The Prehispanic Maya Burnt Lime Industry:

Socio-Economy and Environmental Resource Management in the

Late and Terminal Classic Period Northern Maya Lowlands (650-950 CE)

by

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ABSTRACT

The recent identification of a series of annular pit-kilns used for producing burnt lime in and around the Prehispanic Maya site of Kiuic in the Puuc region of the Northern lowlands provides the opportunity to examine Prehispanic lime production technology and organization. This dissertation investigates three main issues: 1) The functionality and practicality of the annular pit-kilns for the production of lime; 2) The implications of the pit-kilns' production efficiency for Prehispanic resource management practices; and 3) The socioeconomic organization of the lime production industry. Powdered lime (*cal* in Spanish) was one of the most significant and ubiquitous materials in the daily lives of the Prehispanic Maya. Lime was a key ingredient in the mortar that they used to construct monumental edifices and residential buildings, as well as in the lime plaster that they used to coat the facades, floors and interior walls of these structures. Lime plastered plazas and house floors were more easily swept clean than bare earth and provided a more sanitary environment within densely populated settlements. Lime was even crucial for maintaining a viable maize-based diet through the *nixtamalization* process. By soaking maize in lime-infused water the peoples of Mesoamerica not only softened the kernels for grinding but also unlocked essential nutrients such as niacin for absorption into the body. Considering the importance of lime for construction, hygienic and dietary purposes, there is surprisingly little information regarding lime production prior to the arrival of Europeans

in the 16th century. The standard method of lime production documented in the Yucatán peninsula in the 19th and 20th centuries involves the construction of an open-air wooden pyre onto which small pieces of limestone are stacked. This method uses a large quantity of wood fuel and raises questions about whether fuel requirements for lime production contributed to deforestation towards the end of the Classic Period (ca. 850 CE). The annular pit-kilns identified in and around Kiuic were designed to use fuel more efficiently than the open-air pyres. This suggests that the Prehispanic Puuc Maya took steps to conserve their fuel consumption at a time of demographic and environmental stress. The widespread distribution of the annular pit-kilns within the Kiuic polity as well their spatial relationships to other archaeological features suggests that lime production was largely decentralized and organized by small-scale production groups.

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Chapter 1 – Prehispanic Maya Burnt Lime Production

Introduction and Problem Orientation

Powdered or burnt lime (*cal* in Spanish) was one of the most significant and ubiquitous materials used in the daily lives of the Prehispanic Maya. Starting at least as early as the Middle Preclassic Period (ca. 1100 BCE) (Hammond and Gerhardt 1990:464) lime became a key component of Prehispanic Maya architectural programs. It formed the basis of the mortar used to construct monumental edifices and residential structures, as well as the plaster that coated the facades, floors and interior walls of these structures. Lime plastered plazas and house floors were more easily swept clean than bare earth and provided a more hygienic environment within densely populated settlements (Villaseñor and Barba 2013:269). Lime also may have been used for water purification, soil maintenance, paper-making, and maize storage purposes (Smyth 1990:54; Villaseñor 2010:47). It was even crucial for maintaining a viable maize-based diet through the *nixtamalization* process. By soaking maize in lime-infused water the Prehispanic peoples of Mesoamerica not only softened the kernels for grinding but also unlocked the essential nutrient niacin for uptake into the body (Russell and Dahlin 2007:407; Villaseñor 2010:66; Barba 2013:25). A diet based on non-*nixtamalized* maize would eventually lead to pellagra, a niacin deficiency disease characterized by diarrhea, dermatitis, and dementia (Hegyi et al 2003).

Considering the importance of lime for construction, hygienic, dietary, and other purposes, archaeologists have documented relatively few Prehispanic Maya lime production features (Hansen 2000:5-6; Schreiner 2002:2-5; Wernecke 2004:169). While several potential lime pit-kilns have been identified, they represent but a small fraction of lime production features

that were likely in use during the Prehispanic period (Redfield and Villa Rojas 1934; Fauvet-Berthelot 1980; Viel 1983; Freidel and Sabloff 1984; Johnston et al 1989; MacKinnon and May 1990; Sabloff and Tourtellot 1991; Abrams and Freter 1996; Ortíz Ruíz 2014). This relative lack of evidence is partly a result of the ephemeral nature of the aboveground open-pyre (*calera*) method of production in the archaeological record, a lack of structures identified as Prehispanic kilns, and a lack of investigations specifically dedicated to investigating Prehispanic Maya lime production (Abrams 1996:200-201; Schreiner 2002:2-5; Russell and Dahlin 2007:407). The recent identification of a series of annular structures hypothesized to be lime pit-kilns in and around the Puuc site of Kiuic in the north-central Yucatán peninsula provides an opportunity to investigate Prehispanic lime production technology and socioeconomic organization.

This research is prompted by broader questions about the nature of sub-regional socioeconomic and resource management systems in the Prehispanic Maya world, especially leading up to and through the sociopolitical transformation of the Late and Terminal Classic Periods (ca. 650-950 CE). During this period, populations in many sub-regions of the broader Maya area began to disperse from larger centers at the same time that populations in a few sub-regions experienced a socio-cultural fluorescence. Discrepancies in Late and Terminal Classic Period societal trajectories likely resulted from combinations of several factors, including differences in resource management practices and socioeconomic organizational structures. The Kiuic case study yields results regarding both of these issues on a sub-regional scale through the investigation of the fuel-efficient annular pit-kiln technology. The annular pit-kilns appear to have been used at a time when the community was undergoing a series of demographic and perhaps environmental stresses. In this dissertation I examine the Prehispanic Maya burnt lime production industry with three main objectives: 1) To determine whether the annular structures

in the Eastern Puuc were pit-kilns used to produce lime; 2) To investigate the potential fuel conservation benefits of the invention of the pit-kiln technology; and 3) To examine the socioeconomic organization of the burnt lime production industry. I hypothesize that the pit-kilns identified in and around the Prehispanic site of Kiuic were used to produce lime, that the annular pit-kiln technology represented a more fuel-efficient alternative to the aboveground calera method documented during the Post-Conquest era, and that lime production was largely decentralized.

The annular pit-kilns appear in the archaeological record as low mounds capped by a single or double ring of boulders that surround a central depression. They appear to be distinctive to the Puuc Region in both form and prevalence. This is based on a review of published literature and available site reports from throughout the broader Maya region (Castillo and Wölfel 2013; Liendo Stuardo 2008, 2010, 2011; Zetina Guiterrez 2010; Escobedo and Freidel 2004; Perez Calderon et al. 2014; Barrientos et al. 2015; Spensley and Garrido Lopez 2008; Rangel and Reese-Taylor 2005; Garrido Lopez 2011; Golden et al. 2005; Acuña 2014; Hutson 2013; Reese-Taylor and Anaya Hernández; Garrido Lopez et al. 2010-2015; Donado 2014; Lentz et al. 2011; Abrams et al. 2012:1649). Over 140 annular pit-kilns were identified during a nine-square-kilometer inter-site survey between the Puuc sites of Labná and Kiuic (Gallareta Negrón et al. 2015:3-2). Annular structures similar to those identified in and around Kiuic have thus far only been identified at other Puuc sites. These include examples from Oxkintok (n=~13) (Ortíz Ruíz 2014:35; Ortíz Ruíz et al 2015), and Sayíl (n=~24) (Sabloff and Tourtellot 1991; Dunning 1991:25), as well as from along the Sierrita de Ticul that marks the Eastern boundary of the Puuc Region (Gallareta Negrón personal communication 7/12/15).

While the superstructural annular form and frequency of the pit-kilns currently appear to be distinctive to the Puuc Region, different lime pit-kilns have been identified at other lowland Maya sites. A few shallow pit-kilns have been described at sites such as Chan Kom (Redfield and Villa Rojas 1934) in the central Yucatán, Cauinal (Fauvet-Berthelot 1980:5-7) and Dos Pilas (Johnston et al. 1989) in Guatemala, and Copán in Honduras (Viel 1983; Abrams 1996). None of these pit-kilns, however, exhibited an annular superstructure similar to those identified in the Puuc. Abrams and Freter (1996) identified and described a partially-enclosed lime pit-kiln at Copán in Honduras that was also dissimilar to the Puuc annular pit-kilns. They hypothesized that the pit-kiln would have provided a more fuel efficient alternative to aboveground *caleras* at a time of environmental resource stress (Abrams and Freter 1996:426) and noted the potential for technological variability throughout the Maya area. While future research will likely result in the identification of additional pit-kiln technologies used elsewhere in the broader Maya region, at the time of my research the annular pit-kilns appear to be distinctive to the Puuc Region in both form and prevalence. This may be as much a result of an absence of lime-related investigations as an absence of lime pit-kilns themselves. Should more pit-kilns be identified at other Prehispanic sites in the Maya area or elsewhere in Mesoamerica, my research will provide a model for comparison.

Kiuic is a mid-level Range III site (Garza and Kurjack 1980) located in the Eastern Puuc Region of the Northern Maya lowlands with an inner core that covers approximately four km^2 (Gallareta Negrón et al. 2015a). It is one of several dozen similarly sized sites spread relatively evenly throughout the region (Figures 1-1 and 1-2) (Garza and Kurjack 1980). Recent archaeological projects in the Eastern Puuc at sites such as Xocnaceh, Paso del Macho, and Kiuic have uncovered evidence of permanent settlements in the region dating back to the Middle

Preclassic Period (ca. 800 BCE) (Gallareta Negrón et al. 2014:1-7). It wasn't until the Late and Terminal Classic Periods (ca. 650-950 CE), however, that the Eastern Puuc experienced a tremendous population and construction boom that is reflected in the archaeological record by the elaboration of a sub-regional architectural program (Table 1-1). It has been estimated that the Eastern Puuc has one of the highest concentrations of stone vaulted masonry structures of anywhere in the Northern Lowlands (Gallareta Negrón et al 2015a:1-4; Ringle and Tun 2016) (Figure 1-3). The Kiuic polity provides a characteristic case study of the changes that occurred in the Eastern Puuc leading up to and through the Late and Terminal Classic Periods. Excavations in and around the site center as well as in elite residential complexes on the outskirts of the inner core have dated large construction projects to this time period. Ceramic evidence points to most of Kiuic's masonry architectural compounds supporting a Late and/or Terminal Classic occupation (Gallareta Negrón et al. 2014:33-34). The combination of an expansive architectural program and a booming population that required much nixtamalized maize suggests that burnt lime production likely increased during this time period as well. The large investment in raw materials and physical labor involved in the production of burnt lime likely made it an important economic activity. All of these factors combine to make Kiuic a great location to investigate human-environment relationship issues and the socioeconomic organization of the burnt lime production industry.

Lime powder is created by burning calcareous material, which in the Maya area includes both limestone and marine shell. Lime production begins with calcination, wherein raw calcium carbonate (whether stone or shell) is heated to a high enough temperature for long enough duration that carbon dioxide and water are forced out, producing quicklime (calcium oxide). The second stage, hydration, involves adding water to the highly reactive quicklime to stabilize it and

produce lime powder (also called slaked lime or calcium hydroxide). When it is to be used for architectural purposes, the slaked lime is mixed with water and a variety of aggregates and binders to create a paste or slurry that can be used as plaster, mortar, or stucco. As the lime slurry dries it absorbs carbon dioxide from the air and hardens once again into calcium carbonate, completing the third stage of the production and use cycle called carbonation (Abrams 1996:197; Schreiner 2002:12-13; Russell and Dahlin 2007:408-409).

- Calcination: $CaCO_3$ (s) + heat → CaO (s) + CO_2(g)
- Hydration: CaO(s) + H_2O (l) → $Ca(OH)_2$ (aq) + heat
- Carbonation: $Ca(OH)_2$ (l) + CO_2(g) → $CaCO_3$ (s) + H_2O(g)

The majority of powdered lime used in the northern Yucatán today is produced by gas-powered kilns in large factories (Russell and Dahlin 2007:407). However, some older members of small rural communities still know how to produce lime using the non-mechanized calera method. This technique involves the construction of an aboveground wooden pyre onto which fist-sized pieces of limestone are placed. The pyre is made from green wood with high moisture content and then lit from the center of the base, which allows for a slow outward burn. The pyre slowly caves in on itself forming an aboveground kiln that cooks the pieces of limestone as they collapse into the center (Morris et al. 1931:220-225; Abrams 1996:200; Schreiner 2002:17). It is unclear exactly how far back in time this calera method was used by the Maya of the Northern Yucatán. Despite the lack of explicit early ethnohistoric research on the subject, the calera has generally been accepted as the standard or "traditional" technique for producing lime in the Yucatán. The large amount of wood fuel used in this aboveground production process raises

questions about resource sustainability and whether the Prehispanic Maya may have used other, more resource-efficient techniques for lime production.

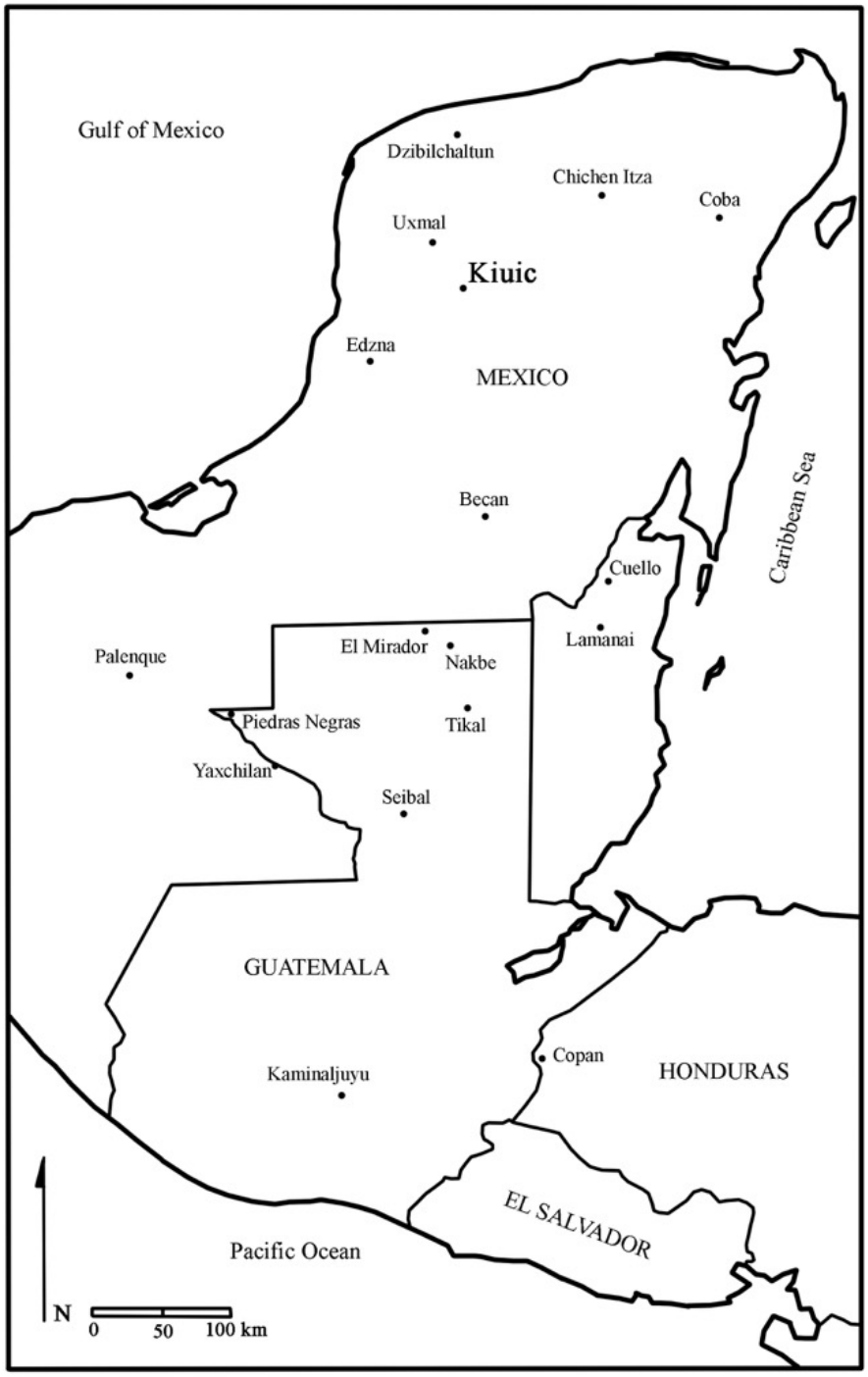


Figure 1-1: Map of the Maya area showing the location of Kiuic in relation to larger sites.

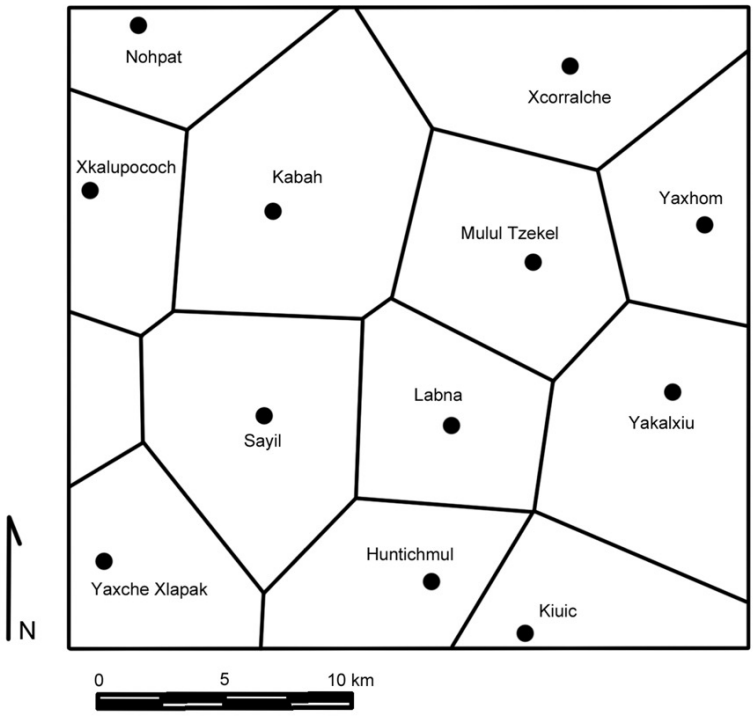


Figure 1-2: Thiessen polygons drawn around the major Late/Terminal Classic sites in the Eastern Puuc to demonstrate their relative equidistance from one another. Kiuic is on the bottom right (adapted from Andrews 2004:597).

Table 1-1: General chronology of the Maya area paired with developments at Kiuic.

General Chronology Maya Area		Kiuic
Colonial Period	ca. 1520-1821 CE	No activity until founding of Rancho Kiuic in valley in 1700s
Postclassic Period	ca. 950-1520 CE	Rapid abandonment of site center and other compounds ca. 950-1000 CE
Late/Terminal Classic Period	ca. 650-950 CE	Population and construction boom
Early Classic Period	ca. 250-650 CE	Small local population
Terminal Preclassic Period	ca. 100 BCE - 250 CE	Small local population
Late Preclassic Period	ca. 400-100 BCE	Small local population
Middle Preclassic Period	ca. 1000-400 BCE	Earliest evidence of occupation ca. 800 BCE



Figure 1-3: Map showing the density of archaeological sites in the Eastern Puuc, most of which had a Late and Terminal Classic Period occupation.

Understanding the varying forms and functions of annular structures in the Kiuic polity is significant for three main reasons: 1) Their function as pit-kilns for the burning of raw limestone into quicklime provides new information regarding Prehispanic Maya pit-kiln technology; 2) The identification of lime pit-kilns has important implications for understanding Prehispanic Maya resource conservation practices in a specific sub-region; and 3) The physical evidence of lime production locales provides a foundation for understanding the socioeconomic organization of an otherwise ephemeral industry. Also, the dating of the annular pit-kilns provides an additional marker to track the boom and bust chronology of the Late and Terminal Classic Period Puuc socio-economy.

The data are consistent with a decentralized organization system in which lime was likely manufactured by small-scale producers (e.g. households or small corporate groups including multiple households). The technical skills, knowledge, and large amounts of labor necessary for efficient lime production suggest that specialists directed different stages in the production process. Small corporate groups represent a likely social unit for organizing the labor involved in production episodes. There is evidence for a few semi-isolated hilltop elite residential complexes within the Kiuic community possessing their own lime pit-kilns that could have been used to meet the compounds' own lime consumption needs. However, it is unlikely that all social groups within the Kiuic polity produced their own lime, and non-producers would have had to acquire it from producers through some form of exchange network. Chris Gunn's (2015) postulation of a market exchange system for distributing ceramics throughout the Kiuic community provides a potential model for understanding lime distribution as well.

The absence of clear markers for large-scale, centralized oversight of production does not preclude the possibility that central governing authorities or powerful elites indirectly controlled aspects of the lime industry. Governing authorities and elites could have controlled several of the stages involved in the lime production process, including access to raw materials and/or labor, as well as distribution of the finished burnt lime. The lime required for the construction of the monumental public buildings at the site center could have been acquired through direct sponsorship of lime production and/or procurement of lime through a tax or tribute system. Thus, the available data leave open the possibility for multiple production organization schemes, several of which could have operated simultaneously. Variations in the sizes and forms of the annular structures suggest that access to building materials and technical skill were restricted and may reflect differences in socioeconomic status. Investigating the fuel-efficiency and social

contexts of the Kiuic annular pit-kilns contributes to a more detailed understanding of sub-regional variations in Prehispanic Maya historical trajectories and responses to environmental changes (Bey 2006; Aimers 2007:332; Demarest 2009:255; Dunning et al. 2012).

Hypotheses and Research Strategy

To determine the functions of the annular structures and their potential importance for resource conservation and lime production organization in the Prehispanic Puuc region, I test three interrelated hypotheses: 1) The annular structures were used as pit-kilns to produce lime from limestone; 2) The annular structure technology was developed to use fuel more efficiently than open-air pyres; and, 3) The lime production industry was decentralized.

The starting point for testing all of my hypotheses is the comprehensive inter-site archaeological survey completed by Dr. Tomás Gallareta Negrón and colleagues over the last fourteen years between the ancient sites of Labná and Kiuic. Dr. Gallareta and his colleagues, including myself, mapped all archaeological features throughout a 9-plus-km^2 transect in the hinterlands between these site centers (Gallareta et al. 2014:3.1-3.123) (Figure 1-4). Among the features identified during the survey were approximately 140 annular structures that, when added to the half dozen previously identified within the site center of Kiuic, provide a wide array from which to sample and examine their spatial contexts. The current investigation has been conducted as a sub-project of the larger Bolonchén Regional Archaeological Project (BRAP), co-directed by Dr. Gallareta Negrón, Dr. George J. Bey III (Millsaps College) and Dr. William Ringle (Davidson College).

I tested my first hypothesis, that the annular structures were used as lime pit-kilns, by excavating a sample of nine structures. By systematically taking apart these ring-like mounds, I

uncovered their original forms and construction processes, and thereby shed light on how they were used for the burning of materials. All nine of the structures excavated exhibited much evidence for repeated burning episodes in their central pits, and the majority contained evidence of lime burning in particular. In addition to uncovering the basic forms of the annular structures, excavation to their lowest internal levels and test-pitting in their immediate surroundings turned up evidence that supported their use as lime pit-kilns. Most of the annular structures were surrounded by partially burned small pieces of limestone, called *chich,* that represented the detritus of multiple burning episodes. Charcoal samples recovered from the lowest levels of four of the ring structures helped to date their use to ca. 650-850 CE. There is widespread evidence for demographic and possibly climatic changes occurring in the Eastern Puuc region during this time period.

