves before they were even taken out of the box.

Another source of contamination is from the atmosphere itself, as shown by recovery of maize starch from ACS samples. Maize is grown around the world and maize starch is a common ingredient in many food and commercial products. The sheer amount of maize starch in the modern world means that there are significant quantities of maize starch in the atmosphere that can contaminate artifacts through airborne contamination (Laurence *et al*. 2011). The same holds true for any widely-used domesticated grain crops. Given that artifacts from four of the six sites analyzed in this study were processed under a clean bench, and all FCR and RCS were washed prior to sampling, it is unlikely that airborne starch contributed significantly to the observed contamination, although as the artifact washing experiment suggests, some airborne starch can remain on an artifact after washing. Considering that only a few of the thousands of maize starch granules used to coat the experimental rock were observed after washing, maize starch most likely was deposited on analyzed samples by means of "pre-contaminated" gloves.

Finally, the amount of maize starch recovered in these samples demonstrates a unique challenge when starch research is applied to regions and time periods where domesticated plants are of concern. The fact that maize agriculture did not take place in Central Texas is the very reason why its potential to contaminate artifacts was discovered. If the artifacts analyzed here had come from a region where maize agriculture was known or suspected to occur, then the maize starch granules may have been interpreted as the result of human activity rather than contamination. The potential to confuse archaeological starch with contamination is specifically relevant with studies seeking to push back the dates of agriculture anywhere in the world. For example, if one is trying to determine if maize was grown in a part of the New World (e.g. Perry 2003,

2004) before domestication is believed to occur and no contamination control measures are in effect, when maize starch is discovered, it may be impossible to determine whether or not the starch is in fact archaeological in origin or modern contamination. Finally, when working in regions of the world where maize is not native, control samples should be used to tease out starch contamination from modern local domesticated crops such as wheat, sorghum, rice, etc., from archaeological starch.

Apart from contaminating supposedly starch-free materials and its ubiquity across the world, maize starch has a wide range of morphological and size variation (see Figure 6.1m-p) in Chapter 6). As the results presented in the previous chapter demonstrate, maize starch can resemble starch granules from many other taxa (Figure 7.3). For this reason, one should be very cautious about assigning an identification to a specific taxa based on one starch granule alone.

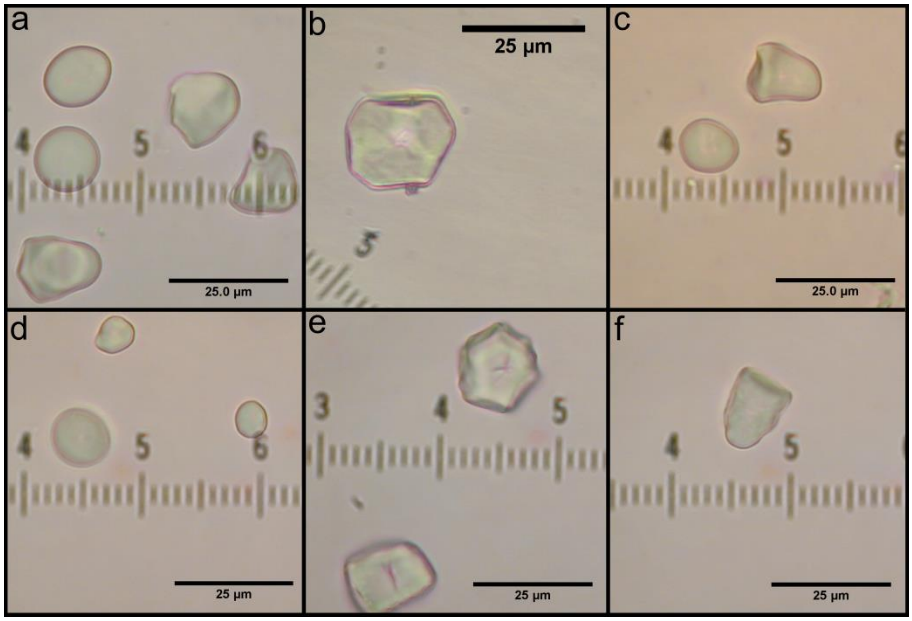

Figure 7.3. Comparison of starch from (a) eastern springbeauty, (b) yucca, (c) yellow-star grass (*Hypoxis hirsuta*), and (d-f) maize.

The above section focuses on maize simply because it was recovered in the samples. The same cautionary tale holds true for any starch-rich domesticated species. Laurence *et al*. (2011) demonstrate that the modern "starch rain" can contaminate artifacts once exposed to the atmosphere. If artifacts are exposed to the atmosphere near domesticated starch-rich species, then they can become contaminated with starch from those species, even though they do not come into direct contact with the plants. Without proper contamination control mechanisms in place, the dates of agriculture can be pushed back across the world based on modern contamination, rather than authentic archaeological starch residues (starch that is related to the use of an artifact).

Future of Starch Granule Research in Archaeology

For starch granule research to go forward more effectively in archaeology, several issues need to be addressed. First and foremost, there is a need for more taphonomic studies. There is a paucity of data regarding if and when starch is expected to survive in different depositional contexts. Few such studies exist (Haslam 2004; Lu 2004), none of which explore the issue into any great detail. Without a firm understanding of starch taphonomy, it is possible that all of the ancient starch has been broken down by microbes or other environmental factors and all of the observed starch is modern in origin. There are a number of mechanisms that can protect starch granules, such as soil aggregates (Golchin *et al*. 1998), microcracks in the surface of artifacts (Haslam 2004), and soil moisture and pH (Haslam 2004). While it is likely that ancient starch can survive in protected settings, more rigorous testing is required to confirm that this is the case (Barton and Matthews 2006:94).