Limestone, lime, and soil samples recovered from within the structures were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). Stable oxygen and carbon isotope analyses provided additional evidence for lime burning within the pit-kilns. The spatial and contextual analysis of annular structures in relation to such other Prehispanic features as quarries, *sascaberas* (quarries of softer, whiter grades of limestone), outcrops of high-grade limestone, and residential groups, provides further evidence for the possible multiple burning-related functions of the annular structures (Figure 1-5).

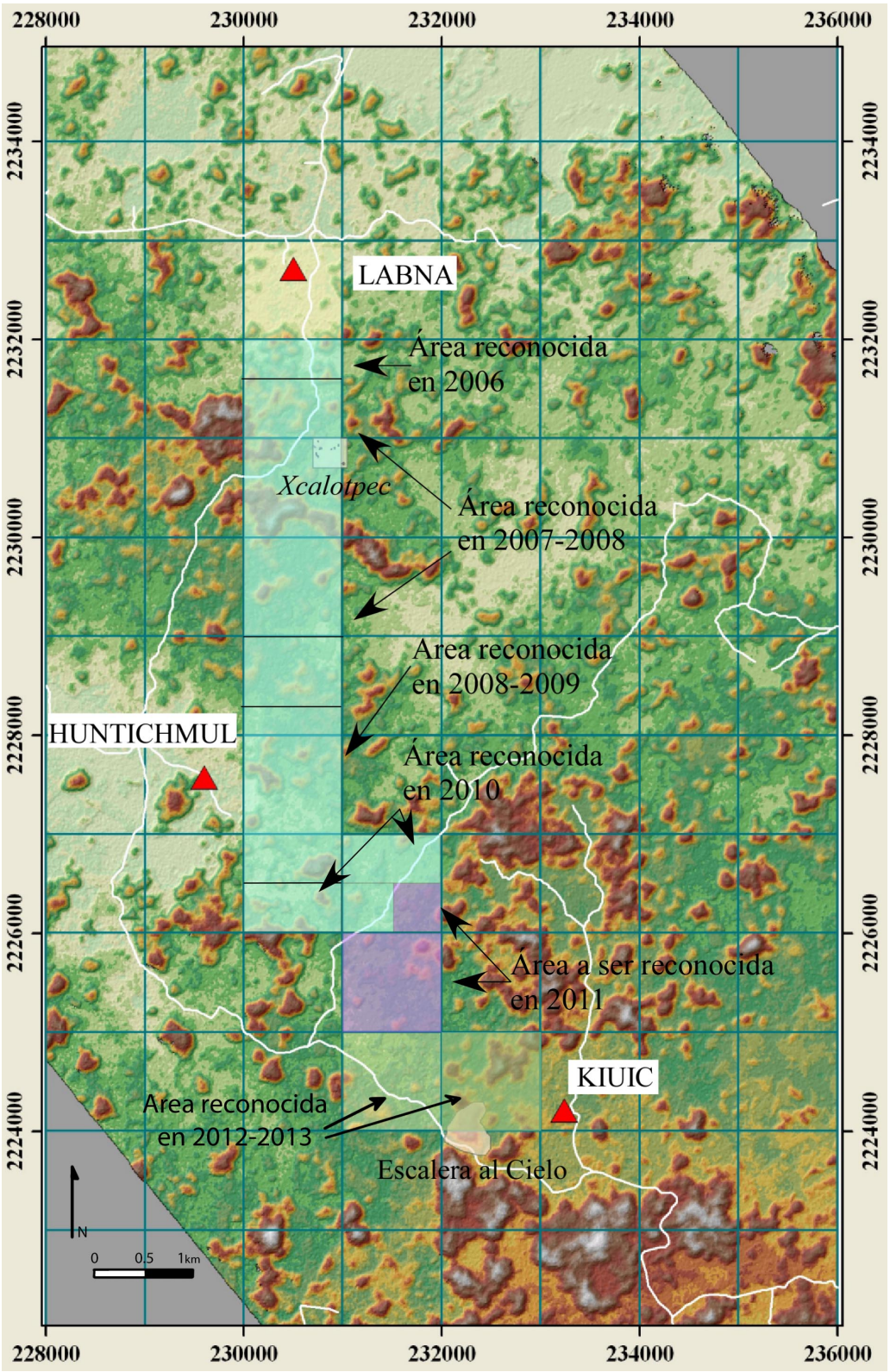


Figure 1-4: Map of the Labná-Kiuic inter-site survey completed by Gallareta Negrón and colleagues between 2001-2014 (adapted from Gallareta Negrón et al. 2011:49).

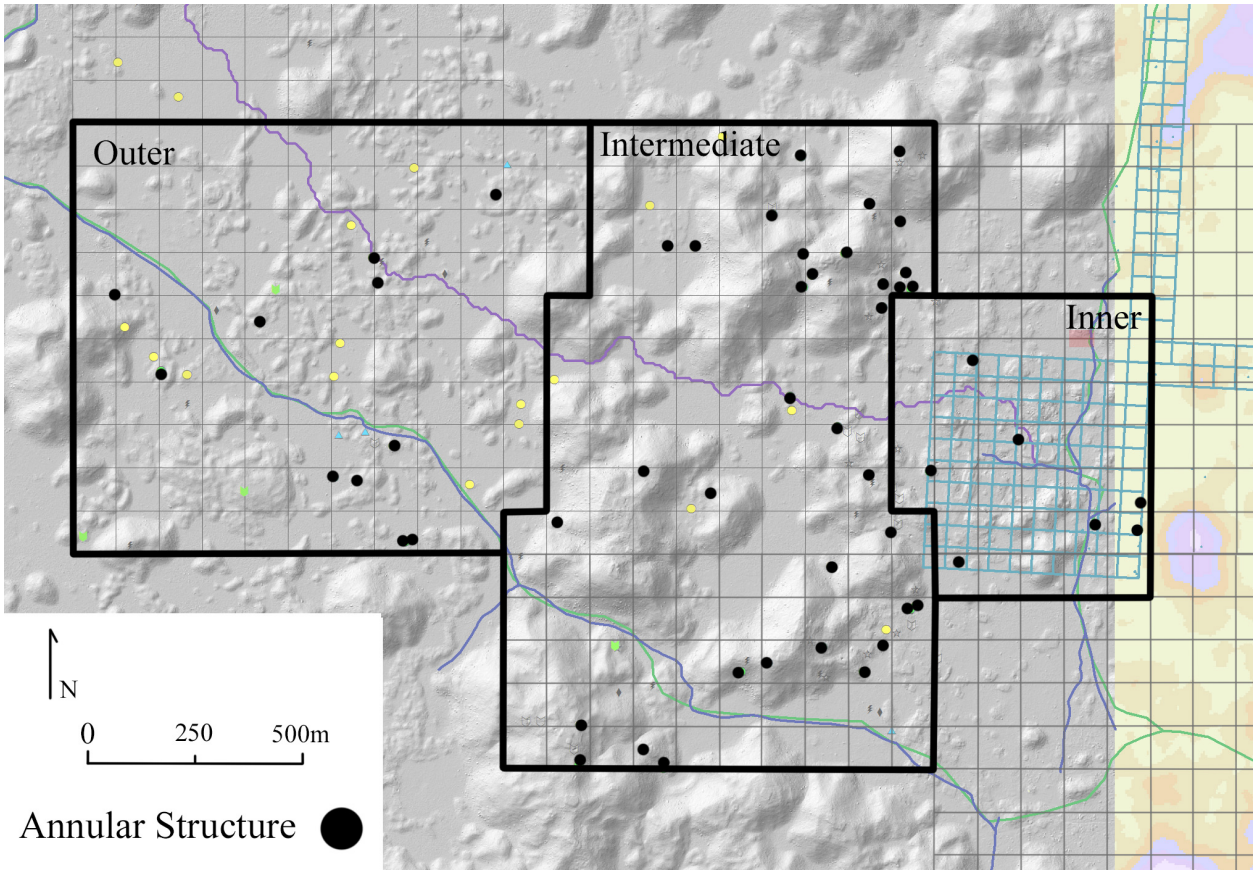


Figure 1-5: Map of the study area broken down into outer, intermediate, and inner zones and displaying the locations of the annular structures (adapted from Gallareta Negrón et al. 2014)

To test my second hypothesis, concerning the improved fuel-efficiency of the annular pit-kilns compared with aboveground pyres, I oversaw the construction and firing of an experimental annular pit-kiln modeled on the Prehispanic structures. I compared labor, wood fuel, and finished product requirements from my pit-kiln experiment with data generated by previous experiments that used the open-air pyre method. These comparisons support the claim that the annular pit-kilns were more fuel-efficient than aboveground caleras. This finding has implications for understanding why the pit-kilns were built and used during a period of demographic and architectural expansion.

To test my third hypothesis, that lime production was a decentralized enterprise, I mainly employed spatial and contextual data. Keeping in mind the limitations of these spatial datasets, I focused on those aspects of production for which the data could be most practically applied. The widespread and fairly evenly dispersed locations of the annular pit-kilns throughout the community suggest a decentralized, small-scale production scheme. Small corporate groups of various socioeconomic means likely organized the labor for production episodes that were directed by lime specialists. The data do not preclude the possibility of non-producing elites and/or central governing authorities controlling certain aspects of lime production, such as access to raw materials and distribution of finished lime. Distribution analyses also indicated that the most important factors influencing the locations of the annular structures were the location of optimal raw materials and the desire to limit pre- and post-production transportation efforts.

The Importance of Lime to Prehispanic Maya Communities

Burnt lime was used throughout the Prehispanic Maya area for construction, sanitary, dietary and other purposes (Abrams and Freter 1996; Schreiner 2002, 2004; Wernecke 2005, 2008; Russell and Dahlin 2007:407; Villaseñor 2010:47; Barba 2013). The constant demand for and consumption of lime made lime production a significant industry. Much labor and raw materials were devoted to lime production, making it an important socioeconomic activity. The burnt lime industry may have been especially significant in the Bolonchén district of the Puuc region where archaeologists have noted a particularly high concentration of Prehispanic masonry architecture (Gallareta Negrón et al. 2015a:1-4; Ringle and Tun 2016).

Despite the lack of glyphic or iconographic evidence, the recovery of architectural lime products from archaeological contexts provides abundant evidence for the widespread production

of lime starting during the early first millennium BCE. While the earliest evidence for architectural lime in Mesoamerica dates to approximately the 14th century BCE in Oaxaca (Marcus 1989:163) and ca. 1100 BCE in the Maya area specifically (Hammond and Gerhardt 1990:464), it is likely that scattered incidents of lime production occurred earlier. Due to the amount of materials and technical knowledge involved in lime production, it is possible that different specialists oversaw different steps in the process. These specialists likely managed laborers organized by small-scale corporate groups. Specialists had to locate and direct the excavation outcrops of specific grades of limestone that were most desirable for producing lime powder. This required knowledge of limestone grades, where to access them, and how to extract them (Abrams 1996:205; Carmean et al. 2011:147-148). Lime producers also had to be knowledgeable about the different tree species that provided the best woods for lime production (Russell and Dahlin 2007:410-413; Santini 2016:73-75). The transportation of raw materials to production sites required a significant amount of labor to chop wood and crush the limestone to manageable sizes at the quarry site or carry large pieces of limestone out of the quarry (Abrams 1987:493-494). Different pyrotechnological methods might have been employed at different times by different groups of people, but all required the gathering of wood fuel and the construction of a lime burning apparatus. The amounts of labor, raw materials, and technical knowledge required to produce lime powder strongly suggest that the lime industry played an important role in Prehispanic Maya socio-economies.

After the lime powder was produced, it had to be transported and/or mixed with other materials to create finished and usable products. All of these steps required organization, cooperation and direction (Abrams 1987:493-496, 1996:206; Schreiner 2002:68-72, 99-102). The many different stages in the production, distribution and consumption cycle provide a wide

array of angles from which to investigate the economic impact of the lime industry. In this dissertation I examine the production stage of the process. I will pursue the issues of distribution and consumption of lime products further in future investigations that branch off from the current project.

Chapter Outline

In Chapter 2 I discuss how my research draws on and contributes to theoretical frameworks pertaining to pre-modern small-scale craft production industries and political economies. Most studies of Prehispanic Maya socioeconomies have focused on architectural disparities and on the production, distribution, and consumption of durable materials like ceramics and lithics (Ball 1979, 1989; Hirth 1996, 1998, 2009; Masson and Freidel 2002; Foias 2002; Wells 2006; Emery and Aoyama 2007; Aoyama 2006, 2007; Brumfiel and Nichols 2008; Folan et al 2009; Rice 2009; Carmean et al 2011; Braswell et al 2011; Demarest et al 2014; Gunn 2015; Masson et al 2016). My case study introduces lime production industry into broader discussions of how Prehispanic Maya communities operated. I examine how lime production was embedded within the local political and socio-economies. I argue that lime production was a decentralized craft industry that provided at least some small-scale producers within the community with a means of supplementing their subsistence through multi-crafting. Although my data on lime production pertain to the Kiuic polity specifically, my findings serve as a model for understanding lime production within other Prehispanic communities in the Puuc region and the Maya area more broadly. I draw on recent theories regarding the organization and functions of small-scale corporate economies and craft production to demonstrate the theoretical significance of my exploration of small-scale burnt lime production.

Chapter 3 is dedicated to discussing the importance of my case study with regard to Prehispanic Maya environmental resource management and societal collapse. I evaluate frameworks for studying human-environment relationships and societal decline in the past and discuss how the Prehispanic Kiuic lime industry serves as an example of pre-modern adaptability. Some researchers have argued that the decline of Classic Period Maya communities resulted from environmental overexploitation or even 'ecocide' (Wingard 1996; Webster 2002:251-259; Diamond 2005; Pringle 2009; Oglesby et al. 2010). The annular pit-kilns appear to reflect a conscious effort on the part of the Puuc Maya to conserve their natural resources in the face of demographic and climatic stresses. The burnt lime industry played a significant role in the Kiuic economy as it likely did in most of the economies of the Eastern Puuc region. The use of wood fuel to produce lime connected issues of political and socioeconomic importance with concerns for resource management and human-environment relations. In this chapter I explore the related themes of environmental resource management and societal 'collapse' to contribute to a growing recognition of Prehispanic Maya resource management practices and pre-modern human-environment relationships more generally. I explain how the development of the more fuel-efficient lime pit-kiln technology provides an example of a pre-modern resource conservation strategy that can be used to combat charges of 'ecocide' and mismanagement of resources by pre-modern communities.

Chapter 4 provides background information that helps to situate the current investigation in space and time. The chapter starts with a detailed description of the geographic setting of the investigation and then I discuss previous archaeological research projects completed in the Puuc Region and Kiuic in particular. I outline the reasons for the division of my study area into 'outer,' 'intermediate,' and 'inner' zones and how they provide the basis for many of my spatial

and contextual analyses. I then delve into the specifics of limestone processing and lime production. This section includes discussions of previous research on pre-modern lime production throughout the world. I evaluate different methods of lime production used in the Old and New Worlds, as well as the different techniques that researchers are now using to study pre-modern lime production.

Chapter 5 is dedicated to discussing my hypotheses and the methods that I use to test them. These include basic excavation details and the importance of ethnographic and experimental approaches, as well as in-depth descriptions of ICP-OES and stable isotope analysis techniques. I also describe the different spatial and contextual analyses that I use to examine the organization of the lime production industry and present the different datasets that I generated during my investigation. These include: excavation, archaeometric, experimental, ethnographic and spatial data.

In Chapter 6 I summarize the structural and contextual data recovered from the excavation of nine annular structures in and around Kiuic. This includes descriptions of their construction forms, the materials encountered within the central depressions of the structures, and their construction histories. It also includes line drawings of the structures drawn from different perspectives. In the second part of Chapter 6 I outline a proposed typology for annular pit-kilns, which includes an in-depth description of five type categories and their distributions within the study area. The five types likely reflected differences in topography, access to building materials, and sub-cultural idiosyncrasies in the case of the Oxkintok type.

Chapter 7 covers the experimental and ethnographic portions of the investigation. First I discuss prior experimental research about burnt lime production in the Maya area and then I describe the construction and firing of an experimental lime pit-kiln modeled on the Prehispanic

annular structures. Next I discuss the results of these firing experiments and their implications for local Prehispanic resource management. I also summarize the evidence gathered from the experiments that support the hypothesis that the Prehispanic annular structures functioned as lime kilns. In the second section of the chapter I present ethnographic data that I gathered during the 2014 and 2015 summer field seasons combined with data that Dr. Dean Arnold recorded in the vicinity of Kiuic in the 1960s (Arnold, personal communication 7/2015). This ethnographic information provides the most useful modern analogies available to help us understand how the local Prehispanic Maya processed limestone.

In Chapter 8 I present the results of my archaeometric and spatial analyses. I begin with a discussion of the stable oxygen and carbon isotope analyses and the ICP-OES results. Next, I present the AMS radiocarbon data and discuss their implications for the chronology of annular pit-kiln use. I also discuss the ceramic data and how they provide further chronological evidence for dating the pit-kilns to the Late and Terminal Classic Periods. I conclude this first section by summarizing how the multiple lines of physical evidence support the hypothesis that annular structures were used as Prehispanic pit-kilns. In the next section of the chapter I discuss my spatial and contextual analyses and highlight two main points: 1) That annular structures were located to mitigate transportation efforts; and 2) Lime production was largely decentralized and organized by small-scale corporate groups. I conclude the chapter by discussing other possible functions for the annular structures in addition to lime production.

Finally, in Chapter 9 I discuss the various socio-economic and resource management issues addressed by my lime production study. I argue that lime pit-kiln technology was invented as a result of both push and pull factors. I point to evidence suggesting that the development of the pit-kiln technology represented a deliberate action on the part of the ancient inhabitants of the

Kiuic polity to consume fuel resources more efficiently in the face of demographic and environmental stresses. The second section of the chapter is devoted to discussing the socioeconomic organization of the lime production industry and what the spatial and contextual clues suggest about which members of the community may have been producing the lime and how these issues relate to our understanding of craft production in Prehispanic Maya society. I also discuss the likelihood of lime production being a seasonal activity and present a case study of an inner zone residential compound that produced burnt lime. I conclude the chapter by presenting my overall conclusions about the role that the lime production industry played in the sub-regional socio-economy and how it affected concerns for the management of environmental resources.

Summary of Results

The results of my investigation demonstrated that the annular structures were used for producing lime from limestone and that they were more fuel-efficient than aboveground pyres. The identification of the annular structures as lime pit-kilns subsequently allowed for the examination of the spatial and contextual relationships of lime production locales. These data are consistent with a largely decentralized organization system in which some households or small-scale corporate groups produced lime while others acquired it through exchange networks. This does not preclude the possibility of some degree of centralized oversight of certain aspects of the lime industry.

Through the systematic excavation of nine annular structures I recovered multiple lines of evidence that indicated that the structures were used as pit-kilns for producing lime. These include: 1) evidence for burning on the interior walls and bases of all of the annular structures

excavated, as well as evidence for burning on the exposed interior portions of annular structures that were not excavated; 2) alternating layers of burned materials and reconstituted calcium carbonate (lime plaster) near floors of several of the annular structures; 3) the identification of many small pieces of partially burned limestone scattered around the outside of many structures; and 4) the proximity of most of the annular structures to the grade of limestone known as *saakel bach tuunich*, which is the most desirable grade for producing lime.

The lime production experiments show that the pit-kiln technology was more fuel-efficient than the aboveground pyre technique and that fuel conservation was likely a factor in its initial development and use. While recent experiments with aboveground lime production have demonstrated fuel-to-product ratios of as high as 6.3:1 (10.24 m^3 of wood/1.63 m^3 of lime) (May and Gallareta 2003) and 8.5:1 (4.95 m^3 of wood/0.58 m^3 of lime) (Russell and Dahlin 2007), my experimental pit-kiln produced burnt lime with a ratio of 3.94 parts wood fuel to 1 part burnt lime (2.85 m^3 wood fuel/0.722 m^3 burnt lime). The radiocarbon and ceramic data indicate that the annular structures were constructed and used around 650-850 CE, a time of demographic and architectural expansion in the Eastern Puuc region (Gallareta Negrón et al. 2014:1.3-1.5). The growth in population and construction projects likely strained local fuel resources, especially as much of the flat land in the region was increasingly devoted to agricultural uses. The strain on resources likely encouraged lime producers to develop more fuel-efficient production methods. Additionally, the experimental data indicated that repeated firings in the same location loosened the underlying bedrock. This allowed for the relatively easy excavation of the central pits of the kilns to increasingly greater depths, providing increasing structural stability and protection from wind, leading to greater fuel efficiency.

The multiple lines of evidence pointing to the annular structures being used as lime pit-kilns consequently allowed for the investigation of the organization of the lime production industry at Kiuic. Proximity to high grade limestone and sloping terrain appeared to be the most important factors influencing the location of the annular structures. The location of the majority (66%) of the annular structures in the hilly intermediate zone likely represents an effort on the part of lime producers to limit labor investments in transportation. During the Late and Terminal Classic Periods much of the flat land in the Kiuic polity was likely devoted to agricultural production, which would have left the hill-slopes as the most likely areas from which to harvest wood fuel. The annular structures were built in this area to be as close as possible to the raw materials necessary for lime production while also limiting post-production transportation investments.

Spatial distribution analyses demonstrated that aside from a higher concentration in the intermediate zone, annular structures were widespread throughout the Kiuic community, which suggests a largely decentralized production scheme. A few residential groups, especially in the intermediate hill zone that rings the Kiuic Valley, appear to have had access to their own annular pit-kilns. These households would likely have produced lime for their own consumption as well as possibly for exchange with other households in the community and to provide to central governing authorities for the construction of public buildings. However, more than half of the annular structures in the study area were not directly associated with other archaeological features. It is possible that households that did not have their own annular structures within the confines of their residential complex still may have controlled or had access to the relatively isolated pit-kilns further away from the site center. It is unlikely, however, due to the labor and technical skill involved in lime production that all households in the community were producing

their own lime. This means that non-producing households had to acquire their lime through some form of exchange system. While the data are consistent with a decentralized scheme that included multiple small-scale producers, this does not preclude elite or central government oversight of certain aspects of production and distribution. In the absence of any direct spatial links between annular pit-kilns and the public complexes of the site center, governing elites may have obtained lime for dietary and architectural purposes through several possible means. Procurement methods may have included direct oversight of production locales dispersed throughout the community and/or administration of lime tax or tribute systems.

Chapter 2 – Prehispanic Maya Economies

One of the main goals of this research is to contribute new data and perspectives to the study of craft production organization in pre-modern economies. This objective is addressed through an investigation of burnt lime production in the Prehispanic Maya community of Kiuic. The significance of lime to so many aspects of Prehispanic Maya life raises interesting questions about the organization of lime production within Prehispanic socio-economies. Did all households produce their own lime? Was lime production restricted to certain socioeconomic groups? Was lime production centrally controlled, decentralized, or both? The identification of lime pit-kilns spread throughout the Kiuic area provides the opportunity to address these questions. Most archaeological studies of the Puuc economy have focused on the region's role as a potential 'bread basket' for much of the Northern Lowlands. This argument is based on agricultural production estimates and indirect models of large coastal population centers provisioning themselves through maize imports (Kurjack et al. 1979; Barrera Rubio 1982; Dunning 1991; Smyth and Dore 1992:4; Dahlin 2005; Gallareta Negrón et al. 2014:1). The focus on a possible agricultural export economy has overshadowed the importance of craft industries like lime production to polity-level socioeconomies in the Puuc region.

In this chapter I discuss how my research draws on and contributes to theoretical frameworks pertaining to pre-modern small-scale craft production and political economies. Throughout my discussion I refer to the 'local' or 'polity' scale of my study, by which I mean the Kiuic polity specifically. Although long distance trade of especially high quality lime may have existed, the ubiquity of limestone and fuel resources throughout the Yucatán peninsula suggests that burnt lime was likely produced and consumed at the polity level. My findings

regarding decentralized production organization serve as a model for comparison with other small-scale industries in Prehispanic Maya communities and pre-modern societies around the world.

Early studies of Prehispanic Maya economies tended to treat the broader Maya area as a single economic system if not a series of mirror-image city-states operating under the same economic principles (e.g. Blom 1932; Morley and Brainard 1946; Nash 1967). As with early theory applied to other pre-modern societies, researchers focused on the role that the exchange and control of goods and services played in the development of sociopolitical complexity in the region. In recent decades, archaeologists have developed new approaches that recognize the complex and embedded nature of economic issues within distinctive sub-regional communities (Hirth 1996; Masson and Freidel 2002; McAnany 2010; Garraty and Stark 2010; Chase and Chase 2014; Demarest et at al 2014:189). The focus is no longer exclusively on how economic modeling can help to explain the development of sociopolitical complexity. Instead, with breakthroughs in epigraphy and a constantly growing body of excavation data, researchers can focus more closely on detailed economic issues at more localized scales of examination. This has allowed for the study of other facets of Prehispanic Maya economies in recent decades such as: embedded ritual characteristics (Gillespie 2001; Lucero 2003; LeCount 2001; Brady 2005; McAnany 2010, 2014); production of craft items by members of various socioeconomic sectors (Inomata 2001; Aoyama 2007; Emery and Aoyama 2007; Fish 2015); and gendered divisions of labor (Hendon 1996; Neff 2002; Robin 2002, 2006; Emery and Aoyama 2007; Demarest 2009; Geller 2009).

These new approaches have shed light on the day-to-day processes and relationships of diverse Prehispanic Maya economies and how these economies articulated with other facets of

society. In this chapter I draw on recent theories regarding the organization and functions of small-scale craft production. I examine their articulation with political economic frameworks to demonstrate the theoretical significance of my exploration of small-scale burnt lime production.

Small-Scale Economies

Economies do not exist in a vacuum. Instead they are among many reflexively structuring facets of society (Costin 1991:2; Flad and Hruby 2007:6; McAnany 2010:1-8; Demarest et al. 2014), and along with these other interwoven components, economies are in a constant state of production and reproduction (Giddens 1979, 1984). When examining the intersections of social and economic facets within past societies it is important to choose the appropriate scale or organizational level to address specific research questions. Early archaeological treatises on pre-modern economies largely focused on the origins of socioeconomic differentiation and political economic complexity using polity-wide or even civilization-wide scales of analysis. Decades of research on the origins and prominent institutions of past civilizations laid the foundation for the adoption of more detailed research foci. As a result, many archaeological investigations of pre-modern socio-economies have largely shifted to focusing on smaller scales of production such as the household unit or small corporate group (Wilk and Rathje 1982; Hendon 1996; Hirth 1993, 2006; McAnany 2010; Douglass and Gonlin 2012).

I use the term small corporate group to refer to social units that inhabited spatially- and contextually-related residential compounds and may have included one or more households. Focusing on corporate groups as the main analytical unit allows for the most practical understanding of the diverse production and consumption strategies employed by small-scale social units to ensure their survival (Hirth 1993, 2006; Carballo 2009). This provides the

foundation for making comparisons of disparate strategies adopted by different groups interacting within the larger socioeconomic network. Examining correlations between small corporate groups and lime pit-kilns provides the basis for making inferences about how lime production was organized. A number of such groups in and around the site center appear to have controlled their own lime pit-kilns, which indicates that lime production was at least partially organized at the small-scale corporate level. Groups that did not have their own lime pit-kilns still may have produced lime at more isolated pit-kilns further away from residential compounds.

Despite the various modes of identification used by social groups to differentiate themselves from each other, the main approaches used by archaeologists to differentiate the socioeconomic status of households and corporate units continue to be residential architecture, burial data, and household artifacts (Arthur 2002:331). Comparing residential architecture compounds in terms of the construction materials, spatial layouts, and proximities to one another can also provide information about alliances or social connections between social groups (Arnauld et al. 2013). Webster (2002:135) proposes that a growing web of marriage alliances led to the dissemination of previously exclusive materials and information to ever-wider sectors of elite society leading up through the Terminal Classic Period. Mapping out alliances and social networking patterns also has implications for economic issues such as the exchange of goods and marshaling of work forces for large-scale construction, agricultural, or even lime production projects (Abrams 1987; Hutson and Davies 2015:11,14). While it is beyond the scope of my study to attempt to identify alliances between specific households, it should be noted that annular pit-kiln technology appears to have been used by small corporate groups of varying socioeconomic status at Kiuic. This situation may have resulted from the dissemination of

technical knowledge between groups of differing socioeconomic status at Kiuic relating to social or socio-economic alliances.

In the Puuc region, socioeconomic status is deduced mainly from differences in forms of residential architecture. It is believed that elite households within the Prehispanic Puuc communities occupied residential compounds that included stone vaulted structures, while non-elite households occupied houses with stone foundations but perishable superstructures (Smyth and Dore 1992:7-8; Carmean et al. 2004:442-446; Carmean et al. 2011:154-155; Simms et al. 2012:270; Gallareta Negrón et al. 2015a:1.6). The resources in terms of labor, materials and technical skill required to construct a stone vaulted structure are much greater than those necessary for constructing a thatch-roof structure (Abrams 1987:492-493). Thus, not only would the inhabitants of such compounds possess the capability to muster large quantities of resources resources, but the act of living in such a compound projected and reinforced their elevated status (Kohut et al. 2009; Gallareta Negrón 2013:173-174; Gallareta Negrón et al. 2015a:1.6). I use architectural and ceramic data as a baseline for analyzing the socioeconomic variables of burnt lime production. By focusing on the small-scale corporate group as the main production unit, I demonstrate that burnt lime production was not limited to certain socioeconomic groups and that the overall organization of the industry was largely decentralized. Burnt lime production was likely one of multiple subsistence strategies adopted by some households at Kiuic to ensure their own reproduction.

Charcoal samples recovered from four of the annular structures and ceramic data gathered from five others point to the pit-kilns' use during the Late and Terminal Classic Periods (ca. 650-850 CE). This suggests that the pit-kiln technology was developed in order to conserve wood fuel resources in the face of demographic and construction booms. Johnson et al. (2005)

created a computer model to simulate fuel use and depletion among the Puebloan societies of the Southwestern United States using agent-based modeling. Their results indicated how easy it would be to deplete fuel resources and suggested that changes in cultural aspects of pre-modern societies may have been deliberate adaptations for the purpose of conserving fuel (Johnson et al. 2005:104). Individuals with the knowledge to direct construction and firing of efficient annular kilns could have guarded their trade secrets and they or any patrons may have therefore controlled the efficient production of lime. If environmental resources were indeed at a premium during the Late and Terminal Classic Periods in the Kiuic community, restriction of fuel use would make fuel-efficient lime production a valuable skill. Several of the larger, more elaborately constructed annular structures are located within or in close proximity to elite residential compounds near the Kiuic site center. This suggests that the inhabitants of these compounds had access to the higher levels of labor, knowledge and technical skills required to produce lime more efficiently and on a grander scale.

De León's study of Aztec household-level salt production at workshops distant from residential structures is useful as a reference for understanding the household-level organization of lime production at Kiuic. Just as most of the salt production workshops were located away from residential structures, many of the annular pit-kilns at Kiuic were relatively isolated in the polity's hinterlands. This isolation does not necessarily preclude their use or even control by elite and/or non-elite household groups living closer to the site center. In fact, as De León found for salt production, a number of factors may have even encouraged the purposeful removal of workshops to a greater distance from residences. Lime production episodes include the creation of much smoke and heat pollution. The strenuous physical activities and large amounts of labor involved also likely resulted in much noise pollution. The immediate production of limestone

calcination is quicklime, a caustic material that is dangerous to touch, which could pose risks to unsuspecting children. All of these 'push' factors may have combined with 'pull' factors like easier access to the necessary raw materials to lead many households to construct their personal lime kilns outside the confines of the site center. Thus, the relative spatial isolation of many annular structures does not necessarily mean that they were not affiliated with specific households.

Craft Production

According to Hirth (2006, 2009:18), the most basic function of the household unit is to reproduce itself. I believe that this is also true of the small corporate social group, which is formed in part to benefit the survival and reproduction of its constituent households. Craft production provided a complementary subsistence strategy to agricultural production (especially if agriculture was limited to certain times of year). Activities such as multi-crafting or part-time crafting allowed different members to contribute to the overall social and financial success of the household and/or corporate group at different times of the day and/or year (Hendon 2006; Hirth 2009; Masson et al. 2016). I use the small corporate group as my main analytical unit because it is the smallest practical socioeconomic unit with which to uncover socioeconomic patterns regarding lime production. However, it must be remembered that these social units were composed of individuals, even if we cannot distinguish them archaeologically. Specialized craft production required a certain degree of skill acquired through training and perhaps continuous oversight. This training could have taken place within the context of the corporate group. As Hendon explains: "Craft production is a social process that results in the creation of needed or desired things, while also shaping people through their engagement with the material properties

of what they make, with the technologies employed in the production process, and with the people with whom they interact, whether as teachers, apprentices, patrons, or family members" (Hendon 2015:161).

Many authors list craft production, or more specifically craft specialization, as one of the most prominent forces behind increasing socioeconomic differentiation and stratification in pre-modern societies (Kenoyer et al. 1991:44; Inomata 2001:322; Schortman and Urban 2004:329-331; Hirth 2009). They see the development of specialized production industries as providing opportunities for gaining power through control over any of several stages involved in craft production (Kenoyer et al. 1991:47; Hirth 2009:21; Blitz 2010:4). The lime industry at Kiuic involved many stages, including: 1) the initial construction of the pit-kiln; 2) the identification, quarrying, and crushing of the appropriate grade of limestone for calcination; 3) the felling and transportation of the appropriate tree species; 4) the proper assembly and burning of the raw materials within the kiln; and 5) the slaking and removal of the burnt lime from the kiln. Each of the lime industry stages potentially provided elites and/or central governing authorities with an opportunity to control aspects of production. However, the widespread location of the pit-kilns throughout the Kiuic landscape, within and without residential compounds of varying socioeconomic status suggests that production was largely decentralized.

The data are therefore consistent with a scenario in which centralized authorities may have controlled certain pre- and post-production aspects of the lime industry but the actual *production* of lime was decentralized and organized by small corporate groups. Burnt lime production afforded small corporate groups a certain degree of socioeconomic power. Individual households may not have controlled exclusive access to the raw materials nor the finished products of the burnt lime production process, but the contextual evidence suggests that only

some corporate groups were producing their own lime. This was in a society where all groups needed lime for at least dietary purposes. Thus, lime producing households or corporate groups gained a measure of socioeconomic power through the production for exchange of an essential material. Additionally, a degree of socioeconomic power or independence was afforded to households or corporate groups like the one located in the hilltop compound of EAC that were able to meet their own lime consumption needs.

This discussion is predicated on the assumption that burnt lime should be considered a craft good. I define a craft item or good as a product that requires a level of skill and/or knowledge possessed by a circumscribed number of individuals to correctly and efficiently manufacture. This is linked with a definition of artisans or craft specialists: individuals who possess the specific skills and/or knowledge required to correctly and efficiently manufacture a craft item. Some authors argue that the term 'craft' inherently adds a higher degree of social value to an item than one deemed 'non-craft,' but this must be evaluated on a case-by-case basis depending on the society or culture in question (Bayman 2002; Flad and Hruby 2007; Rochette 2014). Another qualifier frequently associated with craft items is the limited production and distribution of the item; however, this more specifically describes luxury, prestige, or wealth items. 'Craft' items, under my definition, are a broader category that may include utilitarian or non-luxury items as well as prestige goods (Costin 1991; Kenoyer et al. 1991; Masson et al. 2016).

Burnt lime meets the requirements of a craft good based on most definitions, including my own. The knowledge and experience required to recognize suitable grades of limestone, construct a practical kiln, and efficiently assemble and burn the raw materials to produce lime was likely limited to a certain number of individuals in the community (Abrams 1987, 1996;

Abrams and Bolland 1999; Carmean et al 2011; Brennan et al. 2013). Specialized production of high grade lime likely required extensive training as well as the ability to adapt and respond to unforeseen complications in the production process (Hendon 2015:160). Thus it is unlikely that all households had a lime specialist among their members or that all households produced their own lime. This argument is supported by the fact that only approximately 25% of households appear to have had direct access to their own lime-kilns and overall there were approximately one-third more household groups than annular kilns in the study area. Those households that did produce lime probably did so on a part-time basis due to the effort required in gathering fuel and raw materials, as well as a preference for certain meteorological conditions. It is also likely that lime production was one of several crafting activities carried out by members of these households, as multi-crafting provided a safeguard against economic ruin.

While some archaeologists use the term craft specialization to refer to a state of being, most often in reference to the status of artisans who have focused their talents on producing one 'specialized' craft (Costin 1991), others argue that the term specialization refers to an ongoing process. Abrams (1987:486) refers to the more general process of 'economic specialization' of which craft specialization would count as a subset, as "the patterned increase in the kinds, number, and intensity of specialist positions articulated within the broader socioeconomic framework." Kenoyer and colleagues (1991:45) espouse a similar definition of craft specialization as an adaptive process, stating that craft specialists are, "Individuals who have progressively increased their competence on a limited range of produced goods, and have developed appropriate motor-habits for manufacturing specific objects… regardless of the chronological time frame or cultural context." While craft specialization implies a continuing process, many authors continue to refer to it as a state of being. The concept that they are using

the term craft specialization to describe would more accurately be described as specialized craft production.

Inomata (2001:322-323) suggests another distinction that can be made between the process of craft specialization and the act of specialized craft production. He argues that the process of craft specialization implies changes on a macro-scale, meaning that when some members of a society or group begin to specialize in producing specific items, it engenders changes to larger society-wide networks. The craft specialization process is thus one of a multitude of changes occurring within a given society whose many intertwined facets are evolving in tandem (Abrams 1987:486; Inomata 2001:322-323). The act of craft *production* on the other hand, Inomata argues, "may be conducted sporadically by any member of society" (Inomata 2001:322). Some researchers clarify that 'specialized craft production' refers to a deliberate production of a *surplus* of items for distribution outside of the craft producer's household (Blackman et al. 1993:60-61). A third condition often raised is that craft specialists are completely removed from attending to their own agricultural subsistence needs. This third qualification is invalidated by evidence for part-time craft specialists in many pre-modern societies, including the Maya. Part-time craft specialists may be able to take part in agricultural subsistence activities in addition to their crafting activities, whether on a daily or seasonal basis.

Working in the Ulua Valley of Honduras, slightly outside the Prehispanic Maya cultural sphere, Joyce et al. (2014:417) found that pottery production was likely the result of overlapping 'communities of practice' that were based in household settings but united social groups from within and without these households. It is possible that small-scale corporate production groups were also a feature of the lime production industry, a scenario supported by the clustering of several annular kilns away from specific household compounds but near to one another. The

arrangement of several annular kilns near to one another suggests a type of lime production complex or workshop that presumably required the oversight of several skilled lime producers. The amount of labor required to assemble raw materials for lime production would also benefit from a larger labor pool presumably afforded by the cooperation of members of multiple households. While it is theoretically possible that all of the lime production specialists belonged to one household, it is more likely that they came from several different households and shared some sort of partnership or 'community of practice' that united members of different households.

Abrams and Bolland (1999) offer a contrasting opinion in their study of lime plaster production, labor organization, and architectural energetics at Copán. They hypothesize that there were only a limited number of craft specialists skilled in the art of making lime. These few lime production specialists could have overseen a large unskilled labor force that gathered the raw materials and then transported the product. They argue that this low number of specialists most likely reflected their embeddedness within a social structure that did not require the creation of new corporate socioeconomic organizations such as guilds (Abrams and Bolland 1999:271). The widespread distribution of annular pit-kilns suggests that many lime specialists practiced their craft in the Kiuic community. This appears to support a production organization framework closer to Joyce et al.'s (2014) 'communities of practice' model. However, it is also possible that a few specialists oversaw production episodes for various small corporate groups. Whether or not the specialists were themselves members of the corporate groups, these small-scale social units would likely have been able to organize and/or provide the necessary labor for production episodes.

The Prestige-Utilitarian Spectrum

I agree with Masson and colleagues (2016) and others that the old 'prestige' vs. 'utilitarian' item dichotomy is too simple to account for the wide range of social and economic values ascribed to different objects in past societies. However, it would be foolish to completely disregard this categorization scheme, which can still be usefully re-envisioned as a spectrum or continuum. The label "prestige goods" (also wealth or luxury goods) refers to a category of crafted items that do not necessarily have a practical function related to subsistence, but either provide a non-essential luxury for the owner or serve as a status marker. Utilitarian items, on the other hand, are functional and used mainly for subsistence activities (Clark and Blake 1994; Blanton et al. 1996; Trubitt 2000; Rice 2015). Since the prestige/utilitarian dichotomy was first established, prestige craft items have often been associated with a production scheme referred to as 'attached' production, in which the majority of the production process is controlled by patrons to whom the craftspeople are 'attached' (Costin 1991; Hirth 1998; Aoyama 2007; Flad and Hruby 2007). This attachment can refer to physical bondage or to the patron controlling access to the raw materials as well as the consumption and/or distribution of the final product.

In recent decades, archaeologists have challenged the assumption that most prestige items were produced by attached craft specialists. In the Maya area specifically, studies have shown that members of the elite class were often themselves skilled craftspeople. These elites may have produced prestige items to be used by their peers as well as by members of their own households. Evidence from the rapidly abandoned site of Aguateca in particular (Inomata 2001; Emery and Aoyama 2007:84) now points to the production of bone and lithic crafts by members of elite households, not artisans attached to these households. Archaeologists also now have access to

explicit iconographic and epigraphic references to members of elite and royal households being producers of prestige crafts (Stuart 1993; Coe and Kerr 1997).

The flip side of the coin has been the association between 'independent' craft specialists and the production of utilitarian items. Independent craftspeople were thought to produce their items in workshops distant from elite residences and distribute them for consumption by all sectors of the general population (Aoyama 2007). Again, this simplistic picture has been complicated by investigations that have called into question proximity as a necessary indicator of control over production. Many researchers now recognize that workshops located away from elite residences could still have operated under a patron-client or 'attached' production scenario (Costin 2001; De León 2009; Andrieu et al. 2014), and that prestige items weren't necessarily produced in attached labor situations (Bayman 2002; Ball 1989; McAnany 1989; Potter 1989; Hendon 1991; Paris 2008; McAnany 2010; Kovacevich 2015).

Materials recovered from elite residences at Aguateca as well as from non-elite residences at the smaller site of Cerén highlight the importance of multi-crafting in Prehispanic Maya household economies (Sheets 2000; Emery and Aoyama 2007; Hirth 2009). The production of multiple crafts within the same household supports the notion that crafting provided household groups with various buffers against potential downturns in income or subsistence from other economic activities. If the market for certain craft items and/or agricultural goods were negatively affected in some way, producing a range of crafts would allow the household a better chance to survive through the period of economic instability (Hirth 2009).

Burnt lime of differing quality likely existed along a spectrum spanning utilitarian and prestige designations. Differences in the grades of limestone used and the length of time that the

burnt lime was left to slake and mature resulted in finished lime of various qualities. Ethnographic data detailed in Chapter 7 provide the most useful analogy available for the sort of detailed knowledge about limestone likely possessed by Prehispanic burnt lime specialists. At the least, Prehispanic lime specialists likely knew which quarries provided the best grades of limestone for producing lime meant for different purposes. Different socioeconomic groups within the Kiuic community likely had access to different qualities of burnt lime for architectural, dietary, sanitary and other purposes. Especially in the case of lime that was used to make facade stucco, high quality burnt lime may have been considered a prestige item. Also, one can imagine higher status individuals preferring specific grades of lime for nixtamalizing their maize. On the other hand, lime used for fertilizer purposes, or for the mortar stuck deep within the buildings might have been considered more of a utilitarian item.

The ephemeral nature of lime in the archaeological record hinders an examination of its distribution and consumption. The recovery of such finished lime products as mortar and stucco from the residential and public groups in and around the Kiuic site center indicates where specific grades of lime products may have been used (Galván Bernal 2012), but it is next to impossible to trace these finished products to their production sources. Thus I focus instead on the socioeconomic organization of lime *production* using the spatial and contextual data provided by the pit-kilns. Annular structures have been found in association with both elite and non-elite compounds, which leaves open several possibilities for who exactly was overseeing the production of lime. It is possible that members of elite households possessed the skills and experience necessary to oversee the construction of annular pit-kilns and the production of lime, and yet it is also possible that these households employed lime specialists to construct and fire the annular structures within their compounds. The existence of isolated annular structures in the

intermediate and outer zones of Kiuic leaves open the possibility that independent specialists could also have produced lime independent of direct patron oversight. However, even these 'independent' specialists would likely have been members of households in their own rights and though production may have taken place at locations that were physically independent from residences, these producers would still have been 'attached' to a certain degree. It is thus possible that lime production organization existed on an attached-independent spectrum. My detailed contextual and spatial analyses of annular pit-kiln locations in Chapter 8 clarify which scenarios for specialized lime production organization are more likely.

Political Economies

Defining Political Economy

Researchers often use 'political economy' to address a wide range of intersections between political and economic concerns without providing a specific definition for the term (Abrams 1987; Costin 1991; Blackman et al. 1993; Abbott et al. 2007; Arnold 2009; Demarest et al. 2014). Perhaps this is a prudent approach as it sidesteps the inevitable search for exceptions. While I don't eschew a definition altogether, I use a working definition of political economy that lends itself to broader interpretations in order to err on the side of inclusivity. I draw on Michael E. Smith's generalized archaeological approach to the study of ancient political economies, which he defines as: "materialist approaches…[that] share a concern with variability in the relationship between politics and economics" (Smith 2004:77). Basically, I use political economy to refer to any facets of society in which political matters and economic matters intersect or influence one another. Due to high levels of consumption and the substantial

amounts of natural and labor resources involved in production, the burnt lime industry played a significant role in the political economy of the Kiuic polity.