Second, a better understanding of what constitutes starch contamination is required. As it was mentioned above, potential starch-rich plant resources could also be growing in the natural environment around archaeological sites, both in the past and present. The presence of starch granules from a particular taxon in control samples does not mean that the taxon could not have been used as food or packing material.

Third, statistical analysis comparing the starch assemblages recovered from the FCR and RCS analyzed from Fort Hood suggest that there are no significant differences between the FCR and RCS. It is unknown at this time if the observed lack of difference is due to a lack of preservation of starch granules at the investigated sites, or if starch-rich plants were not cooked in any of the ovens besides the feature at 41CV984, as suggested by the recovery of charred camas and wild onion bulbs. Also, it is possible that a greater sample size, especially one with more RCS samples could help to statistically separate starch granule assemblages between FCR and RCS samples. The lack of statistical significance observed in this study can be due to small sample sizes or the depositional environments at Fort Hood. Future studies need to be aimed at comparing starch assemblages from earth ovens where it is known that starch-rich plants were cooked in the ovens with off-site rock control samples from the same depositional environment. Ancient earth ovens that yield charred starch-rich bulbs would be ideal for this type of study.

Fourth, to separate out cultural vs. non-cultural starch on an artifact, future studies need to be aimed at assessing potential differences between ancient and modern starch. Many archaeologists use modification as a standard for determining that starch is cultural in origin (Henry *et al*. 2009; Perry 2004; Perry 2005). The problem with using modified starch as an indication of an archaeological origin resides in the fact that modified starch is airborne and starch can gelatinize via natural processes (Collins and Copeland 2011; Laurence *et al*. 2011). Even if the modified starch is cultural in origin, it is possible that it is modern rather than ancient. New tests and/or methods need to be developed to verify that recovered starch granules are in fact ancient rather than modern. Perhaps observation under SEM may be able to detect weathering patterns that are indicative of age, or dating residues in which starch granules are embedded (Zarrillo *et al*. 2008). Once the age is determined, only then can a determination as to whether the starch is in cultural or non-cultural in origin be made. Starch granules recovered from an artifact should always be considered non-cultural in origin until proven to be cultural. Had the maize starch granules recovered from the FCR in this study been assumed to be archaeological in origin (both ancient and cultural) then the dates of maize agriculture would have been pushed back and the importance of maize in Central Texas would have been redefined. This potential conclusion would have been contrary to both the current archaeological and ethnographic records for Central Texas. Instead, by questioning the authenticity of the maize starch granules, it was discovered that the supposedly powder-fee gloves contained maize starch, thereby providing a more parsimonious explanation for the recovery of maize starch from the FCR, RCS, and ACS examined in this study.

Fifth, while the issue of determining cultural vs. non-cultural starch applies to the identification of starch from all starch-rich taxa, it is a very difficult problem when starch from domesticated taxa is recovered from artifacts. In this study, starch granules belonging to domesticated taxa, namely maize, were teased out as being archaeologically insignificant. Maize starch could be excluded since maize agriculture was not regularly practiced in Central Texas (Collins 2004). Where maize agriculture was practiced, ruling out maize starch as contamination is much more difficult than is the case with non-domesticated taxa. In essence, all starch granules from domesticated taxa, such as wheat and maize, are cultural in origin. Improved methods need to be developed to determine the age of recovered starch granules. Starch granule research has been given much attention due to its apparent ability to demonstrate ancient plant use in areas where environmental conditions are not conducive to the preservation of macrobotanical remains. In several cases, the dates of agriculture have been pushed back in regions of the world based on the recovery of starch granules from domesticated taxa (Perry 2004; Piperno *et al*. 2000; Torrence 2006; Zarillo *et al*. 2008). Given that modern starch from domesticated taxa can contaminate artifacts by means of the starch rain, handling of artifacts without gloves, or the use of contaminated gloves, researchers need to verify that the starch is ancient before claiming that agriculture took place earlier than previously thought. This is especially true for studies that push back the date of maize agriculture throughout the New World (e.g. Perry 2004) given the amount of maize starch recovered from powder-free gloves.

Sixth, the prevalence of contamination on FCR from all features analyzed in this study also demonstrates the need to pursue multiple lines of evidence for feature functions. Wadley and Lombard (2007) suggest that multiple lines of evidence are stronger than individual residue analyses. If the temporal or cultural origin of recovered starch granules cannot be determined, then perhaps starch granule analysis should be used as one of several tools employed in determining what people were eating in the past. For instance, if macrobotanical remains that correspond to the types of starch granules recovered from an artifact are found in associated with the artifact, then the starch granules can be securely determined to be archaeological in origin. If no such correlation exists, then recovered starch granules should be treated as contamination unless the recovered starch granule assemblage is numerically different than starch granules recovered from control samples. This does not mean that macrobotanical remains are always necessary to determine the antiquity and origin of recovered starch granules, but as several lines of evidence, such as phytoliths and starch, should be used increase the overall accuracy of the analysis.