Some scholars investigate the 'political economy' as its own entity, separate from a distinct household economic system that they see as focused specifically on provisioning and sustaining that socioeconomic unit (Potter and King 1995; Earle 2002). Other researchers explore political economy as a dynamic articulation between centralized authorities and household units of production and consumption (Smith 2004; Wells 2006; Cap 2015). Resulting ultimately from the trend towards smaller-scale and non-elite focused projects, archaeological approaches have increasingly focused on production, distribution, and consumption on a more localized scale, including at the community and household levels (Brumfiel and Earle 1987; Ashmore and Wilk 1988; Hendon 1991, 1996; Gillespie 2000; Yaeger 2000; Sheets 2002; Robin 2003; Ashmore et al. 2004; Smith 2004; Canuto 2004; Gonlin 2004; Brumfiel and Nichols 2008; Hirth 2010; McAnany 2010). My case study investigates lime production at the small corporate scale as the basis for then evaluating the industry's role in the polity-level economy. I view both small-scale corporate economic concerns and larger state-centered political economic concerns as intertwined and influencing one another. This is part of a broader recognition of the 'embeddedness' of the economy within the general social milieu (Giddens 1984; Granovetter 1985). Thus, I tend to favor those archaeological approaches that use an integrated approach to politico-economic and socioeconomic issues.

One of the most important issues in the articulation between small-scale production and state economies is the ways in which corporate groups may provision and sustain the state. Researchers have explored many methods through which a state may support itself including taxation, tribute, plunder, rental of state lands, and commercial investment, to name a few

(D'Altroy and Earle 1985:187-188; Smith 2004:87). While the burnt lime itself does not preserve in the archaeological record, we know that the governing authorities at the Kiuic site center used lime and lime products just like the rest of the community. There is no evidence for direct control of lime production by authorities at the site center. Annular pit-kilns are distributed widely throughout the study area, not in easily controlled clusters. Also, there do not appear to have been any large storehouses at the site center where governing authorities may have kept large amounts of lime for consumption and/or distribution. However, these spatial and contextual data do not preclude the acquisition of lime in small tax or tribute consignments from their constituents on a regular basis. It is also possible that lime production was tightly controlled or regulated through control over access to raw materials and/or final distribution of the product. The presence of elite hilltop compounds with their own annular structures, however, seems to suggest that at least some corporate groups were producing lime for their own consumption and distribution. It is difficult to say for certain what type of system was in place to mediate exchange between lime-producing and non-lime-producing corporate groups. More in-depth examinations of the locations and contexts of annular pit-kilns in the polity in Chapters 8 and 9 demonstrate how the data are consistent with a decentralized small-scale production scheme. This favors the tax and/or tribute model for provisioning the Kiuic state; a scenario that is also supported by ethnohistoric data (Foias 2002).

Pre-Modern Political Economies

Early frameworks for studying pre-modern economies centered on such topics as the general organization of production (Marx 1936; Udy 1959; Polanyi 1957; Dalton 1968; Hamilton 1970; Sahlins 1972; Pryor 1977), identifying broad modes of exchange (Polanyi 1944;

Thompson 1954; Dalton 1977, 1982; Earle and Ericson 1977), and discerning long distance trade patterns (Blom 1932; Rathje 1971; Wallerstein 1974). Regardless of the methodology used, the end goal was often the same: to track the development of the overarching political and economic systems of ancient societies and to explain why and how they developed (Hirth 1996; Wells 2006; Feinman and Garraty 2010; Chase and Chase 2014). Some of these early approaches applied a Marxist and/or neoclassical economic perspective, focusing on the means and organization of production and the differential control of resources that fostered social inequalities (Marx 1964; Terray 1974; McGuire 1992; Hirth 1996; Chase and Chase 2014). For Marx, political economy was "…the study of structural relationships that defined the means of controlling wealth and creating inequality in state-level society" (Hirth 1996:204). Classical economists, like Adam Smith (1776), saw the past as populated by rational, economically self-interested individuals, and attempted to establish general laws that explained how this rational behavior articulated with different political economic systems (Feinman and Garraty 2010:172; Garraty 2010).

In reaction to what he saw as the misconception of rational behavior in the past by classical economists, Karl Polanyi drew on Marx's writings and cultural anthropological work such as Malinowski's (1932) research on the Kula ring network in Melanesia to develop his substantivist economic approach (Polanyi 1944). He argued that pre-modern households were largely self-sufficient and most economic transactions were conducted under and within an ethos of mutual favorability for the community. His arguments for the absence of a 'market mentality' in pre-modern societies have had long-lasting effects on the study of ancient political economies (Polanyi 1957; Hirth 1996; Blanton and Fargher 2010:209). Polanyi's position that ancient socioeconomic mindsets were drastically different from their modern counterparts was almost

immediately challenged by Neoclassical economists (modernists) who favored a discrepancy in scale, if anything, over inherent differences in structure or mentality between modern and pre-modern economies. The substantivist approach to pre-modern market exchange appeared to have a greater influence in archaeological circles, exemplified by the monumental substantivist works of Michael Finley on the ancient Mediterranean economy (Finley 1999; Smith 2004:71; Hirth 2010:231).

Researchers (e.g., Isaac 1993; Smith 2004; Wells 2006; Oka and Kusimba 2008:357; Scarborough and Valdez 2009) have been declaring the substantivist/formalist debate to be over since the 1980s, despite the fact that key tenets of these opposing viewpoints continue to crop up in treatments of pre-modern political economies. Over the last few decades the field has opened up to a wider set of foci regarding ancient pre-modern economies, including an immersion in the investigation of the origins and developments of market exchange systems. I follow Feinman and Garraty's (2010:171) definition of market exchange as "…economic transactions where the forces of supply and demand are visible and where prices or exchange equivalencies exist." This and most other definitions do not necessitate the existence of physical marketplaces, making it difficult to identify in archaeological contexts (Cap 2015).

It is now generally recognized that different modes of exchange most likely existed simultaneously within any given society (Blanton and Fargher 2010:222; Hirth 2010:229; Feinman 2013:454). For example, early perspectives on the ancient Mycenaean political economy in the wake of the decipherment of Linear B texts envisioned a highly centralized system of redistribution, in which rulers tightly controlled the economic transactions taking place in their dominions. With the accumulation of more data and the broadening of outlooks, researchers are now recognizing that palace authorities represented just one factor among many

different economic forces at play, some of which were beyond centralized control (Parkinson et al. 2013:414). This revised perspective also makes room for the possibility that different combinations of economic mechanisms were in use within different Mycenaean polities that existed in the same era.

A similar evolution occurred in the study of the Prehispanic Aztec economy, where, in spite of readily available ethnohistoric accounts providing contradictory information, archaeologists focused on state-centric models for much of the mid-20th century. This was largely due to Marxist and substantivist influences (Polanyi 1944, 1957; Smith 2004), as well as that of Karl Wittfogel, who argued for a high degree of centralized control in ancient complex societies, particularly through management of water resources (Wittfogel 1957; Feinman 2013:454). It was only in the latter part of the 20th century that archaeologists broadened their perspective on the Aztec economy and focused on household scale studies, which demonstrated the amount of economic activities that occurred beyond the administration of central authorities (Feinman 2013:455). Redistributive and market transactions actually fit well together in the same political economy, as both are based in the collective action of the constituents (Blanton and Fargher 2010:222). The possibility of multiple socioeconomic exchange systems existing simultaneously within a polity provides an important baseline for evaluating how lime may have been distributed to non-producing households.

Prehispanic Maya Political Economies and Burnt Lime Production

One of the important issues raised in studying the organization of burnt lime production is to what degree the lime industry was controlled and/or regulated by a centralized authority. The nature of state-level administration over economic matters in Prehispanic Maya polities is

still deliberated. Various models have been proposed for different population centers during different time periods. For example, even though archaeologists generally agree that agricultural production was at the heart of most Prehispanic Maya economies, they debate who owned the land and to what degree farming was subject to centralized government control (Carrasco 1978; Freidel 1983; McAnany 1989; Fox et al. 1996; Robin 2003). It is likely that polities in different sub-regions used different organizational systems (Carmean 1990, 1991; McAnany 2010; Chase and Chase 2014; Demarest et al. 2014). The crux of the debate is whether Prehispanic Maya polities were generally organized as highly centralized sociopolitical systems or were more loosely organized, segmentary communities (Fox et al. 1996; Chase and Chase 2014; Demarest 2014). The questions raised regarding the segmentary versus centralized nature of ancient Maya polities have direct implications for the nature of Prehispanic Maya economies and the degree of governmental administration and influence over economic matters.

On one end of the spectrum, 'centralists' see Prehispanic Maya polities as highly stratified hierarchies under the strict administration of rulers who oversaw all aspects of society (Fox et al. 1996). This includes a high level of control over the exchange of goods and services within the polity as well as the polity's role in external trade networks (Chase and Chase 1996; Foias 2002:235). Those in favor of a more decentralized, segmentary state model, however, emphasize the importance of kinship, lineage groups, and/or households as the basis for loosely administered shifting agglomerations of communities. In this scenario, there is little centralized oversight or administration of the economy (Abrams 1994; Fox et al. 1996; Demarest et al. 2014), and elite economic control is limited largely to the production and distribution of prestige or wealth items (Foias 2002:235). Early versions of this argument, based to some degree on Polanyi's substantivist framework, saw Prehispanic Maya non-elites as living under the feudal-

like dominance of elite land-holding families (Adams and Smith 1981; Gunn 2015). One of the arguments for a decentralized economy is the isolated location of some utilitarian goods production sites, which would theoretically have been more difficult to directly administer (Foias 2002:236). However, as discussed above in the case of Aztec salt and Kiuic lime production, distance does not necessarily preclude control (indirect or direct).

More recently, archaeologists have complicated the centralist/decentralist debate by embracing frameworks that account for greater sub-regional diversity and shifting diachronic perspectives (Dunning 1995; Marcus 1995; Fox et al. 1996; Adams and Adams 2003; Aimers 2007; Hutson et al. 2012). Recent studies have taken a micro-scale approach, investigating local economies at the polity or even sub-polity level. These methods are designed to develop a better understanding of the various political economic systems that existed throughout the Prehispanic Maya culture sphere over time. Aoyama's (2001) study of chipped stone artifacts at Copán led him to posit that the Copán state exercised a significant degree of control over the distribution of utilitarian items such as obsidian cores. Conversely, Demarest et al. (2014) find evidence for what they consider "relatively less" direct government involvement in the economy of southern lowland centers, especially at the city of Cancuen that straddled the trade routes behind the highlands and lowlands. Their study of jade and other workshops around the river ports of Cancuen indicates a large involvement by local elites in the commerce of the center, but not necessarily intervention at the state level (Demarest et al. 2014). This distinction between local elites and the central government is a tenuous one and highlights the difficulty of identifying the markers of 'economic control' in the archaeological record.

Still further towards the decentralist end of the spectrum, Sheets's (2000) study of household provisioning at the smaller site of Cerén in El Salvador indicates that non-elite

households likely had more power in economic transactions than previously thought. Cerén was destroyed by a sudden volcanic eruption around 600 CE and was basically frozen in time. By comparing materials from different household groups, Sheets (2000) found evidence for households provisioning themselves through several modes of exchange. He found that the relatively homogeneous distribution of materials such as polychrome pottery and jade axes reflected their acquisition through market exchange and participation in an elite-dominated vertical economy. The heterogeneous distribution of other items such as raw materials and tools on the other hand resulted from trade between households that specialized in the production of different craft items (Sheets 2000). Even smaller than Kiuic, Cerén provides information about intra-community interactions that can be used as a reference for understanding smaller-scale networks. While I cannot study the inter-household distribution of burnt lime products, by focusing on the semi-restricted distribution of production locales I can evaluate the likely modes of exchange that operated within the Kiuic political economy.

Recent studies of pre-modern market exchange in the Maya area have included convincing evidence for the identification of physical marketplaces at sites like Chunchucmil (Dahlin et al. 2007), Calakmul (Carrasco et al. 2009), and Buenavista del Cayo (Cap 2015). These studies have been instrumental in refuting the substantivist position regarding the absence of market exchange in pre-modern societies. Even without the recent physical and iconographic evidence for marketplaces existing in several Prehispanic Maya centers, Mayanists were already arguing for the existence of market exchange in the Prehispanic world (Freidel 2002; Abbott 2010; Chase and Chase 2014). Antonia Foias argued that despite the pitfalls inherent in projecting historic evidence too far into the past, we should not discount ethnohistoric accounts out of hand. Ethnohistoric accounts are useful for making inferences about the Prehispanic

political economy, especially with regard to the existence of marketplaces, merchant groups, currencies, and trade (Foias 2002:225). Ethnohistoric sources such as Landa's (1941) *Relación de las Cosas de Yucatán* and Roys's (1943) *The Indian Background of Colonial Yucatán* mention the limited economic role of local leaders (or *halach uinic*) in the northern Yucatán. One of the *halach uinic*'s few economic responsibilities was to oversee a tribute or taxation-based economic system, which included perishable items such as textiles, foodstuffs, and salt. Tax and tribute systems appear to have been the most prevalent forms of state provisioning used in the small polities of the 16th century Yucatán, which raises the possibility of an analogous system existing during Prehispanic times. The ethnographic sources also explicitly refer to the trade of both non-perishable and perishable items in marketplace settings (Foias 2002:232). While lime itself is not mentioned, many of these other 16th-century trade and tribute items were also perishable, which has implications for the distribution of such items during the Prehispanic period.

In his investigation of ceramic production and distribution within the Kiuic polity, Chris Gunn (2015) finds evidence for a market exchange system that could be used to argue for either a decentralized or a centralized political economy. He proposes a diachronic model in which a Late Classic repopulation of the Eastern Puuc region fostered the development of both a market exchange system and a parallel elite gifting exchange network. He infers that the initial development of the elite exchange network was likely a method for building alliances and sorting out territorial property rights (Gunn 2015:493). This ties in with Gallareta Negrón and colleagues' model of the original settlement of the Puuc in which early settling households staked claims to the most productive agricultural lands from which they drew their wealth and prestige over succeeding generations (Bey 2009; Gallareta Negrón et al. 2014). According to Gunn, the market exchange system expanded over time at the expense of the elite exchange

network, and by the Terminal Classic Period (~800-950 CE) non-elites were acquiring previously elite-exclusive ceramic wares through the market system (Gunn 2015:495-496). While he finds "overall little evidence for the direct administration of ceramic economies" (Gunn 2015:40), he acknowledges the ambiguities surrounding the place of the market exchange system within the overall political economy. Two specific uncertainties raised by the ceramic distribution study are: 1) to what degree local elites administered the market exchange system; and 2) if elites did play a large role in market administration, would this constitute a 'centralized' system? This once again points to the difficulty of distinguishing between elite and government intervention in the economy, a dilemma that affects the study of lime production as much as any other craft industry. Gunn's framework for the ceramic political economy serves as a useful model for the burnt lime industry, as the two materials span elite/non-elite and prestige/utilitarian spectra. I add a new dimension to the model of the Kiuic political economy by evaluating one aspect not available to the ceramic study: production contexts. The widespread distribution of annular structures favors, but does not necessitate, a largely decentralized organization of lime production. I evaluate the implications of this evidence for Gunn's dual economy model further in Chapter 9.

Although the modern name for the site of Kiuic literally means 'market' or 'plaza' in the Yucatec Mayan language, it is unclear whether the name derives from the presence of a market at the site in the Prehispanic period. As of yet, no physical marketplaces have specifically been identified within or around the site center. The site was abandoned around 950 CE during the construction of a large palace complex that was to include a large open plaza (measuring approximately 60 x 75 m) (Gallareta Negrón et al. 2014). Had the site flourished through the completion of this construction project, it is possible that this plaza could have been used for

large gatherings, including marketplace activities. Its location, bounded on two sides by palace structures would have strongly hinted at direct governmental involvement in the economic sphere. However, the lack of a physical marketplace does not preclude the existence of market exchange systems within the Prehispanic Kiuic political economy.

The fact that burnt lime was not produced by all corporate groups but was important to the quotidian activities of all corporate groups suggests that market exchange was a practical means for distribution of the material. Lime production was likely limited by the access to the necessary combination of raw materials, technology, and expertise required to efficiently produce lime, especially when concerns for resource conservation factored into the equation. Restricting access to raw materials in particular may have provided elites or central governing authorities with opportunities to indirectly control the lime industry. However, the locations of at least some annular pit-kilns within relatively isolated elite residential complexes beyond the inner zone indicate a lack of complete centralized political control over most production. Instead, it appears that small corporate groups and perhaps independent specialists were organizing lime production episodes. Some of the lime produced by these small-scale producers was likely traded or sold to corporate groups or members of the community that did not produce their own lime. By focusing on the contexts of the lime production locales and the absence of annular pit-kilns in the majority of residential compounds, I argue for the existence of a decentralized political economic system.

A final social context in which burnt lime may have played an important role is the ritual economy. Limited ethnohistoric and ethnographic resources are available on the subject, and these are separated from the targeted time period by several centuries anyway. Ritual economy refers to the ritual or religious aspects of the production, distribution and/or consumption cycle

or the use of any of these stages for ritual or religious purposes (Wells and Davis-Salazar 2007; Hirth 2009; McAnany 2010) For example, ethnographic accounts recount how lime production was a gendered activity involving taboos against female participation (Schreiner 2002:106). They suggest that lime production episodes were associated with connotations of fertility and purity and could be spoiled or ruined by the presence of a menstruating woman (Schreiner 2003; Bedolla Arroyo 2010). In addition to rituals involved in lime production (Schreiner 2002:104-116, 2003; Barba 2013) the lime itself may have been used in ritual ceremonies. While many hypotheses can be proposed based on the ethnohistoric and ethnographic data, the ritual economy of Kiuic is beyond the scope of my current research.

Chapter Summary

The study of burnt lime production in and around the site center of Kiuic contributes to an increasingly detailed understanding of the local small corporate-level and polity-scale Prehispanic political economy. It is clear that lime consumption was ubiquitous in Prehispanic Maya societies, but that production at Kiuic was limited to a certain number of corporate groups. This created a situation in which certain groups of the ancient Kiuic community received their burnt lime through exchanges with other groups in the community. While lime distribution cannot be traced along the lines of Aoyama's chipped stone study or Gunn's ceramic analyses, the identification of annular structures as lime pit-kilns allows for the investigation of lime production locations and their relationship with other political and social features of the Prehispanic Kiuic community. Thus, in my case study I analyze spatial and contextual data concerning lime production to assess the forms of control that certain sectors of the community or corporate groups may have exercised over the lime industry.

The data suggest that the burnt lime production industry was most likely organized by small-scale corporate production groups. This does not preclude the existence of independent specialists overseeing production at isolated annular pit-kilns in the outer and intermediate zones. However, the amount of labor involved in certain stages of production suggests that corporate groups may have organized the labor forces necessary for production episodes. A lack of storage facilities near the site center suggests that Kiuic did not operate under a highly centralized redistributive political economic system, but does not preclude authorities restricting access to raw materials and/or distribution of the finished product. It is likely that there were multiple exchange networks in place articulating between political and domestic economies. Lime producing groups may have provisioned the state through a tax or tribute system, while provisioning non-producing groups through some form of market or gift-giving exchange system. One of the goals of this dissertation is to narrow down the possible models for the organization of the lime production industry. My case study examines the spatial and contextual data to determine the most likely modes of exchange for lime and how small-scale corporate lime production was linked with the Kiuic political economy.

Chapter 3: Environmental Resource Management and Societal Collapse

In this chapter I discuss contributions that my case study makes to the areas of human ecology, resource management, and the 'collapse' of pre-modern societies. Contemporary concerns about human-induced climate change and the rapid consumption of natural resources have bolstered the study of environmental resource management over the past several decades. The cutting down of forests, in particular, for fuel and construction materials has long been seen as a marker of environmental degradation in the name of 'progress.' Several intertwined strands of human ecological theory seek to interpret the relationships between humans and the environments or landscapes that we have inhabited throughout our history. If possible, the goal is to apply lessons learned from the successes and failures of past societies to influence modern stewardship policies. Archaeological research in particular has the potential to inform about the long-term trajectories of past human-environmental interactions. This area of research has continuously been dominated by the study of societal 'collapse,' mostly due to its tendency to capture the public's imagination.

The burnt lime industry played an important role in the Kiuic economy as it likely did in most of the economies of Mesoamerica. The use of wood fuel to produce lime connected issues of political and socioeconomic importance with concerns for resource management and human-environment relations. Archaeologists have been investigating Prehispanic Maya economies and ecological relationships since the late 1800s, leading to an abundance of data and numerous hypotheses. However, the heterogeneous nature of sub-regional societies in the broader Maya area precludes the formulation of an overarching human ecological model for the 'Prehispanic Maya,' and instead encourages smaller-scale approaches. This case study investigates the

production of a significant material at household- and polity-level scales of organization, which afford a detailed understanding of the interplay between economic and human ecological concerns. In this chapter I explore the related themes of environmental resource management and societal 'collapse' to contribute to a growing recognition of Prehispanic Maya resource management practices and pre-modern human-environment relationships more generally.

Environmental Resource Management

> *"Most people appreciate the view that population growth coupled with increasing resource use eventually leads to loss of environmental quality as the carrying capacity of the land is diminished."* (deMenocal and Cook 2005:S91)

"Most people" is an important qualifier for many well-accepted notions in academia. Even this pretty straightforward and seemingly commonsensical perception – that as a society expands and intensifies its consumption of resources it will inevitably lead to new, and often harmful, effects on environmental resources – has its skeptics. Much of this skepticism stems from the ever-increasing array of theoretical and methodological techniques with which we can parse out the complex elements that compose any given community or society's relationships with their environment. Thus, the statement by deMenocal and Cook is not contradictory to, but actually complementary to Fisher and Feinman's (2005:65) argument that: "Empirically, there is no universal causal link between population growth and land degradation..." The key word in this case is 'universal,' which highlights the fact that while demographic pressures and increased consumption of resources undoubtedly transform environments, they are not the only influential factors. Human ecological studies bring together researchers from a variety of different academic fields including but not limited to anthropology, geography, history, and botany. Archaeologists have a particularly significant role to play in the study of human-environment relationships

because we can examine the entire trajectory a given past society's relationship with their environment. A particularly important focus in contemporary human ecology is the connection between overexploitation of natural resources by human societies and the transformation or 'collapse' of sociopolitical systems. In order to understand how this project contributes to our evaluation of the complex relationships between humans and the environments that they inhabit, it is important to consider the theoretical issues and underpinnings of human-environment relationships.

Human-Environment Relationships

Early 20th-century approaches to investigating human-environment relationships often invoked environmentally deterministic models to explain historical trajectories (Huntington 1924; Demeritt 2005; Aimers 2007). With less nuanced methodologies to delve into smaller-scale transformations and refine chronologies, researchers used external pressures such as natural disasters and climate change to explain stark changes in material culture. This approach was reinforced by the introduction of cultural ecological theory into archaeology in the 1950s and 1960s and the completion of the first archaeological settlement pattern studies (Willey 1953; Steward 1955; Manley 1958; Kirch 2005b). Environmental determinism reached its apex with the formulation of the processualist, or positivist, approach to archaeology in the 1960s and early 1970s (Binford 1962). Processualist archaeologists interpreted cultural developments strictly as humankind's extra-somatic means of dealing with environmental conditions. Thus, nature provided the stimuli and humans merely reacted and adapted to the conditions with which they were presented. This view of the natural environment as something untamed for humans to colonize stemmed partially from now discredited Western beliefs in a Pre-Columbian America

characterized by ‘pristine’ natural settings unmodified or damaged by human action (Ashmore 2004; Hayashida 2005). The notion of an ‘unspoiled’ American natural *environment* was contrasted with the long-inhabited and much modified European *landscape* (Ingold 1986; Knapp and Ashmore 1999; Ashmore 2004). While the origins of such terms are partially rooted in racist and regionalist thinking, this distinction between environments as untamed nature and landscapes as human-conquered or socially constructed space persists through contemporary research.

In the 1970s, researchers in both the United States and Europe adopted and adapted tenets of the post-processualist critique of positivist archaeology, focusing more on human agency and the importance of internal societal factors driving cultural change. Ashmore (2004:258) neatly summarizes the effect this had on human-environment studies as, “[s]pace…and human action were recast as matched participants in a perpetual dialectic of mutual constitution.” More recently, the development of fields like Human Ecodynamics has led to the assertion that there are no such things as ‘pristine’ environments and that everything is a *landscape* modified or socially constructed at some point or other by human behavior (Barton et al. 2004; Kirch 2005b). Drawing from these several theoretical approaches, contemporary researchers in the variety of sub-fields that deal with human ecological interests tend to view human-environmental relationships with the general understanding that the two forces are recursively structuring (van der Leeuw and Redman 2002:600-601; Contreras 2010:243). Fisher (2009) applies Giddens’s (1984:25) ‘duality of structure’ to the reflexive relationship of humans and their environments; in this case social systems would be both the medium and outcome of the ecological systems of which they are a part. Put another way, the earlier ‘nature-culture’ dichotomy based on positivist thinking has been replaced with a more reflexive ‘human-environment’ *relationship* that

incorporates elements of several recent strains of human ecological theory (Fisher and Feinman 2005; Fisher et al. 2009).

While never completely discarded, environmentally deterministic models for societal change fell out of favor during the post-processualist critiques of the late 1970s and early 1980s. They began to resurface slowly in the 1990s and were once again thrust into the spotlight by the publication of Jared Diamond's (2005) public-oriented book *Collapse: How Societies Choose to Fail or Succeed*. While the title suggested that past societies had agency and directly influenced the course of their historical trajectories, most of his case studies focused on the role that external pressures played in the breakdown of sociopolitical and demographic structures (Demeritt 2005). Diamond's overly simplistic examination of archaeological and historical evidence has unfortunately led to misconceptions about human-environment relationships in the public sphere. However, on a more positive note, it has also spawned a series of critiques by academics that delve deeper into the complex social and environmental factors that contributed to the transformation of specific past societies.

Many of these broader theoretical frameworks have considered the human-environment relationship on a grand, society- or even species-wide scale. In examining pre-modern human-environment relationships, it is important to keep in mind that broader trends are composed of numerous building blocks. Approaching pre-modern human-environment relationships from the household and polity scales better accounts for the various factors operating within any complex community. Societies are often composed of competing sociopolitical factions and socioeconomic groups with differing access to wealth, power, and decision-making opportunities (Hornborg 2005). What archaeologists investigate in the material record is thus either the outcome of compromises between factions or the imposition of one group's interests on the

society as a whole. In strictly hierarchical societies, it was likely that elite members made decisions that affected the entire society's human-environmental relations. These decisions may very well have reflected their own interests at the expense of the community at large (Demeritt 2005; Tainter 2006; Middleton 2012). On the flip side, socioeconomic groups left out of larger-scale decisions regarding human-environment relationships in a given community have their own impact on the environment as a result of being left out. Modern examples of these circumstances include: the abundant burning of heavily polluting coal by poorer peoples living on the outskirts of modern cities in colder climates; and, the frequent burning of small amounts of trash by rural residents of Yucatán, Mexico who live outside the official jurisdictions of public waste removal operations.

Other important concepts to the study of past human-environment relations are 'landesque capital' and flux. Landesque capital was coined by Harold Brookfield (1984), to refer to human manipulations of the environment that reflect a long-term investment in the productivity of the land (Fisher and Feinman 2005). It thus refers to humans making a commitment to their environment. They invest time, effort, and often money in the relationship in order to ensure ongoing and even delayed returns. However, environments are often in flux – that is they experience alternating periods of relative stability and transformation beyond the control of humans. This encourages continuous investment in and maintenance of landscape modifications (Fisher and Feinman 2005; Redman 2005). Intra-societal competition and the need to constantly modify investments made in landscape modification to adjust for natural fluctuations factor heavily into discussions of societal 'collapse,' especially as they relate to sunk-cost theory.

Prehispanic Maya Resource Management

The issue of Prehispanic Maya resource management is connected with the ways that the Maya viewed their role within and interacted with their landscapes. I use the term landscapes in reference to the fact that the Maya physically modified their different natural environments in various ways and in so doing imbued them with social significance. While textual evidence from Puuc sites is limited, iconography at sites throughout the northern and eastern Puuc as well as ethnohistoric, linguistic, and ethnographic data hint at the importance of landscape features to the Prehispanic inhabitants of the region. Dunning et al. (2012:3656) highlight the dichotomy between the Yucatec Maya terms *kax* (or *kaax*) and *kol* (or *kool*) with the former referring generally to wild, or untamed forest lands and the latter referring to managed, or ordered agricultural fields. While the majority of land in the Kiuic polity may have been converted to *kol* by the end of the Classic Period, there would likely have been at least some remaining *kax* lands, if only on the slopes of the hills or on the edges of the polity. These *kax* lands were instilled with certain characteristics and perhaps even been attributed a certain degree of agency in their relationship with the human inhabitants of the polity (McAnany 2010; Dunning 2012). Most of the raw materials for the lime production process was likely harvested from *kax* lands. Depending on the degree of adherence to religious beliefs about the *kax* versus *kol* dichotomy held by the Prehispanic households controlling access to the *kax* domains, lime producers would endeavor to maintain respectful harvesting of those resources. Thus, supernatural beliefs about the human-environment relationship might have been a factor in encouraging fuel-efficient lime production practices in addition to socioeconomic or ecological resource stress issues.

Due to the lack of rivers and lakes in the Puuc, and the fact that the water table in the region lies too deep to access with ancient digging technology, the ancient inhabitants of the

region relied completely on rainfall for their livelihood. Rain was the sole source of nourishment for their crops and the growing season therefore coincided with the rainy season (May through November). The Prehispanic inhabitants of the region built deep underground cisterns called *chultúns* to survive the dry half of the year (Andrews 2004). Thus the prominence of the Rain God *Chac* in Puuc iconography is not surprising. '*Chac*' or 'Monster' masks, as they are also known, are stucco or limestone masks of faces with long, curved noses that adorn the facades of buildings at many Puuc site centers (Kowalski 2003; Gallareta Negrón et al. 2014) (Figures 3-1, 3-2). While these masks have not definitely been proven to represent Chac (Schele 1998; Gallareta Negrón 2013), the special importance of rain for sustaining Puuc society supports the interpretation of Rain God-related iconography.

The obvious importance of water in a region where it is scarce for nearly half of the year may have imbued the slaking process in lime production with an added significance. In addition to conserving wood fuel resources, the Puuc Maya would also have taken steps to conserve water. The limited availability of water during half of the year may have encouraged lime producers to either risk calcining limestone during the rainy season or to at least leave quicklime produced during the dry season untouched until the rainy season arrived. A combination of factors, which I discuss in Chapter 9, suggest that lime was mainly produced during the dry season and thus likely left to hydrate naturally. Leaving the lime to hydrate naturally through precipitation events would limit water transportation and resource investments for the lime producers.



Figure 3-1: Monster mask at the Puuc site of Uxmal.



Figure 3-2: Monster mask at the Puuc site of Labná.

Entwined with the importance of water in the Puuc region, was the importance of caves to Maya mythology in general. Caves were considered the watery realm of deities (Brady 2005), and a few deep caves in the Puuc region penetrated all the way down to the subterranean water level (Killion et al. 1989:277; Dunning et al. 2012). One of the main reasons that the Kiuic site center was located in the northwestern part of the Kiuic Valley was to be near to one such deep cave. The earliest civic-ceremonial complex (the Yaxche Group) as well as the later Chulul and Kuche palace groups flanked this cave to access both its symbolic power and possibly its water reserves (Gallareta Negrón et al. 2014). Mountains were also important in Maya mythology. The Puuc's hilly terrain scattered with caves was undoubtedly been imbued with certain mythological and possibly sacred notions tied in with the *kax* concept discussed above (McAnany 2010). The identification of small structure outlines called *paseles* throughout the inter-site areas indicates that almost all of the flat arable land was in use for agricultural production during the Late and Terminal Classic Periods (Gallareta Negrón et al. 2014). *Paseles* are crude limestone foundations that serve to support a perishable superstructure. These simple archaeological foundations bear a striking resemblance to shelters used by contemporary maize farmers in the Puuc region. It is likely that the hill-slopes, unwelcoming to agricultural pursuits, harbored the majority of the trees in the region by the end of the Terminal Classic Period.

Resource Mismanagement and Societal Collapse

Human fascination with the breakdown of complex societies is likely as old as the coalescing of the earliest complex societies, as evidenced by the inclusion of stories of collapse in the sacred canons of many world religions. A scholarly tradition of studying societal collapse can perhaps be traced back to the Islamic Historian Ibn Khaldun's (~1377 CE) (Butzer

2012:3632), who wrote about dynastic cycling in old world kingdoms. Contemporary western interest in the collapse of past societies took off with the publication of Gibbon's (1776-1789) *History of The Decline and Fall of the Roman Empire*. Since then, much research has been devoted to examining the reasons why the myriad of past complex civilizations and sociopolitical systems no longer exist today, often in an effort to inform modern policy and attempt to avoid repeating the past. When used in reference to human sociopolitical systems, the term 'collapse' may include such circumstances and terms as decline, fall, crisis, anxiety, transformation, shift, transition, revolution, disaster, and others (Diamond 2005; Tainter 1988, 2006; McAnany and Yoffee 2010; Middleton 2012). Out of all of these related terms, 'collapse' has a particular connotation of suddenness, and it is in relation to this subtext that it is often misused. While there have indeed been several examples of rapid sociopolitical disintegration or transformation in the past, many cases involve a gradual period of decline before a given sociopolitical order actually ceases to exist. Thus, timescale is an important dimension that must be considered in any discussion of collapse, especially when the focus is on human-environment relationships.

If researchers can reliably argue that there is a rapid or sudden decline that warrants the term 'collapse,' what exactly is it that collapses? Many researchers emphasize precipitous declines in population as hallmarks of collapse (Diamond 2005; Middleton 2012). Tainter (1988) describes collapse as a political process in which there is rapid significant loss of an established level of sociopolitical complexity. Others include the disappearance of elites and elite-based culture in definitions of societal collapse, which is largely a result of the disproportionate investigation of elite material culture in past archaeological research (Lawler 2010; Middleton

2012). In this scenario, an abrupt cessation of the reproduction of elite material culture would indicate a sudden change in the sociopolitical order of a society.

Despite these important considerations, current research on societal decline and collapse still tends to include, if not necessarily focus, on climatic change and environmental mismanagement or degradation (Middleton 2012). Since the 1980s, clear-cut environmentally deterministic explanations for collapse have at least been tempered by discussions of the many social and political factors that made societies ultimately susceptible to the dangers of changing climatic and environmental conditions. Even those investigations that examine civil unrest, governmental mismanagement, demographic changes, and other social factors as contributing to societal deterioration often look to environmental and climatic factors as the ultimate causes of decline and collapse (Butzer 2012). It is the ecological disasters that can be most easily connected to the severe drops in population visible in the archaeological record. Thus, sociopolitical and economic declines that may span decades or centuries generally precede a societal breakdown that may be ultimately attributed to human-environmental woes.

Societal decline and/or collapse generally results from a complex mosaic of factors, overlapping and affecting each other in distinctive ways depending on the society in question. Despite this, many researchers continue to promulgate theories of collapse based on overshoot hypotheses, and it is these that are most pertinent to the current study. Overshoot hypotheses emphasize the use or consumption of resources by a given society at an unsustainable rate that eventually leads to the irrevocable depletion of said resources. While many overshoot hypotheses stem from models of human-environment relations, it is important to recognize that overshoot does not necessarily refer to the simple overexploitation of environmental resources. As Tainter (2006:61) points out, overshoot may include: when those in power in a given society demand

extreme labor or contributions from subordinates to the point where they exceed the subordinates' willingness to comply (civil or politico-economic overshoot); when loosely-integrated empires expand their geographic reach beyond the distances where transportation and communication technology would make governing feasible (territorial overshoot); and, when the day-to-day costs of governing grow to the point where central authorities cannot mobilize resources to effectively respond to immediate crises. Despite these alternative meanings of overshoot, most often the term is used to refer to when a population outgrows its carrying capacity for any of a number of reasons (Middleton 2012). However, outgrowing carrying capacity is rarely the result of a linear progression towards disaster. Using the term 'overshoot' often masks the numerous complex pre-existing conditions and adjustments made by members of a society before a given system eventually gives way (Tainter 2006:72).

Attention must be given to the internal constraints that may limit a society's ability to adapt to environmental, demographic, and even social changes that may ultimately lead to a transformation of activities viewed in the archaeological record as collapse. Simplistic models and phrases like Diamond's "…how societies choose to fail or succeed" overlook the complexities involved in getting different factions and interest groups in a society to negotiate with each other. Even when disparate factions do agree on courses of action that succeed in the present, deferred environmental impacts may not be realized until it is too late (Tainter 2005). For instance, the overexploitation of resources takes time to actually build up to critical levels. Compromises between competing societal factions may lead to short-term solutions that over time lower risk thresholds and weaken the potential resilience of societies faced with sharp environmental or external crises (Butzer 2012). This situation is unfortunately visible today in contemporary governments being very slow to change energy policies in the face of human-

induced climate change. The course of action has been to continuously set short-term goals that barely satisfy the competing interests involved in the negotiations, as the risk threshold approaches the point of no return (Fisher et al. 2009; Redman et al. 2009).

A key factor in this situation is the concept of sunk cost effects, to which large groups are very prone to succumbing. Sunk cost effects refer to situations in which societies have collectively decided to follow a certain course of action and invest in a strategy (Strategy A). Even if the Strategy A begins to yield poor returns, they are reluctant to switch to Strategy B because they have already invested so much time and resources in both reaching a consensus and implementing Strategy A (Janssen et al. 2003). An example of this is the elaborate water system constructed around the Angkor Wat complex in Cambodia. Over time, new canals and irrigation systems were added to the network as short-term fixes when older channels began to silt up, until the entire system became too complex to manage or revolutionize (Fletcher 2008). Another aspect of sunk cost hypotheses is that communities continue to invest in ceremonial and larger site centers in the face of deteriorating returns and conditions, but smaller communities and projects are abandoned more readily. The continuous sinking of costs into construction and landesque capital-related projects up until they completely fall apart make the final collapse and abandonment of the system appear that much more dramatic (Janssen et al. 2003; Fisher and Feinman 2005:65). Thus, an appreciation for the social constraints working against a coherent society-wide adaptation or change in policy or approach should inform any examination of deteriorating human-environment relationships in the past in order to avoid the simplistic explanation of collapse being the result of a mere "failure to adapt" (Janssen et al. 2003; Kirch 2005; Tainter 2005).

Issues of scale also play an important role in the investigation of societal collapse. Depending on the chronological scale used, researchers may view the processes of societal decline as grave mismanagement of environmental resources or as an inevitable byproduct of any human subsistence strategy. If a society maintains relatively stable agricultural exploitation practices for generations but eventually succumbs after several centuries to deteriorating soil fertility, should the society's practices be considered sustainable or unsustainable? Researchers that focus on the final generation that lived with this agricultural exploitation system may view their practices as environmental mismanagement. Other researchers who take a longer diachronic view may emphasize the centuries of sustainability that preceded the ultimate demise. What is the amount of time that a society needs to exist for its human-environmental policies and practices to be considered sustainable? For example, the Norse established permanent settlements in the harsh environment of southern Greenland and battled severe conditions for much of their 500-year tenure there before eventually succumbing and dispersing from their settlements (Middleton 2012). Should this be considered an example of societal collapse or instead an example of resilience in the face of an inevitable conclusion? All sociopolitical systems that have existed have come to an end or transformed into new ones; none are infinite. Therefore, it is important to qualify discussions of societal collapse by examining the entire trajectory of a society's growth and decline.

The other main issue of scale in studies of societal collapse concerns the level of sociopolitical organization under investigation. What level of analysis should one use to examine decline and collapse? For instance, authors like Diamond (2005) use a general society-wide scale to interpret collapse, which isn't always the most appropriate level of analysis (Hornborg 2005). If the governing authorities of a few city-states within a larger network of dozens of city-states

are overthrown causing them to drop out of the larger network of exchanges while others continue on, should the overall system be considered to have collapsed? Combining chronological and sociopolitical scales, if city-states within the network blinked out one by one over the course of a century, should this be considered a collapse or a gradual decline of the overall system? As I'll explore in my case study, it would be incorrect to refer to the "Classic Maya Collapse" as there was no such thing as a cohesive "Classic Maya" society; instead, there were hundreds of city-states and polities that shared certain cultural traits but inhabited a variety of different environments and experienced sociopolitical changes in different ways. These city-states were not all abandoned simultaneously, but instead succumbed to different combinations of factors over a broad span of time. Many of these city-states, including Kiuic, likely devised and implemented resource conservation policies to avoid or combat environmental mismanagement issues.

The Decline of Classic Period Maya Communities

> *"Rather than thinking of a single Classic Maya collapse, the Terminal Classic period can best be conceptualized as a long period that was experienced in a variety of ways by people of different status at different sites and in different regions" (Middleton 2012:274).*

Resource management issues factor prominently into discussions of the decline of Classic Period Maya communities. Beginning in the mid-8th century CE, polities throughout the Southern Maya Lowlands began to undergo significant sociopolitical changes that resulted in the abandonment of many large centers. This process, which continued on through at least the 10th century CE, has come to be known colloquially as the 'Collapse of the Classic Maya Civilization.' The term 'collapse' connotes certain processes that are not necessarily applicable

to the Classic Maya case study, not to mention the fact that the Classic Maya cultural area consisted of a heterogeneous web of polities that experienced their own trajectories.

It is true is that most of these polities experienced significant changes within a roughly two-century-long period. The scale of the sociopolitical change even suggests that the events were linked at some level, either through a domino-like effect or as a result of systemic problems with their shared organizational structures. The different polities were linked through common cultural traits, sociopolitical alliances, and trade networks, and similar factors likely influenced the breakdown of governing systems within many if not all of the Classic Period polities. It is important to note, however, that the similar factors may have expressed themselves to different degrees in the case of different polities and may have occurred in different combinations. For instance, at certain sites in the Petexbatun region of the Southern Lowlands there is concrete evidence for an increase in violence and destruction of architecture leading up to the abandonment of several site centers like Aguateca and Dos Pilas (Demarest et al. 1997; Demarest et al. 2004; Inomata 2003). At other sites researchers postulate that class conflict and internal unrest were the main factors in bringing about the decline of the local sociopolitical system (Chase and Chase 2004). Aimers (2007:333) provides a convenient chart tracking all of the different factors that have been proposed as proximate causes for Maya site abandonment. Thus, while it would be incorrect to refer to the 'Classic Maya Collapse' per se, archaeologists can use detailed micro-scale approaches to look at the factors that initiated the sociopolitical decline and abandonment of individual site centers and polities.

Many archaeologists have put forth environmental overexploitation as one of the key factors precipitating the decline and collapse of Classic Period socio-political systems between 750-950 CE (Curtis et al. 1998; Shaw 2003; Andrews 2004:608; Aimers 2007; Dunning et al.

2012), and some have even suggested the fuel costs of lime production played a key role in resource mismanagement (Abrams and Rue 1988; Schreiner 2000, 2002; Hansen et al. 2002:288). The Classic Maya 'Collapse' has been used an example of civilizational 'overshoot' dating back to the early 20th century (Cooke 1931; Sanders 1962, 1963). Researchers have used this basic explanatory scenario over and over again albeit with new twists and iterations. Some have claimed that Classic Maya polities were doomed to fail because their sociopolitical organization was based on a 'growth system' that required constant economic and territorial expansion to maintain the viability of divine rulership (Culbert 1988; Dunning et al. 2012:3654). Others have pointed to elite mismanagement of resources and lack of information feedback as being the main culprits (Tainter 2006). A more likely scenario, espoused by most researchers today, is that a variety of human ecological issues were among several social, political, and climatic factors that likely played roles in the transformations of the Terminal Classic Period.

Burnt Lime Production and Deforestation

My case study draws on human ecological and landscape theory to identify to what extent human-environment relations were influenced by, and contributed to, the sociopolitical transformations experienced by a specific community at the end of the Classic Period (~650-950 CE). There is concrete evidence for an increase in population and construction boom during the time period leading up to a rapid abandonment of the Kiuic site center ca. 950-1000 CE. Changes to the lime production industry within the Kiuic polity inform about broader changes that were occurring in the community and the role that human-environment relationships played in the processes.

Over the past two decades, researchers working in different areas of the Maya lowlands have offered contrasting opinions about the role that lime production played in Prehispanic human ecological relationships. Their disparate findings suggest the need for more case studies concerning Prehispanic Maya lime production and that problems related to the potential environmental costs of the industry should be evaluated on a sub-regional scale (Villaseñor and Barba 2011:84). Eliot Abrams and colleagues addressed the issue of whether lime production requirements would have contributed to the deforestation of the Copán Valley in western Honduras during the Late and Terminal Classic periods (650-900 CE). Ultimately, they concluded that the lime industry would have had a "negligible" effect on wood fuel resources in the region (Abrams and Rue 1988:389-390). Abrams and Rue (1988) drew on accurate lime plaster consumption estimates and well-accepted lime powder-aggregate ratios to demonstrate that demand for lime would not have contributed to deforestation in any significant way. However, Schreiner pointed out that Abrams and Rue drew from published data including that of Erasmus (1965) and Morris et al. (1931), whose fuel ratio calculations may have been skewed. Erasmus (1965:291) claimed that 6.75 tons of firewood was all that was necessary to produce 8.33 tons of lime, which would result in a ratio of less than one-to-one fuel to product. Based on the evidence gathered from the other experimental sources, Erasmus's figures are highly suspect. Erasmus did not witness the fuel production process himself but instead relied on estimates recounted to him. As discussed above, Morris et al.'s fuel-efficiency estimate may have been altered by an overstated burnt lime output. Despite these potentially erroneous fuel-efficiency estimates, Abrams and colleagues' argument for a negligible impact of lime consumption on deforestation remains practical. The lower overall quantity of masonry architecture at Copán

compared with sub-regions further to the North would have translated to lower levels of lime produced for architectural purposes (Schreiner 2002:84).

A contrasting view to that from the Copán Valley study comes from researchers working in the El Mirador Basin of the northern Petén, Guatemala. Hansen et al. (2002:288,290) and Schreiner (2002) suggest that the need for lime for architectural and other purposes did play a significant role in the deforestation of the region, especially leading up to the period of socio-political transition at the end of the Preclassic Period. As part of his lime production study, Schreiner tested the sustainability of the open-air pyre technique in terms of fuel resources. By compiling results of kiln burning experiments from both the Petén region and the northern lowlands of the Yucatán, he concluded that a reasonable estimate of forest usage for lime production would be approximately 438 kg of lime powder produced per hectare of at least 20-year-old forested land per year. Applying this estimate to an admittedly speculative estimation of the lime requirements of El Mirador and other Late Preclassic centers in the El Mirador Basin, Schreiner concluded that:

> "If forests were distributed only in that remaining upland area the environmental impact of harvesting fuel for essentially unnecessary architectural lime production, and for other absolutely necessary uses, such as cooking fuel, would have been significant. Hansen's proposition that a deforested landscape was the consequence of building at so grand a scale in a relatively short time-span is strongly supported by these projections if the underlying assumptions that produced them are correct." (Schreiner 2002:90).