Finally, visible residues should be targeted for analysis. Since visible residues present on an artifact are determined to be cultural in origin, then starch granules recovered from the residue are most likely archaeological, and related to the use of the tool (Barton 2007). Furthermore, visible residues can be directly dated, thereby verifying their antiquity (Zarrillo *et al*. 2008). Zarrillo *et al*. (2008) convincingly use starch granules to demonstrate early maize use at the Loma Alta site in Ecuador. Visible residue from cooking-pots were both dated and analyzed for starch granules and phytoliths. Maize starch granules were recovered in the cooking-pot residue, as were phytoliths consistent with maize cobs, although the phytoliths were not conclusively identified as originating from maize (Zarrillo *et al*. 2008). By targeting and dating the visible residues, as well as the use of multiple lines of evidence, Zarrillo *et al*. (2008) were able to securely demonstrate that the recovered maize starch was archaeological in origin.

In sum, the recovery of starch from an artifact does not prove that the starch is archaeological in origin. Starch can contaminate artifacts in the past or present through a variety of mechanisms including airborne contamination (Laurence *et al*. 2011; Beck and Torrence 2006). In order for starch granule research to move forward in archaeology, more studies aimed at increasing our understanding of starch taphonomy and contamination related issues are required.

Recommended Protocols

This study demonstrates the propensity for starch granules to contaminate archaeological samples during all stages of artifact recovery and sampling. Laurence *et al*. (2011) describe methods that can reduce contamination in the lab. These steps were employed in the Paluxy Sand project and warrant reiteration. Artifacts should be gently washed or rinsed with distilled water prior to processing to remove loosely adhering starch granules on an artifact's surface where contamination is most likely to accumulate. When the mock artifact was used to process an Irish potato and sprinkled with maize starch, washing the rock remove the majority of the loosely adhering maize starch while leaving behind the potato starch. Washing artifacts is particularly useful for removing modern contamination if artifacts were collected in the field without using protocols to control for contamination. Analysts should also wear protective surgical-type caps to prevent contamination from their hair. As a further safeguard, starch removal and processing should be conducted on a clean-bench with a 0.5 µm air filter to prevent possible contamination from the lab. Artifacts should never be taken out of their sealed plastic bags and exposed to the atmosphere unless they are under the protected setting of a clean-bench or a similar device that removes or limits airborne contamination. All of these techniques proved to be useful in limiting airborne contamination in the lab, although it could not deter the introduction of maize starch into the samples from the latex gloves. Therefore, cleanroom gloves should be used instead of "standard" powder-free gloves as they are less prone to be contaminated. Future research should focus on refining the contamination control methods purposed by Laurence *et al*. (2011) to increase the accuracy and precision of starch granule analysis.

Laurence *et al*. (2011) also describe analytical methods that may help to differentiate contamination from archaeological starch. Those methods were used by Thoms *et al*. (2013) to minimize contamination in the field and lab, particularly the use of powder-free latex gloves during all stages of research including excavation, washing artifacts prior to sampling, and sampling under a clean bench. As in the lab, cleanroom gloves should be used instead of "standard" powder-free gloves. Furthermore, quantitative analysis was used in an attempt to statistically separate starch assemblages recovered from artifacts with those recovered from control samples. Quantitative analysis did not prove to be useful in determining which starch granules were the results of human behavior and which starch granules were the results of airborne contamination. As noted previously, the lack of statistical difference observed between starch granules recovered from artifacts and those recovered from the control samples may be due to the sample size. Future studies need to be aimed at increasing the sample size of both artifacts and control samples to see if quantitative analysis can be used to determine differences between culturally derived starch or contamination. Furthermore, higher concentrations of modified and damaged (classified as unidentifiable and gelatinized in this study) starch granules on artifacts that are believed to suggest past human activity (Babot 2003), were recovered in similar concentrations on both artifacts and control samples. More research is required to see if this pattern holds true with samples from different locations, or if the lack of numerical difference between modified starch granules is limited to certain areas or artifact classes, such as FCR from Fort Hood.

CHAPTER VIII

CONCLUSIONS AND SUMMARY

The results of this study demonstrate the need for a greater understanding of starch granule taphonomy and contamination. FCR from every earth oven was contaminated with maize starch, none of which can be considered to be archaeological in origin. Furthermore, statistical analyses could not detect significant differences between starch granule assemblages recovered from either FCR or non-cultural rock control samples. The lack of statistical significance, however, may be due small sample sizes and not a true representation of the differences between starch granule assemblages from FCR and RCS from Fort Hood. Therefore, future work should use larger sample sizes and sampling areas when comparing starch granule assemblages recovered from artifacts with those from control samples, including the analysis of more off-site non-cultural rocks and artifacts. Even if larger sample sizes cannot statistically separate FCR from RCS samples, however, an increase in sample size and/or sampling area will increase the likelihood of recovering quantitative differences between individual pieces of FCR and RCS samples. This type of quantitative difference was observed with Sample 44 from 41CV984 where over 5054 starch granules were recovered compared to the 8 starch granules recovered from the RCS from that site. If larger samples sizes cannot distinguish between starch assemblages recovered from artifacts and control samples, then starch granule analysis should be used in conjunction with other analytical tools so that multiple lines of evidence can place confidence in interpreting starch assemblages as being both ancient and human in origin.

If proper field and laboratory control measures and adequate sample sizes and sampling areas are used, then starch granule research can provide invaluable information regarding ancient starch-rich plant use in earth ovens. Experiments by Thoms *et al*. (2013) demonstrate that starch granules can be recovered from FCR whereas Sample 44 from 41CV984 demonstrates that archaeological starch can be recovered from ancient earth ovens even with contamination issues. The picture is “noisy” due to contamination. Future work aimed at working through contamination, however, should be able to increase the reliability of ancient starch granule research, therefore increasing our confidence that starch granules recovered from artifacts are archaeological in origin regardless of tool or feature class.

Recommendations

Starch taphonomy as it applies to archaeological studies remains poorly understood (Barton 2006). It is unclear at this time as to why starch granules survive over time given that there are so many factors including microbial activity, soil pH, soil temperature, and soil moisture that limit starch survival (Haslam 2004). Therefore, future work needs to address if, when, and where starch granules will survive for long periods of time, rather than assuming that starch granules recovered from artifacts must be ancient in origin simply because it was recovered from an artifact.

Along with starch taphonomy, starch contamination is another poorly understood research area. Several studies note the potential for modern starch to contaminate artifacts (Beck and Torrence 2006; Fullagar 2006; Laurence *et al*. 2011; Loy and Barton

2006; Zarrillo and Kooyman 2006), but only one study to date has thoroughly examined even one source of modern contamination (Laurence *et al*. 2011). For starch research to continue to be used in archaeology, more studies aimed at understanding potential sources of contamination as well as how to circumvent them needs to be done. Specifically, studies that address starch survival under different environmental conditions and on different artifact classes such as FCR and groundstone tools, similar to that of Lu (2006) are required. Furthermore, differential survival rates between modified and unmodified starch granules on different artifact classes also need to be addressed.

Finally, analytical methods, particularly quantitative analyses that can differentiate between starch granules from artifacts and control samples are needed. In this study, a greater number of taxa were recovered from the FCR compared to the RCS, but there were only a few starch granules from each additional taxon and were therefore not statistically significant. Perhaps if more FCR and RCS samples and/or a greater surface areas were analyzed it is possible that significant differences may be observed. Therefore, future work needs to address the question: What is a statistically significant sample size and sampling area? Contamination remains a significant problem, but it can be overcome. Most of the FCR in this study had similar starch granule assemblages to the RCS, but Sample 44 from the earth oven at 41CV984 demonstrates that there can be significant numerical differences between FCR and control samples thereby warranting further studies to increase our understanding of starch taphonomy and contamination. By increasing the number of samples and/or sampling area, it may be possible to recover starch granule assemblages quantitatively more starch granules from FCR than RCS samples. Even if FCR and RCS samples cannot be statistically separated, there may be one or two pieces of FCR per feature that have significantly higher concentrations of starch from non-domesticated taxa compared to RCS samples, thereby securing their identification as archaeological in origin rather than contamination or possibly both.

Summary

Fire-cracked-rock from 27 earth ovens at six sites was analyzed for starch granules. Contamination control methods were used including taking air and non-cultural rock control samples in the field, air control samples in the lab, handling all artifacts with powder-free latex gloves, washing samples prior to sampling to remove modern airborne contamination, wearing surgical caps during processing, and washing and processing samples under a clean bench. Whereas most of the contamination control measures proved to be effective at minimizing contamination, the powder-free gloves turned out to be "pre-contaminated" with maize starch. Future studies should use clean-room gloves rather than powder-free gloves as they are guaranteed to be contamination free. Furthermore, statistical analyses were used in attempt to significantly separate the number of recovered starch granules and taxa from the rock control samples and artifacts. The starch assemblages from these sample classes could not be statistically separated. Furthermore, starch granules recovered on the artifacts were also recovered in the air samples. While it would seem that any taxa recovered both in the air samples and artifacts should be considered contamination, the plants growing in the natural environment in the past and present were also cooked in ancient earth ovens. Therefore, taxa recovered in air samples cannot automatically be considered strictly contamination with no economic value (i.e. it was not used as a food resource).

With all of the contamination control methods in place, only the starch granules recovered from 41CV984 (Feature 4) can be considered to be archaeological in origin. The number of starch granules and taxa recovered from this feature was much greater than any of the other features or control samples and both starch granules and charred bulbs belonging to a Liliaceae species was recovered. Apart from the charred Liliaceae bulbs, very high concentrations of Liliaceae, cf. *Yucca*, cf. *Opuntia*, and cf. *Liatris* starch granules were recovered. These taxa were recovered in much higher concentrations than what was recovered from the RCS samples. This suggests that not only can starch granules be recovered from ancient earth ovens, but that starch from FCR, and by extension other artifacts, can be differentiated from contamination. Furthermore, the fact that the high numbers of starch granules recovered from the lowest level of the oven is consistent with the model put forth by Thoms *et al*. (2013) where FCR at the bottom of the feature should have the greatest number of starch granules.