This conclusion takes into account that much of the flat arable land would have already been cleared for agricultural and settlement purposes. Luís Barba and colleagues made a similar argument for lime industry-induced deforestation in their study of the energetics of lime production at the Central Mexican metropolis of Teotihuacan (Barba and Córdova 1999:176).

They argued that the tremendous need for lime at the Early Classic city contributed to the deforestation of the neighboring Tula region from where they found the city acquired the majority of its limestone products (Barba and Córdova 1999:169). Douglas Byers (1967:61) mentioned offhandedly that cutting forests for lime production fuel may have contributed to disturbances in plant cover in Preclassic and Classic Period Tehuacan Valley.

Daniel Wernecke, in turn, questioned the validity of Hansen et al. (2002) and others' proposals regarding lime production's contribution to deforestation in his studies of ancient Maya construction materials and technology (Wernecke 2005, 2008). First, he noted that many studies of lime consumption for architectural purposes conflate lime powder with lime plaster and other finished lime products. Lime plaster may have a ratio of aggregate to lime of as high as 9:1, and some researchers do not necessarily differentiate between burned lime and naturally occurring *sascab*, which often superficially resembles lime (Wernecke 2008:203). This means that estimates of lime production based on the volume of lime plaster involved in architectural projects may be drastically overestimating the quantity of lime necessary and thus lime produced. Wernecke also recognized that the projection of the use of the open-air pyre method deep into Prehispanic times is not necessarily prudent (Wernecke 2008:204). It is therefore possible that fuel ratios based on experimental firings of open-air pyres do not serve as accurate estimates for fuel consumption ratios in the past. He concluded by arguing that in laying blame for deforestation on lime production, modern researchers have been underestimating the Prehispanic Maya's knowledge of burnt lime technology and resource management strategies (Wernecke 2008:206-207).

Russell and Dahlin (2007) oversaw the construction and firing of an experimental open-air lime pyre at Mayapán in 2006. Their calculations for the environmental impact of lime

production at Mayapán nominally support Wernecke's arguments. As part of their lime production experiment, Russell and Dahlin (2007) estimated the amount of lime that the Mayapán population consumed annually, and extrapolated their figures to a discussion of fuel sustainability. They took into account the use of lime for both dietary and architectural purposes. Based on their calculations, assuming a 25-year fallow period of forest regrowth and no more than a 5 km walking distance from Mayapán to harvest wood fuel, they concluded that fuel use "…would have been high but sustainable" (Russell and Dahlin 2007:419). All of these case studies address the question of whether or not lime production practices were sustainable in an environmental resource sense, but few can demonstrate whether Prehispanic Maya lime production strategies represented a conscious effort to conserve and manage resource.

The use of the annular pit-kilns at Kiuic for lime production would support Wernecke's contention that the Ancient Maya may have used more fuel-efficient methods than the standard open-air pyre method. Given the broad and significant implications of such a debate, it is important to continue to investigate the effects that lime production had on the environment on a local level (Villaseñor and Barba 2011:84). Abrams and Rue attempted such a study at Copán, albeit with the possible shortcomings highlighted by Schreiner, and the deforestation studies in the El Mirador Basin might likewise have suffered from some foundational misconceptions as well, as highlighted by Wernecke. Russell and Dahlin's experiment at Mayapán suggested that lime production was likely a sustainable industry at least during non-stressed climatic periods. My case study of burnt lime technology at Kiuic provides new insights into the relationship of burnt lime production and environmental conservation issues. Addressing the function(s) of the annular structures and any fuel conservation benefits they may have offered sheds light on whether the ancient inhabitants of the Bolonchén District actively attempted to manage their

resources leading up to a period of climatic stress in the Northern Lowlands (Dunning et al. 2012:3655).

The construction of annular pit-kilns throughout the Kiuic polity can be viewed as a form of landesque capital. By constructing the pit-kilns for multiple lime burning episodes that would require wood and stone resources, lime producers were investing in a long-term relationship with the local environment. In order to protect and continue this relationship, lime producers likely attempted to manage their resources. However, one must view human-environment relations as embedded within a larger society made of competing factions with opposing concerns. Smaller communities than Kiuic that are not necessarily connected to broader trade networks do not deal with the same pressures to exploit their environment. For example, some modern researchers promote what they refer to as "indigenous patterns of communal land use" (Alcorn 1993:426) as a model for rethinking Western patterns of land division, property ownership and consumption of natural resources. They argue that indigenous groups maintain a more balanced relationship with their environment and often these assertions are correct, if only due to the fact that they are being examined in the short-term. Kirch (2005:S96) argues that the relative fluorescence on Tikopia island compared with Rapa Nui (Easter Island) was the result of population management and bottom-up decision making that appreciated the fact that the entire population would be affected by changes to their environment. This type of bottom-up decision-making becomes problematic the larger and more complex that a society grows as an ever greater number of factions compete to ensure their own well-being.

Even if Kiuic households strove to manage their own resources, if there were communal lands available in the Kiuic polity these households had to compete with other craft producing and/or agriculturalist households for access to resources. These competing factions may have

reached compromises to deal with the sharing and management of resources in the short-term, and due to sunk-cost effects they may have continued these practices for quite some time. Over time whatever compromises were originally put in place may have had unintended consequences or may have been stressed by changing demographic and/or climatic factors until they eventually reached a breaking point (Janssen et al. 2003).

The development and use of annular pit-kiln technology in the Kiuic polity during the Late/Terminal Classic Period population and construction boom was unlikely a coincidence. A concatenation of factors, including shrinking available wood resources, more mouths to feed, and more architecture to be constructed created circumstances favoring the development of fuel conservation technology. The AMS radiocarbon dates and ceramic data suggest that the technology was initially developed by elite groups in the areas of higher population concentration near the site center. Only later did it spread out into the more sparsely populated hinterlands. This makes sense in light of Gallareta Negrón et al.'s (2014) and Gunn's (2015) claims that control of land was the basis for elite status in the region. If it were the elite members of the community that made the decisions about land use strategies at Kiuic, they would be the ones looking to develop sustainable practices. The annular pit-kilns appear to date to the beginning of this Late/Terminal Classic Period growth period and the Kiuic community continued to thrive for at least 250 more years. This suggests that the development of the fuel conservation technology was an act of foresight in resource management practices on the part of elite members of the local community.

It is also important to consider how different socioeconomic groups may have approached the use of environmental resources differently. While higher status households may have developed resource management policies that benefitted themselves, these policies may

have adversely affected or not applied to the larger population over the longer term. In many case studies from around the world, it has been found that the ultimate demise of societal structures was preceded by a long period of sociopolitical and economic decline. What is particularly fascinating about the Kiuic case study is that the local socio-economy appeared to still be growing when it was suddenly abandoned. My case study thus has the potential to contribute to human-environment issues in two ways: 1) An exploration of the different socioeconomic, political and resource management factors that may have influenced the development of the pit-kiln technology provides evidence of purposeful resource conservation initiatives; and 2) The investigation of societal growth and decline through a focus on lime production has the potential to shed new light on sunk cost, resilience, and human ecological theory in general.

The Potential for Archaeology to Inform Contemporary Policy Decisions

For decades now, researchers have touted archaeology's potential to inform contemporary policy initiatives with regard to human-environment relationships (Fisher and Feinman 2005; Hayashida 2005; Kirch 2005; Redman 2005). This claim is based largely on the diachronic research perspective afforded to archaeologists and their ability to study complete growth and decline cycles of past societal 'experiments' (Redman et al. 2009; Contreras 2010; Orr et al. 2015). Some researchers see the combining of approaches from landscape theory rooted in the post-processualist critique and harder environmental sciences as the recipe for bringing archaeology's potential to fruition (Contreras 2010). As archaeologists, we have the ability to examine past human-environment relations that appear to be clear cases of mismanagement or overexploitation of environmental resources and say 'here's what we should

not do' (Hayashida 2005). However, as discussed in the previous sub-section, the mosaic of factors influencing the decline and collapse of societies are not as straightforward or correctable with hindsight as we would like.

Some researchers suggest that we could learn 'sustainable' practices and resilience methods from past societies (McAnany and Yoffee 2010). Worthy examples put forth include: the inhabitants of Kissigoudou Prefecture in Guinea planting and maintaining patches of forest amidst the surrounding savanna; the renewable harvest of wood and bark in Pacific NW and Northern Scandinavia; and, the sustainable management of mangrove forests for fuel in Florida and Caribbean (Hayashida 2005). Though there are a few examples (Erickson 1988; Morrison 2015), very rarely can we as archaeologists take methods and/or technologies from the archaeological record and apply them directly to improve modern policies and practices. More important and useful, is the capacity of archaeology to instruct us to recognize what is actually 'adaptable' and 'changeable' about our current systems as opposed to things that are so ingrained that we must make our plans for the future around or including these 'built-in' impediments (Redman 2005; Redman et al. 2009).

In this vein, Redman et al. (2009) encourage archaeologists to work with specialists in other academic fields who address human ecological issues using resilience theory. Resilience theory looks at the reasons for and roles of change in societies and how societies adapt to change (Levin 1999; Redman et al. 2009). It examines hierarchical societies through the adaptive cycle, which includes four stages: exploitation, conservation, release and reorganization (often depicted with an infinity symbol diagram). These stages represent the growth, maintenance, 'collapse', and transformation/regeneration of human-environment relationships in complex societies. Resilience theory is a useful framework for investigating pre-modern human-environment

relationships when long-term data are available, but as we'll see from the current case study the fourth stage (reorganization) is not always easy to recognize or interpret. Archaeological investigations of sub-regional scale responses to changing human-environment circumstances and the outcomes of these responses such as this current study, contribute to the growing body of data that emphasize the importance of adaptation. Lessons from sunk cost analyses of past societies indicate that no matter how difficult it may be, societies need to find ways to change the underlying principles of their human-environment relations before they pass the threshold.

Chapter 4 – Previous Research and the Kiuic Case Study

In this chapter I discuss previous archaeological research that provides the foundation for several of the issues addressed in this dissertation. I introduce the archaeological setting for the current project and provide a brief summary of prior archaeological work at Kiuic and in the Puuc Region. This section also outlines the latest models for the historical trajectory of the Northern Maya Lowlands. I also describe the spatial setting for my case study, including an explanation for the division of my study area into 'inner,' 'intermediate', and 'outer' zones. In the second part of the chapter I discuss previous archaeological investigations concerning pre-modern lime production in both the Old and New Worlds in order to situate this Kiuic case study within the larger corpus of research.

The Archaeological and Environmental Setting

The Puuc Region

The Puuc Region is a distinctive topographic and archaeological sub-region of the northern Maya lowlands that straddles the Mexican states of Yucatán and Campeche (Figure 4-1). Puuc means "hill" in the Yucatec Maya language and this reflects the unique hilly topography of the region compared with the flatter karst plains that dominate the rest of the Northern Yucatán. The Puuc is bordered on the east by the Sierrita de Ticul escarpment that runs southeast from the ancient site of Oxkintok. To the west of the Sierrita in the northern zone of the Puuc lies the triangular, relatively flat stretch of land known as the Valle de Santa Elena (Figure 4-2). Large archaeological sites including Uxmal, Nohpat, Kabah, and Yaxhom that are located in the valley most likely controlled access to the deep and fertile soils that likely drew ancient settlers

to the region (Barrera Rubio 1987; Simms et al. 2012). To the south and southeast of the Valle de Santa Elena is the Bolonchén District, where Kiuic and other ancient sites such as Labná and Sayíl are located.



Figure 4-1: Map of the Yucatán Peninsula showing the location of Kiuic with regard to several larger sites (from Gallareta Negrón et al. 2014).

The Puuc region is also distinguished by its lack of *cenotes* – the sinkholes that provided many of the peninsula's ancient inhabitants with reliable access to fresh groundwater. The water table in the eastern Puuc lies from 45 to over 100 m below the surface, far beyond the well-digging capabilities of the Prehispanic Maya. The only surface water is found in a limited number of seasonal rainfall catchment areas called *aguadas* and *haltúns* (Dunning 1992; Gill 2000; Carmean et al. 2004). Thus, the ancient inhabitants of this hilly region relied completely

on rainfall to support their communities and agricultural production. Human-made reservoirs dug into limestone outcrops (*chultúns*) are omnipresent features of all settlements (Gill 2000:268; Carmean et al. 2004:438; Gallareta Negrón et al. 2014). Countering this daunting feature of the Puuc environment is the aforementioned presence of the highest concentration of fertile soil in the northern part of the peninsula.

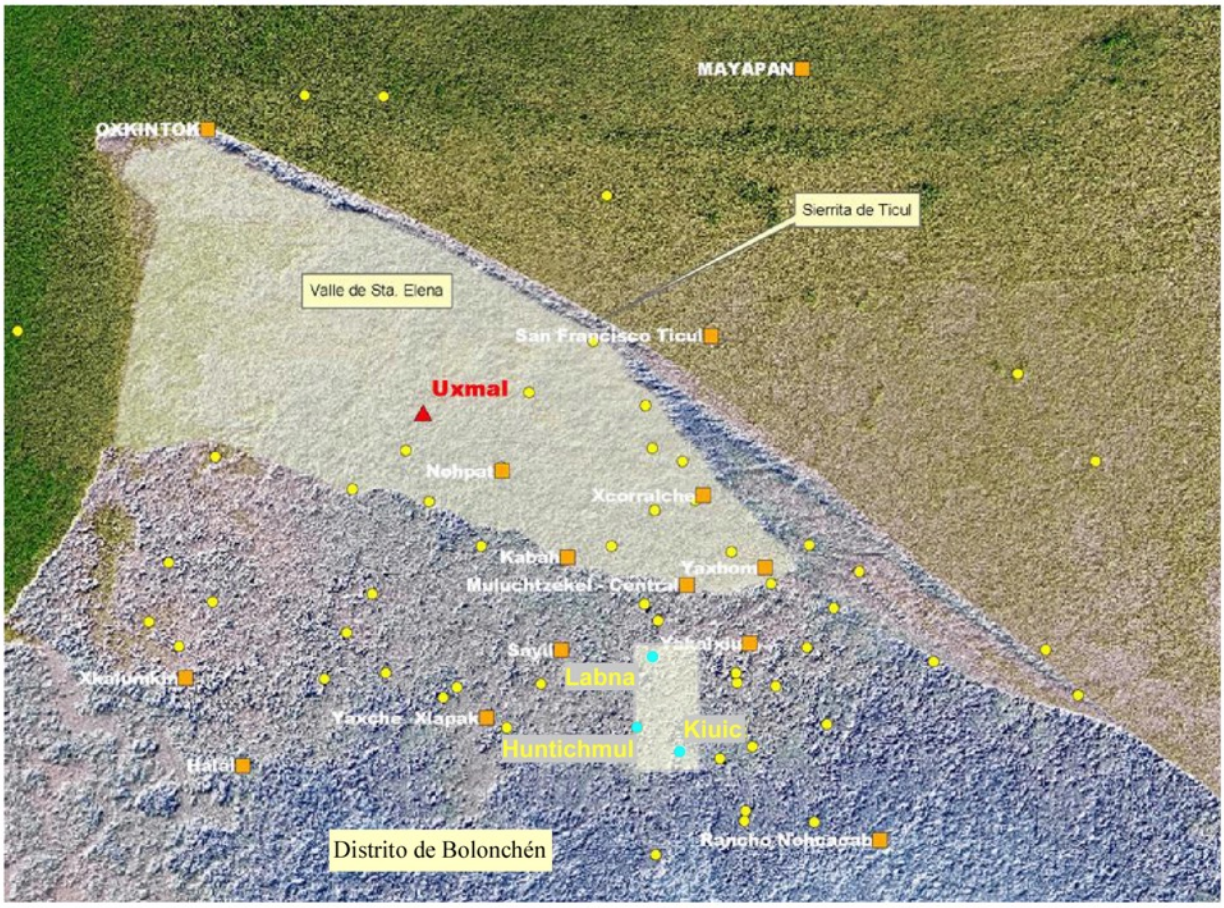


Figure 4-2: Map of the Puuc Region highlighting sites and sub-regions (from Gallareta Negrón et al. 2014).

Since the earliest archaeological investigations in the region in the late 19th century, researchers have recognized the Puuc Region as possessing unique architectural and ceramic traditions that distinguish it as a sub-cultural zone within the broader Maya area (Pollock 1980;

Bey 2006; Braswell et al. 2011). Many Puuc sites dating to the Late and Terminal Classic Periods (ca. 650-950 CE) have higher concentrations of vaulted masonry structures than in other sub-regions throughout the Northern Lowlands (Ringle and Tun 2016). It is possible that this cultural uniqueness extended to the development of distinctive fuel-efficient methods of lime production to accommodate this relatively extensive masonry architectural program and a Terminal Classic population boom (Gallareta Negrón et al. 2014). A higher frequency of masonry architecture required greater quantities of lime for mortar and plaster. My research addresses the implications of Late and Terminal Classic Period demographic and architectural stress for sub-regional socioeconomic organization and resource management practices in the Puuc.

Previous Research in the Puuc Region

American explorer John Lloyd Stephens and British artist Frederick Catherwood passed through the Puuc region during their travels throughout the Yucatán Peninsula between 1839 and 1842, visiting the sites of Uxmal, Nohpat, Kabah, Sayíl, Labná and Kiuic, among others (Stephens and Catherwood 1962 [1839]; Killion et al. 1989; Wernecke 2005; Ringle 2009; Gallareta 2013). Their accounts and drawings introduced the Western World to the monumental architecture of the Ancient Maya civilization and sparked archaeological interest in eastern Mesoamerica. Some of the earliest subsequent archaeological expeditions to the Maya area focused on the Northern Lowlands including many of the aforementioned Puuc sites. From the late 19th century, the Puuc Region was identified as a distinct sub-region within the broader Maya area along both environmental and cultural lines. Unique Puuc architectural traditions were documented as early as the 1880s by Teobert Maler, who photographed structures at Labná,

Huntichmul, and Kiuic among other Puuc sites (Maler 1997), and Edward Thompson who studied settlement patterns and water reservoirs at Labná (Thompson 1892; Brainerd 1956; Gallareta Negrón et al. 2011) and described the site of Xkichmook on the border between the Puuc and Chenes sub-regions (Thompson 1898). In his brief review of the current state of archaeology in the northern Yucatán, George Brainerd (1956:163) noted that the Puuc was an especially favorable region to study settlement patterns due to the abundance of well-preserved ceremonial architecture and limited modern overburden.

Large-scale architectural studies of the Puuc Region were conducted in the 1930s and 1940s by the Carnegie Institution (Pollock 1980), and by 1977, Joseph Ball (1979:18) noted the large amount of research that had been devoted to the Puuc architectural tradition. He claimed that it was "…considered by many to represent the peak of architectural development in Pre-Columbian Mesoamerica." Given the significant amount of attention already paid to the architectural tradition, he encouraged archaeologists to focus more on tightening ceramic typologies and site chronologies in the Puuc. This, however, did not stop researchers from continuing to study the distinct aesthetics and aforementioned abundance of vaulted architecture in the region. Pollock's (1980) survey drew on archaeological work as far back as the 1930s and is perhaps the most comprehensive documentation of Puuc architecture to date, containing figures and descriptions from over 140 Puuc sites. Paul Gendrop (1983) followed this up with his own study that traced the development of the Puuc Florescent architectural style to earlier iterations in the Río Bec and Chenes Regions to the south. George Andrews (1990) also expanded the architectural literature on the Puuc tradition through systematic studies in the 1980s and early 1990s. Justine Staneko (1996) conducted an in-depth architectural design study in the Puuc for her doctoral dissertation. Kowalski and Dunning (1999) summarized decades of

research into analyzing the symbolic importance of the intricate architecture of Uxmal. Smaller-scale projects based at different sites throughout the Puuc region continue to contribute architectural information, particularly about construction sequences (Gallareta et al. 2014) but more importantly, have expanded the research foci to include other features of Prehispanic Puuc society.

Based on early architectural, iconographic, and ceramic studies, archaeologists developed a model for Puuc settlement that saw the region as largely uninhabited until the Late and Terminal Classic Periods. In this scenario, populations fled the larger sites to the south and migrated northward to settle previously empty regions (Morley and Brainard 1946; Thompson 1954). The widespread notion that the Puuc region (along with much of the rest of the northern Yucatán Peninsula) only experienced a brief period of cultural development after the South had 'collapsed' stunted archaeological investigations into sub-regional socioeconomic and human-environment issues (Bey 2006). Archaeological investigations in the Northern Lowlands mostly examined political systems and largely drew upon architectural and iconographic interpretations. These studies of alliances and conflicts centered on the rise of Chichén Itzá and its relationships with other large sites in the North like Uxmal (Kowalski 2003), Yaxuná (Ambrosino et al. 2003; Suhler et al. 2004), and Cobá (Folan et al. 1983, 2009; Andrews and Robles 1985). Previously thought to date firmly within the Early Post-Classic Period (ca. 1000-1200 CE), a reevaluation of ceramic sequences has now placed Chichén Itzá's main occupation largely in the Terminal Classic Period (ca. 800-1000 CE) with eventual abandonment around 1100 CE (Cobos 2004; Suhler et al. 2004). The dating of Chichén Itzá's rise and fall, as well as the possible multi-ethnic composition of its population and relationship with Central Mexican forces are still debated (Aimers 2007:339-340).

Not until the 1980s did archaeologists really begin to examine more closely the unique developmental trajectory of the Puuc Region through systematic surveys and excavation programs that looked beyond the ornately decorated Puuc facades. Since then there have been several archaeological projects in the Puuc Region, including a handful at sites within the Bolonchén District where Kiuic is located. In the 1980s and 1990s, researchers like Alfredo Barrera Rubio and Nicholas Dunning completed intensive hydraulic and agricultural studies of the Puuc Region (Barrera Rubio 1987, 1990; Dunning 1992). Dunning's (1992) cultural ecological study of the Puuc was especially comprehensive, linking the distribution of soil types and water resources with the rise and fall of Prehispanic Puuc sites. Jeff Kowalski and colleagues studied the impressive public architecture and political history of the paramount Puuc site of Uxmal (Kowalski 1990, 1994, 1998, 1999). During the late 1980s and early 1990s Jerry Sabloff and Gair Tourtellot (1991, 1994) directed survey work and excavations at the site of Sayíl. Michael Smyth, who had worked on the Sayíl Project, then co-directed survey and excavation work at the nearby site of Chac II (Chac) in the mid-1990s (Smyth et al. 1998; Smyth 2006; Smyth and Ortegón Zapata 2006). Tomás Gallareta Negrón and colleagues initiated a new round of excavations and survey at Labná in the last few decades (Gallareta Negrón et al. 2003; 2013). Following and alongside his work at Labná, Gallareta Negrón has been co-directing the Bolonchén Regional Archaeological Project (BRAP) with George J. Bey III and William Ringle that includes the sites of Labná, Huntichmul, and Kiuic (Gallareta Negrón et al. 2014). The BRAP project in particular has been devoted to investigating the changing settlement patterns and the sociopolitical trajectory of the sites in the Bolonchén District.