Finally, more research investigating starch taphonomy and contamination sources is required. Starch granules recovered from only 1 of 27 investigated features was determined to be archaeological in origin. This is not to say that the starch granules recovered from the other 26 features could not be the result of past human actions. Both contamination and human action can account for the presence of the starch granules on the artifacts, so a determination that the starch is archaeological in origin cannot be made with confidence. Furthermore, inulin-rich plants are common throughout Fort Hood and are known to have been cooked extensively in earth ovens from this region (Boyd, Ringstaff and Mehalchick 2004:179-186). In fact, three of the six investigated sites yielded charred camas and/or wild onion remains, and of the three remaining sites, two did not produce any non-wood charcoal whereas one yielded an unidentified tuber fragments (Leslie Bush, personal communication 2010; 2012). This suggests that inulin-rich plants may have been cooked in these ovens rather than starch-rich bulbs, thereby accounting for the low starch recovery. The results of this study demonstrate the great potential contamination has to obscure archaeological results. However, as Sample 44 from 41CV984 demonstrates with the recovery of 5044 individual starch granules, many of which corresponded with recovery of charred Liliaceae bulbs, starch granules can be recovered from FCR in significantly higher concentrations, suggesting that important information can be obtained from FCR using starch granule research. To summarize the most important finding of this dissertation, if starch granules are recovered from an artifact, they should be considered contamination in origin until proven to be the result of past human action.

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APPENDIX A

STARCH GRANULES RECOVERED FROM TOPS AND BOTTOMS OF FCR AND RCS FROM 41CV984, 41CV1667, 41CV594, 41CV947, 41CV1104, AND 41CV1553

Table A.1. Starch granules recovered from top of FCR and RCS from 41CV984.

Artifact and Level	Site and Feature	Artifact Type	Total Starch Recovered from Artifact	Number of recovered starch: Top	Percent of Starch Recovered from Top	cf. *Yucca*	Liliaceae	*Quercus* sp.	*Opuntia sp.*	cf. *Liatris mucronata*	UnID Tuber	Faceted > 5 µm	Small Faceted (<5µm)	Small Round (< 5 µm)	Unknown A	Unknown B	Clusters of Starch	Un-identifiable/ Degraded	Gelatinized
8 - 2	41CV984	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 - 3	41CV984	FCR	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 - 4	41CV984	FCR	114	105	0.92	1	0	1	0	0	0	0	> 100	3	0	0	0	0	0
23 - 5	41CV984	FCR	19	1	0.05	0	0	0	1	0	0	0	0	0	0	0	0	0	0
29 - 6	41CV984	FCR	8	6	0.75	0	0	0	0	0	0	2	0	3	0	0	0	1	0
35 - 6	41CV984	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 7	41CV984	FCR	3	3	1	1	0	0	2	0	0	0	0	0	0	0	0	0	0
37 - 7	41CV984	FCR	4	2	0.5	2	0	0	0	0	0	0	0	0	0	0	0	0	0
38 - 7	41CV984	FCR	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 - 9	41CV984	FCR	5059	5054	0.99	1161	531	4	1266	90	70	1200	528	46	69	1	11	79	9
44 Pipette - 9	41CV984	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 - 9	41CV984	FCR	4	2	0.5	2	0	0	0	0	0	0	0	0	0	0	0	0	0
53	41CV984	Sediment Sample	N/A	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bedrock	41CV984	rock	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A.2. Starch granules recovered from bottom of FCR and RCS from 41CV984.

Artifact and Level	Site and Feature	Artifact Type	Total Starch Recovered from Artifact	Number of recovered starch: Bottom	Percent of starch recovered from bottom:	cf. *Yucca*	Liliaceae	UnID Tuber	Quercus sp.	*Opuntia* sp.	Faceted > 5 µm	small faceted <5 µm	Round >5 µm	Clusters of Granules	Un-identifiable /Degraded	Gelatinized
8 - 2	41CV984	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 - 3	41CV984	FCR	3	3	1	0	0	0	0	0	2	0	0	0	1	0
17 - 4	41CV984	FCR	114	9	0.08	6	1	0	0	0	0	1	1	0	0	0
23 - 5	41CV984	FCR	19	15	0.95	4	0	0	0	6	0	0	3	0	2	0
29 - 6	41CV984	FCR	8	2	0.25	0	0	1	0	1	0	0	0	0	0	0
35 - 6	41CV984	FCR	1	1	1	1	0	0	0	0	0	0	0	0	0	0
36 - 7	41CV984	FCR	3	0	0	0	0	0	0	0	0	0	0	0	0	0
37 - 7	41CV984	FCR	4	2	0.5	1	0	0	0	0	0	0	0	0	1	0
38 - 7	41CV984	FCR	12	12	1	1	0	0	0	0	0	0	0	11	0	0
44 - 9	41CV984	FCR	5059	5	0.01	1	0	0	0	0	0	0	0	0	1	3
44 Pipette - 9	41CV984	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 - 9	41CV984	FCR	4	2	0.5	1	0	0	0	0	0	1	0	0	0	0
53	41CV984	Sediment Sample	N/A	N/A	N/A	0	0	0	0	0	0	0	0	0	0	0
Bedrock	41CV984	rock	8	8	1	5	1	0	1	1	0	0	0	0	0	0

Table A.3. Starch recovered from top of FCR and RCS from 41CV1657.