Western Puuc sites have also seen their fair share of recent research, especially by Mexican, European and Canadian archaeologists. Hanns Prem and Alfredo Barrera Rubio co-

directed a seven-year project at Xkipché, located approximately 9km southwest of Uxmal, in the 1990s. The large-scale research program sought to refine the local site and ceramic chronologies (Schlegel 1997; Prem 2003; Vallo 2005; Braswell et al. 2011). Projects at the sites of Xculoc and Xcalumkin since the early 1990s have addressed the settlement patterns and the historical trajectories of these sites (Becquelin and Michelet 1994; Becquelin et al. 1996; Michelet and Arnauld 2000; Becquelin et al. 2011). There have also been shorter-term survey and reconnaissance projects at Puuc sites such as Kankí (Zapata 1991), Siho (Dunning and Andrews 1994), Kuxub (Garcia Campillo 1995), Ichmac (Benavides 2000), Hunto Chac (Prem and Dunning 2004), Xuch (Isendahl 2006), Kichpampak (Merk and Mayer 2012), and Xkayum (Mayer and Merk 2012), and salvage work in and around Oxkintok (Ortíz Ruíz 2014).

Based on this slew of recent studies, archaeologists have been able to develop a more nuanced picture of ancient socio-cultural, economic, and political developments in the Puuc Region. Work at Kiuic, Xocnaceh and Yaxhom (Gallareta Negrón et al. 2014; Simms 2014) has demonstrated that not only were these areas inhabited as far back as the Middle Preclassic Period (ca. 800 BCE), but that by ca. 500 BCE local populations were erecting monumental constructions on par with the large centers further south. Current evidence suggests that there was a steep decline in population throughout the Puuc by the end of the Late Preclassic (ca. 250 CE) and that populations remained low through the Early Classic Period (ca. 250-550 CE) (Gunn 2015). This was followed by a resurgent occupation during the Middle Classic Period (Varela Torrecilla 1998) and an eventual peak in settlement and construction activity during the Late and Terminal Classic Periods (ca. 650-950 CE). Thus it is likely that groups migrated north from southern sites as they were abandoned near the end of the Classic period, but that by no means did they encounter an untouched, uninhabited landscape. Following a relatively brief florescence

of about 250-300 years, the majority of the investigated sites in the Puuc Region experienced a fairly rapid decline at the end of the Terminal Classic Period (ca. 950-1000 CE) (Carmean et al. 2004; Gallareta Negrón et al. 2014; Simms 2014; Gunn 2015).

While socioeconomic and political circumstances in the Preclassic and Early Classic Periods remain somewhat unclear, archaeologists have made a lot of headway in understanding later Classic Period Puuc society. An expansion of archaeological projects has allowed for the division of Puuc architecture into several temporal phases, which in turn has shed light on the spread of sociocultural influences. The Early Oxkintok and Proto-Puuc architectural traditions, which date to the Middle Classic Period, appear to be more closely linked with sites in the Western Puuc (Andrews 1995; Gunn 2015). The succeeding Early Puuc architectural tradition, which dates to the Late Classic Period, is more widespread throughout both the Eastern and Western Puuc. The evolution and distribution of these successive architectural styles indicates that Middle-Late Classic Puuc socio-cultural trends (and perhaps populations) most likely spread from West to East (Gunn 2015:13). A combination of settlement, architectural, iconographic, and epigraphic evidence indicate the development of power-sharing sociopolitical organizations in the Western Puuc that then spread to other regions of the northern lowlands (Carmean 1998; Grube 2003). Based on the proliferation of dated monuments towards the second half of the 9th century CE, at sites such as Uxmal, Sayíl and Labná, it appears that governance was becoming more centralized leading up to the abandonment of most sites by the end of the 10th century CE (Gunn 2015).

Kiuic

The mid-level, Range III site of Kiuic (Garza and Kurjack 1980) (Figure 4-3) is located in the Bolonchén District of the Puuc region, which encompasses the territory just to the south and east of the Valle de Santa Elena. The Bolonchén topography is characterized by numerous rounded limestone hills that rise between 40 and 60 m in height above the surrounding flat valley floors. Kiuic is located within a circular valley surrounded by a ring of these low hills (Figure 4-4), many of which possess archaeological complexes on their apices. The Bolonchén Regional Archaeological Project (BRAP) directed by Tomás Gallareta Negrón, George J. Bey III, and William Ringle has overseen excavations and archaeological surveys in and around Kiuic since the year 2000 (Simms et al. 2012; Gallareta Negrón et al. 2014). By combining intensive excavations of both monumental and residential architecture in urban and extra-urban contexts with survey and test-pitting programs over a wide swath of territory, the BRAP directors have promoted a holistic approach to investigating the sub-regional social development of the Bolonchén District (Gallareta Negrón et al. 2014; Gunn 2015). Excavations in the Dzunun plaza of the Kiuic site center have uncovered evidence of occupation dating back to ca. 800 BCE and continuing through to a peak era of construction activity between CE 650-950 (Bey 2009; Gallareta Negrón et al. 2014). This peak era of building activity includes the construction of the large Kuche and Chulul palace complexes in the site center (Figure 4-5), as well as residential hilltop complexes like *Escalera al Cielo* (EAC), which is located approximately 1.5 km to the west of the site center (Figures 4-6, 4-7).

Systematic excavations in the Yaxche Group have indicated that this was the original central group of the Kiuic polity, with the earliest plazas and buildings dating to the Middle Preclassic Period (ca. 810-760 BCE) (Gallareta Negrón et al. 2014:16). Over time the Dzunun

Plaza was expanded and new monumental buildings were constructed around it between the Preclassic and Early/Middle Classic Periods. Three buildings were constructed on the northern side of the plaza that likely formed the seat of power and possible residence for the ruling lineage of the site. Starting in the second half of the 6th century CE, the site center and the scale of its architecture began to expand at a more rapid pace. A large *popol nah* or 'council house' was constructed at the southern end of the Dzunun Plaza and the buildings on the north side were filled in and covered to form a small pyramid. This was part of a construction program that converted the Yaxche group into an Early Puuc Civic Complex (*Complejo Cívico Puuc Temprano* or CCPT), an architectural complex seen at many sites in the Eastern Puuc around the start of the Terminal Classic Period (ca. 700 CE). Large residences were built on the Eastern and Western sides of the Dzunun Plaza, closing it off and completing Yaxche's transformation into a palatial group that served as the political and religious heart of the site. Side patios and plazas were built around Yaxche at this time. According to the BRAP directors, the Early Terminal Classic architectural changes reflected rapid social, political, and economic changes at Kiuic (Gallareta Negrón et al. 2015a:2.16-2.17). The Yaxche Group was converted from a fairly open civic ceremonial plaza into a more close-off palatial residence group that brought together a heterogeneous mix of elite and non-elite members of the community in the service of the ruling family. During this period elite and non-elite compounds were constructed around the site center and atop some of the hills that ringed the Kiuic Valley, including EAC (Simms 2014).

Later in the Terminal Classic Period, the center of power at the site shifted to the Kuche and Chulul palace groups, just to the west and southwest of Yaxche. These new architectural groups dwarfed the older Yaxche complex, whose pyramid was likely converted into a temple monument to the original rulers of the site (Gallareta Negrón et al. 2014:21). Thus, the new

function of the Yaxche complex was likely to venerate the previous rulers and legitimate the authority of the new ruling family that moved to the new palatial groups. Similar patterns have been uncovered at Labná and Uxmal (Gallareta Negrón et al. 2014). While it is unclear whether one ruling dynasty was responsible for moving the seat of power or a new ruling family initiated the transfer from Yaxche to Kuche/Chulul, the massive scale of the new palatial groups reflects the general population and construction boom that was occurring within the polity. This growth was possibly augmented by migrations from the South.

Evidence from the site center and EAC indicates that the Kiuic polity was rapidly abandoned around 950 CE, leaving several ongoing construction projects unfinished in the site center (Simms et al. 2012; Simms 2014; Gallareta Negrón et al. 2014; Gunn 2015). The Bolonchén district in general appears to have been largely depopulated around this time period, perhaps due to shifts in climatic patterns and prolonged demographic stress. Lake and marine cores indicate that an extended period of drought affected the Maya lowlands between the 9th and 10th Centuries CE (Brenner et al. 2002; Hodell et al. 2005; Gill et al. 2007; Luzzadder-Beach et al. 2012). Extensive dry periods were particularly disastrous for sub-regions like the Puuc, where inhabitants relied almost completely on rainfall to provide their water requirements (Isendahl 2011). The theory of drought cycles contributing significantly to the disintegration of the Terminal Classic Maya sociopolitical organization is not without its challengers (Carleton et al. 2014), but regardless of the specific cause(s) Kiuic ceased to exist as a significant population center by the end of the 10th century CE.

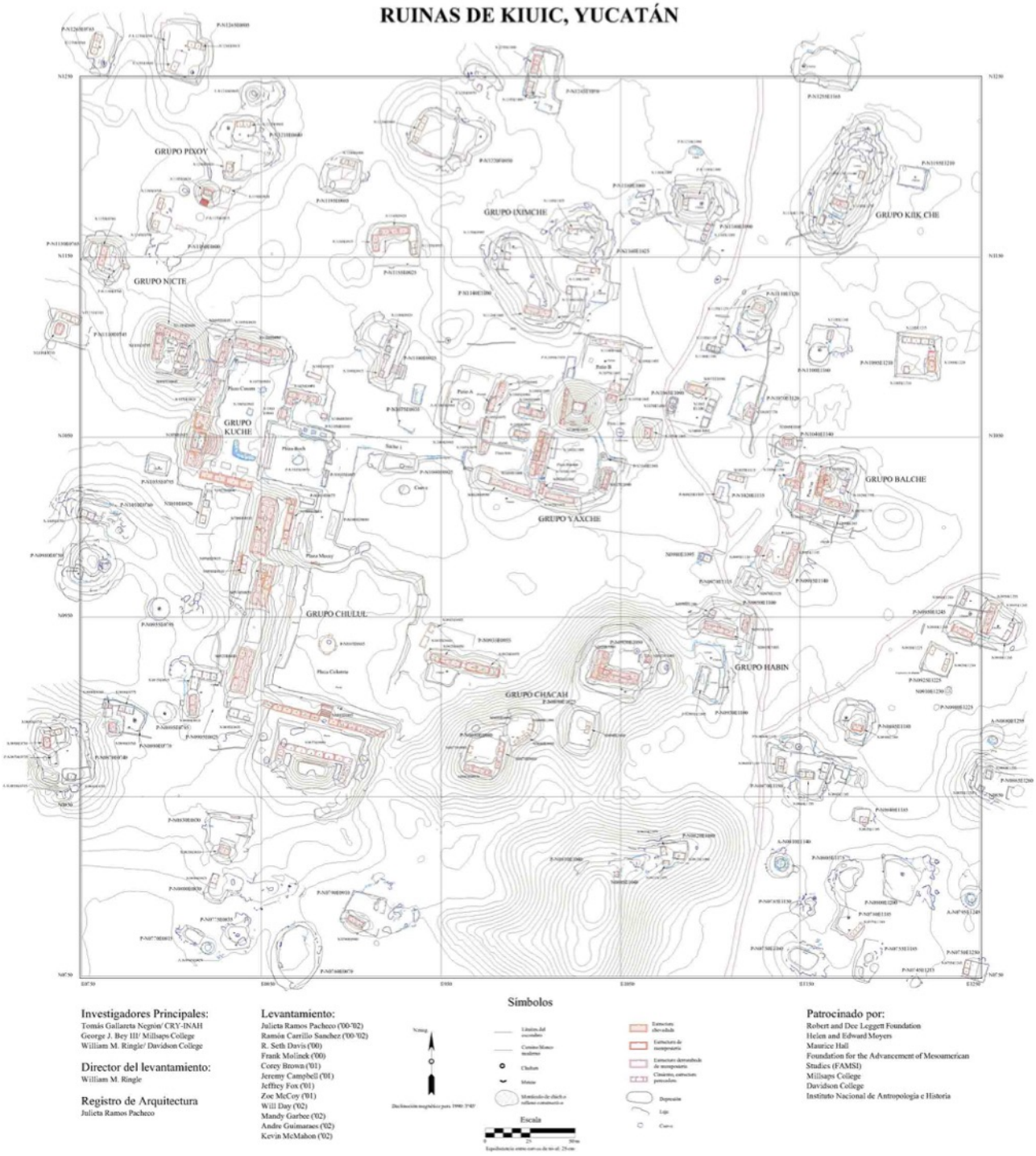


Figure 4-3: Map of the Kiuic site center created by William Ringle and colleagues (Gallareta Negrón et al. 2012).



Figure 4-4: View of the Kiuic Valley looking north from the southern edge.

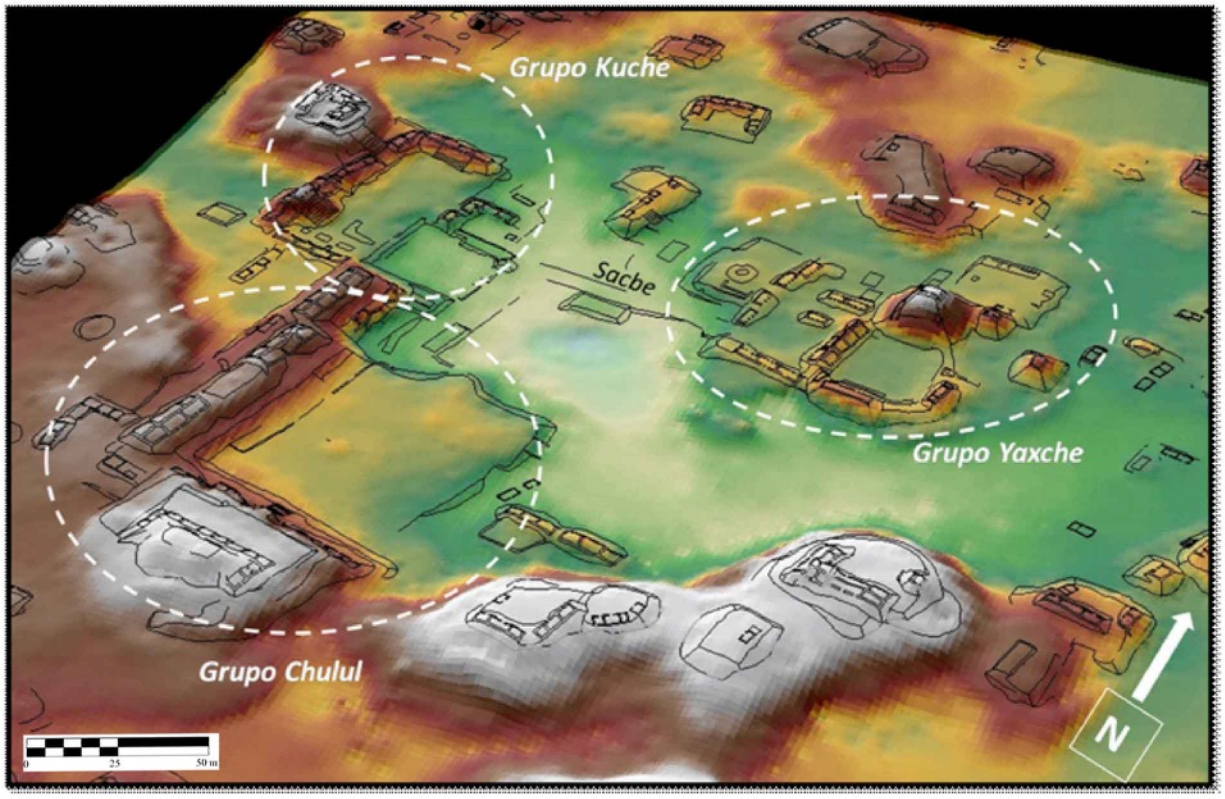


Figure 4-5: A topographic model of the Kiuic site center showing the locations of the Chulul and Kuche complexes (from Gallareta Negrón et al. 2014).

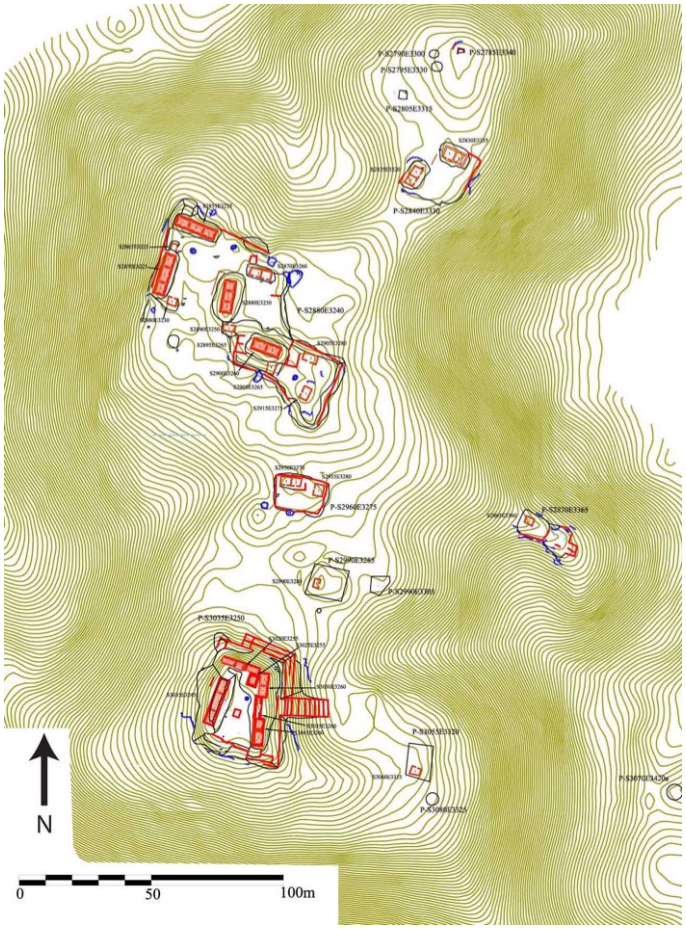


Figure 4-6: Map of the Escalera al Cielo hilltop elite complex located approximately 1.5 km west of the Kiuic site center (adapted from Gallareta Negrón et al. 2014).

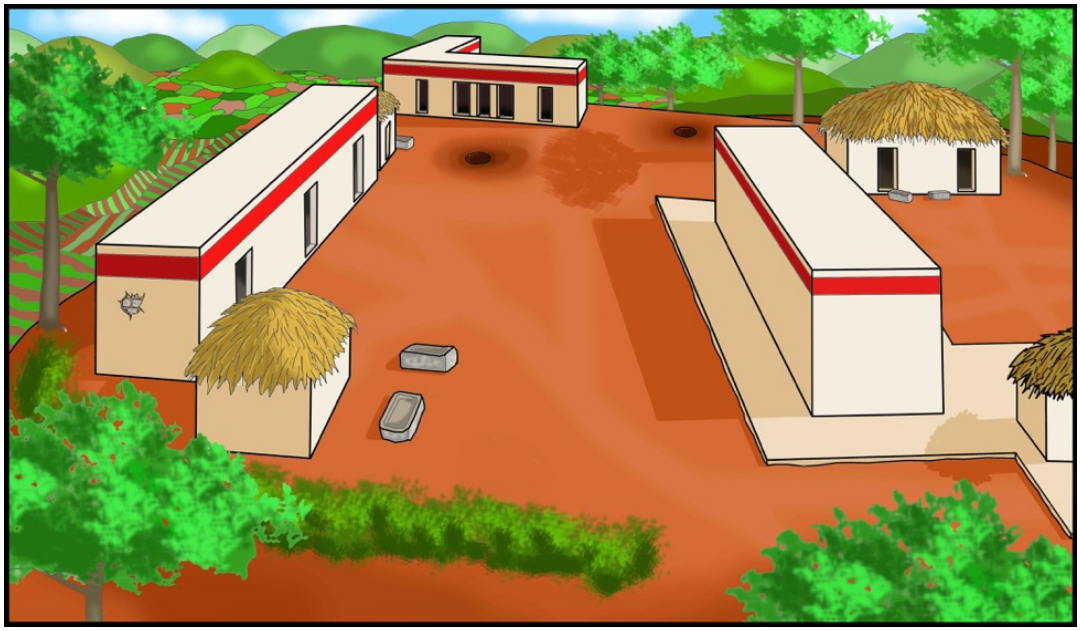


Figure 4-7: A reconstruction drawing of the Escalera al Cielo Norte residential compound.

It is unclear exactly when permanent populations returned to the Bolonchén District, but by the time Stephens and Catherwood visited Kiuic in 1839 the ruins had come under the stewardship of the noble Canul family. The Canul family owned and operated Rancho Kiuic from the early 18th century up through the early-to-mid 20th century and their property included the ancient ruins (Stephens and Catherwood 1962 [1839]:41). An INAH-sponsored report from 1913 describes the Canul family's property titles as being "*muy antiguos* (very ancient)" (Martinez 1913). The report also suggests that the Canul family could trace their roots back to a local *cacique*, or chief, who owed obedience to Francisco de Montejo, the Captain-General of the Yucatán under the Spanish Crown in the early 16th century CE (Martínez 1913). Rancho Kiuic itself was abandoned in the early-to-mid 20th century as laboring families became increasingly dissatisfied with their Canul patrons and moved to the nearby towns of Kobenhaltún and Yaxhachen (Morgan-Smith, personal communication 5/6/15). Near the end of the 20th century, the Helen Moyers Biocultural Reserve, a non-profit organization co-founded by Millsaps College and INAH that supports multi-disciplinary research, including the BRAP, purchased much of the former Canul lands including the Prehispanic site of Kiuic.

The Labná-Kiuic Inter-Site Survey

As part of the larger BRAP program, Gallareta Negrón and colleagues (2014) conducted an intensive 9 km long by 1 km wide ground survey between the sites of Labná and Kiuic between 2001 and 2014 (Figure 1-3). During the survey they identified all human-made or human-modified features in the survey area including more than 140 annular structures, a sample of which form the basis of the current study. My case study focuses on that part of the survey that includes much of the western half of the Valley of Kiuic and the hills that mark the western

and northwestern border of the Valley as well as ~1.15 sq km to the west of the hills. This sub-section represents the part of the survey that most likely fell within the bounds of the Late and Terminal Classic Period Kiuic polity (Figure 4-8).

The 2.83 km^2 study area provides a cross-section of the densely populated center of the site as well as the more sparsely populated agricultural lands to the west of the Kiuic Valley. I divided the study area into 'inner', 'intermediate', and 'outer' zones of the Kiuic polity based solely on topographic, geographic, and architectural factors. The designations are based on differences in distance from the ceremonial site center, the frequency of vaulted architecture, and topographic delimitations (Table 4-1). These three variables line up well to demarcate distinct zones within the polity and have important implications for understanding the organization of lime production activities (Table 4-2). The inner zone of the study area is ~0.38 km^2, the intermediate zone is 1.32 km^2, and the outer zone is 1.13 km^2 (Figure 1-5).

Table 4-1: Comparisons of the total numbers and frequencies of residential groups between the three study area zones.