Artifact and Level	Site and Feature	Artifact Type	Total Strarch Recovered	Number of recovered starch: Top	Percent of Starch Recovered from Top	cf. *Yucca*	cf. *Callirhoe involucrata*	*Opuntia sp.*	Maize	Compound	Faceted (> 5µm)	Small Faceted (<5µm)	Small Round (< 5 µm)	Un-identifiable/ Degraded	Gelatinized
A	41CV1657 - 3	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0
D	41CV1657	Control Sample	2	2	1	0	0	0	1	0	0	0	0	0	1
E	41CV1657 - 3	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0
L	41CV1657 - 3	FCR	2	2	1	2	0	0	0	0	0	0	0	0	0
O	41CV1657 - 3A	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0
Q	41CV1657 - 3A	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0
V	41CV1657 - 3	FCR	7	1	0.14	0	0	0	0	0	0	0	0	1	0
X	41CV1657 - 3	FCR	1	1	1	0	0	0	0	1	0	0	0	0	0
AG	41CV1657 - 1	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0
AJ	41CV1657 - 1	FCR	5	2	0.4	0	0	0	0	0	0	0	1	0	1
AR	41CV1657	rock	7	1	0.14	1	0	0	0	0	0	0	0	0	0
AT	41CV1657 - 4	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0
AW	41CV1657 - 4	FCR	1	1	1	0	0	0	0	0	1	0	0	0	0
BA	41CV1657 - 4	FCR	3	2	0.67	0	0	1	0	0	0	0	0	1	0
BB	41CV1657 - 4	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0
BC	41CV1657 - 4	FCR	3	1	0.33	0	0	0	1	0	0	0	0	0	0
BC Pipette	41CV1657 - 4	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0
BD	41CV1657 - 2	FCR	1	1	1	0	1	0	0	0	0	0	0	0	0
BE	41CV1657 - 2	FCR	9	6	0.67	0	0	3	0	0	1	1	0	1	0
BF	41CV1657 - 2	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0
BJ	41CV1657 - 2	FCR	5	0	0	0	0	0	0	0	0	0	0	0	0
BK	41CV1657 - 2	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0
Off Site Sample 1	41CV1657	rock - control sample	4	0	0	0	0	0	0	0	0	0	0	0	0
Off Site Sample 2 Profile 3	41CV1657	rock - control sample	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A.4. Starch granules recovered from bottom of FCR and RCS from 41CV1657.

Artifact and Level	Site and Feature	Artifact Type	Total Strarch Recovered	Number of recovered starch: Bottom	Percent of Starch Recovered from Bottom	cf. *Yucca*	*Opuntia sp.*	Liliaceae	UnID Tuber	cf. *Liatris mucronata*	*Quercus* sp.	Maize	Faceted > 5 µm	Round >5 µm	Un-identifiable /Degraded	Unknown
A	41CV1657 - 3	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	41CV1657	Control Sample	2	0	0	0	0	0	0	0	0	0	0	0	0	0
E	41CV1657 - 3	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	41CV1657 - 3	FCR	2	0	0	0	0	0	0	0	0	0	0	0	0	0
O	41CV1657 - 3A	FCR	1	1	1	0	0	0	0	0	0	1	0	0	0	0
Q	41CV1657 - 3A	FCR	1	1	1	0	0	0	0	1	0	0	0	0	0	0
V	41CV1657 - 3	FCR	7	6	0.86	0	0	1	0	0	0	5	0	0	0	0
X	41CV1657 - 3	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0	0
AG	41CV1657 - 1	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AJ	41CV1657 - 1	FCR	5	3	0.6	2	0	0	0	0	1	0	0	0	0	0
AR	41CV1657	rock	7	4	0.86	0	1	1	0	1	0	1	0	0	1	0
AT	41CV1657 - 4	FCR	1	1	1	0	0	0	0	0	0	1	0	0	0	0
AW	41CV1657 - 4	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0	0
BA	41CV1657 - 4	FCR	3	1	0.33	0	0	0	0	0	0	0	1	0	0	0
BB	41CV1657 - 4	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BC	41CV1657 - 4	FCR	3	2	0.67	0	1	0	0	0	0	0	1	0	0	0
BC Pipette	41CV1657 - 4	FCR	1	1	0	0	0	0	1	0	0	0	0	0	0	0
BD	41CV1657 - 2	FCR	1	0	0	0	0	0	0	0	0	0	0	0	0	0
BE	41CV1657 - 2	FCR	9	3	0.33	0	0	0	0	0	0	0	0	0	3	0
BF	41CV1657 - 2	FCR	1	1	1	0	0	0	0	0	0	0	0	1	0	0
BJ	41CV1657 - 2	FCR	5	5	1	2	0	0	0	0	0	1	0	0	2	0
BK	41CV1657 - 2	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Off Site Sample 1	41CV1657	rock - control sample	4	4	1	1	2	1	0	0	0	0	0	0	0	0
Off Site Sample 2 Profile 3	41CV1657	rock - control sample	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A.5. Starch granules recovered from top of FCR and RCS at 41CV594.

Artifact	Site and Feature	Artifact Type	Total number of recovered starch	Number of recovered starch: Top	Percent of starch recovered from top	Maize	Liliaceae	Bluestem grass	Faceted > 5µm	Faceted < 5µm	Clusters of granules	UnID	Gelatinized
M-2	41CV594	FCR	1	1	1	0	0	0	0	0	0	0	1
M-3	41CV594	FCR	7	6	0.86	0	0	0	0	0	0	4	2
M-9	41CV594 - Test Pit	FCR	3	2	0.67	0	0	1	1	0	0	0	0
M-10	41CV594 - Test Pit	FCR	496	196	0.4	0	0	162	0	0	29	0	5
M-10 $CaCo_3$	41CV594 - Test Pit	FCR	3	2	0.67	1	0	0	0	0	0	1	0
M-14	41CV594	FCR	1	0	0	0	0	0	0	0	0	0	0
M-15	41CV594	FCR	23	23	1	23	0	0	0	0	0	0	0
M-17	41CV594	FCR	4	4	1	0	0	0	0	0	0	1	3
M-18	41CV594	FCR	9	3	0.33	0	1	0	1	0	0	1	0
M-28	41CV594 F 2C	FCR	0	0	0	0	0	0	0	0	0	0	0
M-29	41CV594 F 2C	FCR	3	0	0	0	0	0	0	0	0	0	0
M-46	41CV594 F 2A	FCR	8	3	0.37	3	0	0	0	0	0	0	0
M-56	41CV504 F2B	FCR	3	2	0.67	1	0	0	0	0	0	1	0
M-61	41CV594 F 2F	FCR	0	0	0	0	0	0	0	0	0	0	0
M-61 CaCO3	41CV594 F 2F	FCR	0	0	0	0	0	0	0	0	0	0	0
M-67	41CV594 F 2C	FCR	3	1	0.33	1	0	0	0	0	0	0	0
M-68	41CV594 F 2C	FCR	1	1	1	0	0	0	0	0	0	1	0
M-68 CaCO3	41CV594 F 2C	FCR	0	0	0	0	0	0	0	0	0	0	0
M-69	41CV594 F 2C	FCR	1	1	0	1	0	0	0	0	0	0	0
M-69 $CaCO_3$	41CV594 F 2C	FCR	1	0	0	0	0	0	0	0	0	0	0
M-71	41CV594 F 2G	FCR	1	0	0	0	0	0	0	0	0	0	0
M-75	41CV594 F2D	FCR	2	0	0	0	0	0	0	0	0	0	0
M-77	41CV594 Trench 1	FCR	13	4	0.31	3	0	0	0	0	0	0	0
M-86	41CV594 F 2E	FCR	8	5	0.62	2	0	0	0	2	0	1	0
Off Site 1	Off Site	Rock	3	3	1	2	0	0	0	0	0	0	1
Off Site 2	Off Site	Rock	2	1	0.5	0	0	0	0	0	0	1	0
Off Site 4	Off Site	Rock	2	2	1	1	0	0	0	0	0	0	1

Table A.6. Starch granules recovered from bottom of FCR and RCS at 41CV594.

Artifact	Site and Feature	Artifact Type	Total number of recovered starch	Number of recovered starch: Bottom	Percent of starch recovered from bottom	Liliaceae	Grass	Oak	Maize	Faceted > 5μm	Unknown A	Clusters of granules	UnID	Gelatinized
M-2	41CV594	FCR	1	0	0	0	0	0	0	0	0	0	0	0
M-3	41CV594	FCR	7	1	0.14	0	0	0	0	0	0	0	1	0
M-9	41CV594 - Test Pit	FCR	3	1	0.33	0	1	0	0	0	0	0	0	0
M-10	41CV594 - Test Pit	FCR	496	300	0.6	0	> 100	0	0	0	0	> 100	0	> 100
M-10 CaCo$_3$	41CV594 - Test Pit	FCR	3	1	0.33	0	0	0	0	0	0	0	0	1
M-14	41CV594	FCR	1	1	0	0	0	0	0	0	0	0	1	0
M-15	41CV594	FCR	23	0	0	0	0	0	0	0	0	0	0	0
M-17	41CV594	FCR	4	0	0	0	0	0	0	0	0	0	0	0
M-18	41CV594	FCR	9	6	0.67	1	0	0	0	0	0	0	1	4
M-28	41CV594 F 2C	FCR	0	0	0	0	0	0	0	0	0	0	0	0
M-29	41CV594 F 2C	FCR	3	3	1	0	0	0	0	1	1	0	0	1
M-46	41CV594 F 2A	FCR	8	5	0.63	0	0	0	2	1	0	0	2	0
M-56	41CV504 F2B	FCR	3	1	0.33	0	0	0	1	0	0	0	0	0
M-61	41CV594 F 2F	FCR	0	0	0	0	0	0	0	0	0	0	0	0
M-61 CaCO3	41CV594 F 2F	FCR	0	0	0	0	0	0	0	0	0	0	0	0
M-67	41CV594 F 2C	FCR	3	2	0.67	0	0	0	0	0	0	0	0	2
M-68	41CV594 F 2C	FCR	1	0	0	0	0	0	0	0	0	0	0	0
M-68 CaCO3	41CV594 F 2C	FCR	0	0	0	0	0	0	0	0	0	0	0	0
M-69	41CV594 F 2C	FCR	1	0	0	0	0	0	0	0	0	0	0	0
M-69 CaCO$_3$	41CV594 F 2C	FCR	1	1	1	0	0	0	0	0	0	0	1	0
M-71	41CV594 F 2G	FCR	1	1	1	0	0	0	0	1	0	0	0	0
M-75	41CV594 F2D	FCR	2	2	1	0	1	0	0	0	0	0	0	1
M-77	41CV594 Trench 1	FCR	13	9	0.69	0	0	0	1	0	0	0	1	0
M-86	41CV594 F 2E	FCR	8	3	0.38	0	0	0	0	2	0	0	1	0
Off Site 1	Off Site	Rock	3	0	0	0	0	0	0	0	0	0	0	0
Off Site 2	Off Site	Rock	2	1	0.5	0	0	1	0	0	0	0	0	0
Off Site 4	Off Site	Rock	2	0	0	0	0	0	0	0	0	0	0	0

Table A.7. Starch granules recovered from FCR and RCS 41CV947.

Artifact	Feature	Artifact Type	Total number of recovered starch	Number of recovered starch: Top	Percent of recovered starch from top	Maize	Unknown F	Faceted > 5µm	UnID	Gelatinized	Number of recovered starch: Bottom	Percent of recovered starch from bottom	Common Bean	Prickly Pear	Maize	Unknown G	Faceted > 5µm	Clusters of granules	UnID	Gelatinized
M-2	F-4	FCR	18	11	0.61	5	0	0	0	6	7	0.39	0	0	4	0	0	0	1	2
M-6	F-6	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M-9	F-8	FCR	3	1	0.33	0	0	0	1	0	2	0.67	0	0	0	1	1	0	0	0
M-14	F-5	FCR	3	3	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
M-25	F-9	FCR	2	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	2	0
M-45	F-5	FCR	3	1	0.33	0	0	0	1	0	2	0.67	0	0	0	0	0	0	2	0
M-30	F-5	FCR	5	4	0.8	0	0	0	3	1	1	0.2	0	0	0	0	1	0	0	0
M-61	F-7	FCR	104	0	0	0	0	0	0	0	104	1	2	0	0	0	1	1	0	1
Off-Site	N/A	Control Sample	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Off-Site 1	N/A	Control Sample	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Off-Site 2	N/A	Control Sample	9	4	0.44	3	0	0	1	0	5	0.56	1	0	4	0	0	0	0	0
Off Site 3	N/A	Control Sample	8	3	0.36	2	0	0	1	0	5	0.63	0	0	0	0	0	0	4	1

Table A.8. Starch granules recovered from FCR and RCS from 41CV1104.

Artifact	Feature	Artifact Type	Total number of recovered starch	Number of recovered starch: Top	Percent of starch recovered from top	Maize	Common Bean	UnID	Gelatinized	Number of recovered starch: Bottom	Percent of starch recovered from bottom	Liliaceae	Maize	UnID	Gelatinized
M-2	F-3	FCR	2	1	0.5	0	0	1	0	1	0.5	0	1	0	0
M-3	F-3	FCR	2	2	1	0	1	0	1	0	0	0	0	0	0
M-4	F-4	FCR	15	3	0.2	2	0	0	1	12	0.8	2	6	3	1
M-7	F-2	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0
M-8	F-2	FCR	2	1	0.5	1	0	0	0	1	0.5	0	1	0	0
M-10	F-1	FCR	2	1	0.5	1	0	0	0	1	0.5	0	0	1	0
Off-Site 2	N/A	Control Sample	0	0	0	0	0	0	0	0	0	0	0	0	0
Off-Site 6	N/A	Control Sample	5	0	0	0	0	0	0	5	1	0	1	1	3

Table A.9. Starch granules recovered from FCR and RCS from 41CV1553.

Artifact	Feature	Artifact Type	Total recovered starch	Number of recovered starch: Top	Percent of starch recovered from top	Maize	Gayfeather	Common Bean	Unknown D	Faceted > 5µm	UnID	Gelatinized	Number of recovered starch: Bottom	Percent of starch recovered from bottom	Oak	Eastern Springbeauty	Groundnut	Faceted > 5µm	UnID	Gelatinized
M-2	F-8E	FCR	2	1	0.5	0	0	0	0	0	0	1	1	0.5	0	0	0	1	0	0
M-3	F-8E	FCR	2	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	1
M-3 CaCO3	F-8E	FCR	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M-4	F-8E	FCR	10	3	0.3	0	0	1	0	0	1	1	7	0.7	0	0	3	0	2	2
M-4 CaCO3	F-8E	FCR	3	0	0	0	0	0	0	0	0	0	3	1	1	0	0	0	0	1
M-5	F-8E	FCR	2	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	2	0
M-6	F-8E	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M-7	F-8F	FCR	2	2	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
M-8	F-8	FCR	6	1	0.17	0	1	0	0	0	0	0	5	0.83	0	1	0	1	0	1
M-9	F-6	FCR	3	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	3	0
M-12	F-6	FCR	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
M-16	F-6	FCR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M-17	F-6	FCR	5	2	0.4	1	0	0	0	0	0	1	3	0.6	0	0	0	0	0	3
M-17 CaCO3	F-6	FCR	4	4	1	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0
M-18	F-6	FCR	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0
M-18 CaCO3	F-6	FCR	2	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	1
M-19	F-6	FCR	2	1	0.5	0	0	0	0	0	0	1	1	0.5	0	0	0	0	0	1
Bedrock 1	F-6	bedrock	3	1	0.33	0	0	0	0	0	0	1	2	0.67	0	0	0	1	0	1
Off-Site 1	off site	bedrock	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0
Off-Site 3	off site	rock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0