	Area (sq km)	**Elite Residential Groups**	**Elite groups per sq km**	**Non-elite Residential Groups**	**Non-elite groups per sq km**	**Total groups**	**Total groups per sq km**
Inner	0.38	21	55.3	24	63.2	45	118.4
Intermediate	1.32	6	4.5	30	22.7	36	27.3
Outer	1.13	0	0	0	0	0	No residences
Total	2.83	27		54		81	28.6

Table 4-2: Comparisons of the total numbers and frequencies of annular structure between the three study area zones.

	Area (sq km)	**Annular Structures**	**AS per sq km**
Inner	0.38	7	18.4
Intermediate	1.32	35	26.5
Outer	1.13	11	9.7
Total	2.83	53	18.7

The inner zone of Kiuic, consisting of monumental edifices and residential compounds with and without vaulted architecture is located in the flat northwestern sector of the Kiuic Valley. It has by far the highest frequency of elite residential compounds identified by the presence of vaulted architecture (55 elite residential compounds per km^2, compared with 4.5 for the intermediate zone and zero for the outer zone). It also has the highest frequency of overall residential compounds, elite or non-elite (118 residential groups per km^2, compared with 27 for the intermediate zone and zero for the outer zone). The intermediate zone includes the ring of hills that surrounds the Kiuic Valley. It has the highest frequency of annular structures between the the three zones (26.5 annular structures per km^2, compared with 18.4 for the inner zone and 9.7 for the outer zone). Residential architecture in general drops off dramatically in the intermediate zone, and vaulted elite architecture is limited to a few hilltop compounds such as EAC. The inhabitants of these elite residential compounds, while most likely having social and political ties to the Kiuic polity, were also distant and topographically isolated enough from the site center to have maintained a degree of privacy or independence from the everyday social activities of the site center. The flatter outer zone of the Kiuic polity begins immediately beyond the intermediate hill zone but the lack of Prehispanic territorial markers precludes determining a maximum extent of this outer area. This zone is characterized by the absence of residential groups and architecture of any kind is less frequent than in the intermediate and inner zones. These outer hinterlands were likely integrated into the polity as productive agricultural lands that may have even been controlled or administered by households living in the hilltop complexes like EAC (Bey 2009; Gallareta Negrón et al. 2014:2,6). The outer zone of the study area is circumscribed based on a conservative estimate of the extent of the Kiuic polity in relation to the

nearest other large Terminal Classic site of Huntichmul located approximately 3.5 km to the northwest.

Combining spatial and contextual data gathered during the inter-site survey with the excavation of a sample of structures, I analyze the socioeconomic organization of the lime production industry as represented by the annular pit-kilns. Investigations of the sub-regional Puuc socio-economy have largely focused on the agricultural productivity of the region (Barrera Rubio 1987; Dunning 1992; Simms 2014) at the expense of other potentially significant factors, such as the limestone processing industry. Early archaeological research in the Puuc focused mainly on its distinctive architectural tradition, water storage system, and agricultural potential. Now, through more intensive excavations at larger site centers and smaller residential complexes, as well as extensive inter-site surveys, archaeologists are unraveling the historical trajectories of specific sites and learning the intricacies of ancient Puuc society. The current study of the socio-economic and resource management aspects of lime production at Kiuic contributes new perspectives to this increasingly comprehensive mix. It illuminates the socioeconomic organization of a significant industry at the household- and polity-scales, as well as the industry's effects on environmental resource management issues.

Previous Research on Lime Production

The Origins of Lime Production

Burnt lime was produced and consumed by pre-modern societies throughout the world. However, the ephemeral nature of burnt lime in the archaeological record limits our abilities to trace the earliest lime production events. It is likely that the earliest instances of lime production occurred by accident when peoples living in limestone-rich areas noticed changes in bedrock that

had been exposed to fire for an extended period of time (Kingery et al. 1988). Eventually these fortuitous observations were put to use and burnt lime was purposely produced.

The earliest archaeological evidence for burnt lime production in the world currently comes from Epi-Paleolithic Geometric Kebaran Period (ca. 12,000 BCE) sites in the Levant. While lime production likely developed after the domestication of plants and animals, it appears to have predated (and perhaps influenced) ceramic firing technology in the region (Frierman 1971; Kingery et al. 1988). Lime used for specifically architectural purposes in the form of lime plaster dates to the succeeding Natufian Period in the Levant (11^{th}-9^{th} millennium BCE) (Kingery et al. 1988; Rehhoff et a 1990; Ronen et al. 1991). As is the case throughout the world, lime production in the Levant is almost always identified through the recovery of lime products such as plaster or mortar that have higher preservation and archaeological visibility rates than the unadulterated powdered burnt lime. Relatively few actual lime production areas have been identified compared with the prevalence of lime products (Goren and Goring-Morris 2008).

Lime plaster floors had become such a common feature in the Levant by the PPNB that researchers consider them to be a characteristic trait of this time period (Gourdin and Kingery 1975; Thuesen and Gwozdz 1982; Kingery et al. 1988; Hauptmann and Yalcin 2000). Examples of PPNB-era lime plaster have been uncovered not only in the Levant, but in Turkey and Iran as well. Though in the latter the plaster was predominantly of a gypsum variety. Gypsum plaster requires less labor and fuel to produce, with firing temperatures only needing to reach 100-200 degrees Celsius as opposed to the 800° C necessary for lime plaster (Thuesen and Gwozdz 1982:99; Kingery et al. 1988; Rehhoff et al. 1990; Rollefson and Kohler-Rollefson 1992). Following the PPNB, there appears to have been little or no production of lime in the Levant for

millennia until the start of the Iron Age and it only became widespread again during the Roman period (Ronen et al. 1991:149).

Lime production technology spread from the Near East to southeastern Europe by the 6th millennium BCE. Lime plaster floors dating to the Early Neolithic Period (ca. 6500-3300 BCE) have been uncovered in Greece (Karkanas and Stratouli 2008) and at the site of Lepenski Vir in Serbia around (6200-5400 BCE) (Boric 2002; Elsen 2006). While it is likely that lime technology also diffused to Egypt early on from the Near East, the earliest securely dated lime plaster in Egypt comes from the site of Timna and dates to approximately 1400 BCE (Gourdin and Kingery 1975; Carran et al. 2011). During the 2nd and 1st millennia BCE, Phoenician traders and colonizers spread burnt lime technology throughout the Mediterranean region.

Evidence for early lime production is scarcer in other parts of the Old World. The production and use of lime was widespread in China by the middle of the Western Zhou Period (1046-771 BCE) (Yang et al. 2009:1642), but it is unclear whether it was an indigenous development or diffused from the west. There is indirect evidence for possible gypsum plaster production in Punjab, Pakistan dating to the proto-Harappan and Harappan periods (3500-1900 BCE) in the form of what appears to be gypsum plaster on the outsides of ceramic vessels (Strahan 2011:530), though it is possible that the gypsum attached to the vessels in a post-depositional context. Also, it has been suggested that the beveling of the edges of some shell ornaments at Mohenjo Daro was meant to enable the setting of gypsum plaster (Marshall 1931:197,566; Kenoyer 1983:180,187). However, gypsum and lime plaster production does not appear to have become widespread in the Indian subcontinent until near the end of the 1st millennium BCE (Mate 1993:245; Carran et al. 2011:123).

Burnt lime products first appear throughout Mesoamerica near the end of the 2nd millennium BCE. The earliest evidence for lime use in Mesoamerica comes in the form of lime plaster and pits dug into platforms that contained lime powder at the site of San Jose Mogote in the Valley of Oaxaca and dates to between 1400-1150 BCE (Marcus and Flannery 1996:83-87). Lime plaster coated the floors of structures that are believed to be among the earliest examples of public architecture in Mesoamerica and date to around 1320 BCE (Marcus 1989:163). Marcus (1989:191) lists "the use of lime plaster for one-room public buildings by 1400 BC" as one of the features distinguishing early Oaxacan cultures from the Olmec cultures of the Gulf coast. Indeed, there appears to be a complete absence of lime plaster or other lime products at the early Olmec centers of San Lorenzo and La Venta (Flannery and Marcus 2000:8; Cyphers and Di Castro 2009:34). This is partially a result of the absence of locally available limestone and is reflected in the use of mud, earthen bricks and pole and thatch in the architectural constructions, both residential and monumental (Diehl 1981:69). Recent studies show that maize may have played only a limited role in the Preclassic Period Gulf Coast diet (Arnold 2009:397; VanDerwarker and Kruger 2012:510), which suggests that lime would not have even been important for dietary purposes in the Olmec area until later on. Recent studies have also suggested that maize did not become a significant component of the Maya diet until around the beginning of the first millennium BCE (Cheetham 2010; Simms 2014:76). This would be concurrent with the founding of the earliest large permanent settlements in the Maya area. Maize can also be treated with wood ash to serve a similar nutritional function as lime in the nixtamalization process. It is possible that the increased production of lime around the turn of the first millennium BCE was connected with the widespread adoption of the lime-based nixtamalization process around this

time. This allowed for the increasing incorporation of maize as a significant dietary component, which in turn facilitated the growth of sedentary occupations.

The earliest identification of burnt lime in the Maya area comes in the form of lime plaster from the site of Cuello in Belize and dates to around 1100 BCE (Figure 4-8) (Hammond and Gerhardt 1990:464; Hammond et al 1991:30-33). The use of lime plaster has also been identified at the Preclassic sites of Tlapacoya (Barba de Piña Chan) and Tlalancaleca (Majewski 1976) in Central Mexico dating to around this time period. Almost all of the early evidence for lime production in Mesoamerica comes in the form of burnt lime products like stucco or mortar, as few lime production features such as permanent kilns have been identified in the region. I describe these early lime production features in the following sub-section. The fact that burnt lime products first appear in the archaeological record in sub-regions throughout Mesoamerica within what appears to be an approximately 200-year window suggests that architectural burnt lime technology spread rapidly along existing trade networks. However, due to the importance of lime for treating maize, it is likely that lime was produced for dietary purposes much earlier than this. In the absence of the identification of earlier lime production areas, we must rely on the identification of lasting lime products such as plaster to trace the earliest production and use.

Methods of Lime Production

In the absence of permanent kiln structures, it is difficult to determine what specific methods were used to produce burnt lime. The discrepancy between the large quantity of burnt lime products recovered in a given region and the low quantity of identifiable lime production sites suggests that ephemeral production methods were widespread in the pre-modern world. It is

likely that aboveground wooden pyres similar to the 'standard' ones used in the 20th century were built and used for the majority of early lime production around the world.

The earliest permanent lime kiln-like structure yet identified in the world is located at Hayonim Cave in Israel and dates to approximately 10,400-10,000 BCE (Figure 4-9) (Kingery et al. 1988). This pit-kiln, which resembled a round hearth, had a diameter of 2.5 m and was located near a large opening or chimney at the back of the cave. From inside the hearth or kiln, excavators recovered a 20-cm thick layer of mixed partially calcined limestone and reconstituted calcium carbonate (Kingery et al. 1988:223). Goren and Goring-Morris (2008) tentatively identified Pre-Pottery Neolithic B (PPNB) era (ca. 8700-7000 BCE) lime production areas at the site of Kfar HaHoresh in northern Israel. These features consisted of "poorly defined irregular circular/oval" pits with burnt pieces of limestone in and around the depressions (Goren and Goring-Morris 2008:784).

A peculiar lime plaster production method was identified at Drakaina Cave in Western Greece through micro-morphological analysis of the lime plaster floors (Figure 4-10). It appears that instead of allowing the slaked lime to mature in storage areas, the producers slaked the lime immediately after production directly on the floors that the lime was then used to coat as plaster. This led to incomplete mixing of the slaked lime with other aggregates and binders, which resulted in the presence of many lumps of pure lime within the floor plasters. Other studies have demonstrated that the longer slaked lime is allowed to mature, whether in powdered form as an irreversible colloidal submerged in water, the higher quality plasters and mortars it can be used to produce in terms of strength and durability (Cazalla et al. 2000; Elert et al. 2002; Hansen et al. 2008). The researchers at Drakaina Cave point to a probable part-time, low-intensity

organization of production as the reason for this lower quality result (Karkanas and Stratouli 2008).

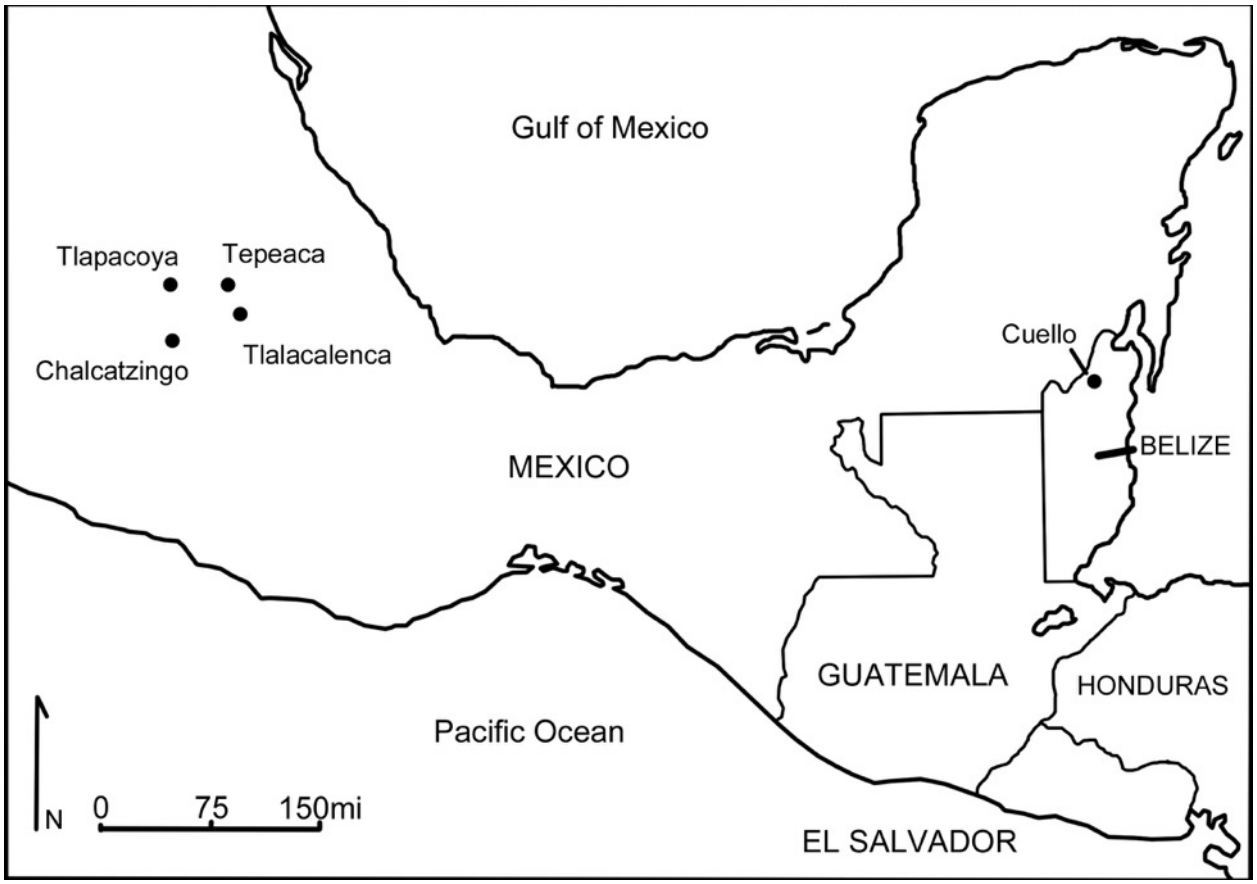


Figure 4-8: Map of the Mesoamerican archaeological sites mentioned in this sub-section.

The Phoenicians developed a lime-based mortar agglomeration known as 'cocciopesto' mortars, which combines lime, sand, and brick fragments into a mixture that holds together well in moist environments and was adopted by the Romans (Zendri et al. 2004; Carran et al. 2011). Lime plaster hardened by Pozzolanic reactions is a variation that possibly appeared as early as the PPNB by chance or experimentation but didn't become widespread until the 1st millennium BCE (Hauptmann and Yalcin 2000; Regev et al. 2010). Pozzolanic reactions refer to the mixing

of calcium hydroxide with silicic acid, which is found in ash (most notably volcanic ash, called pozzolana). The resulting material is a calcium silicate hydrate (CaH_2SiO_4), which formed the basis of the Roman cement, or *opus caementicium*, that was used for architectural purposes throughout the Roman period (Hauptmann and Yalcin 2000; Dunn and Rapp 2004; al-Bashaireh 2008; Villaseñor 2010). It is an example of a hydraulic lime, which means that it can set under water. The perfection of the incorporation of pozzolanic materials along with optimal water-to-lime-to-aggregate ratios by the Romans allowed them to construct large-scale, durable edifices that are still standing today.

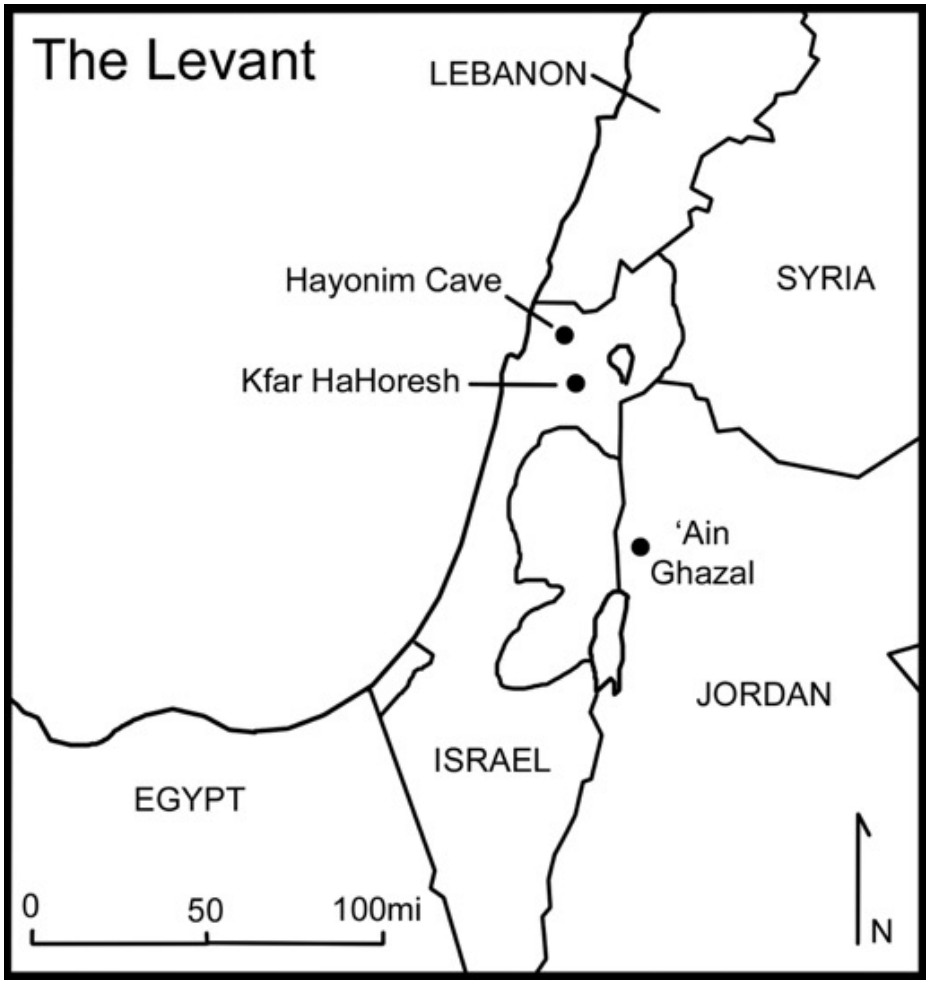


Figure 4-9: Map of the Levant highlighting the sites mentioned in this section.

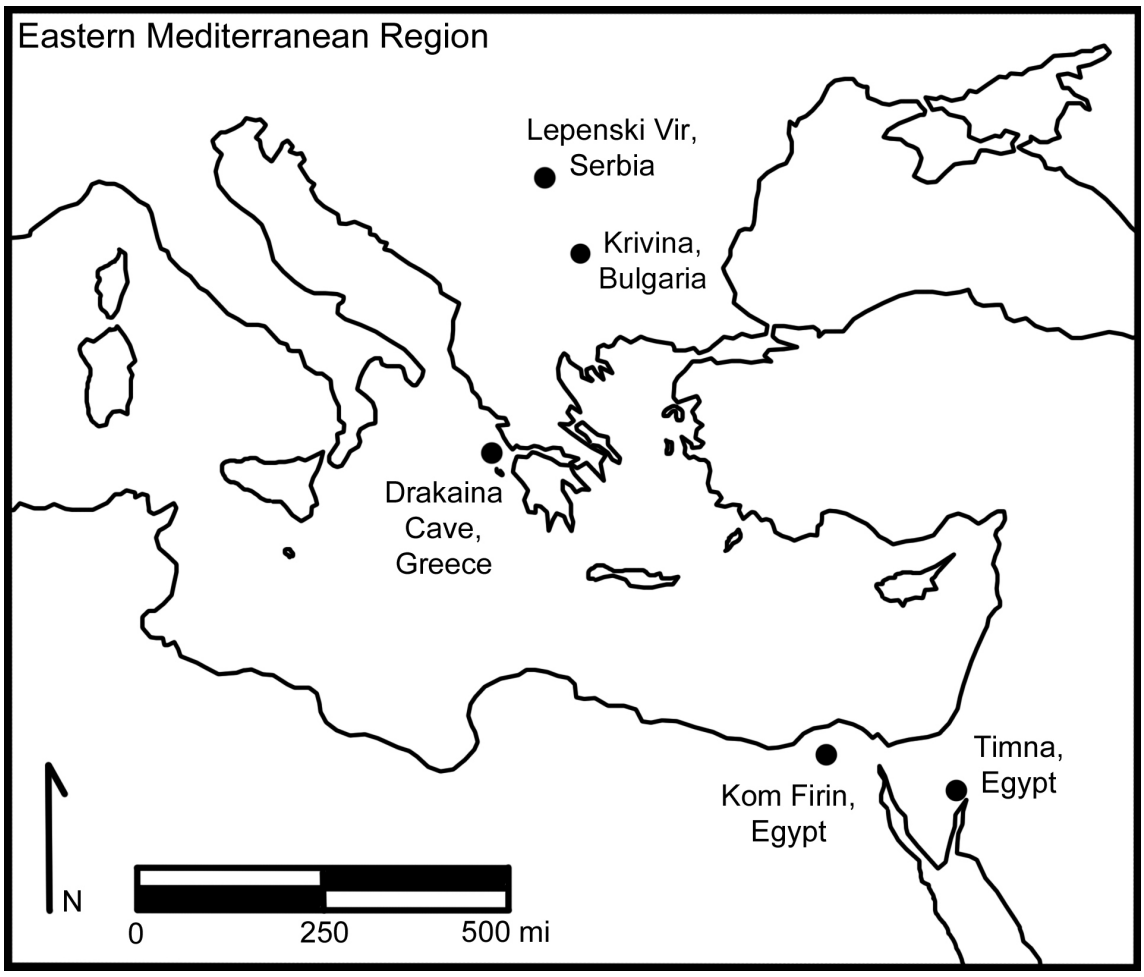


Figure 4-10: Archaeological sites in the Eastern Mediterranean region mentioned in this section.

Romans constructed and used thousands of enclosed kilns for producing lime, but relatively few have been excavated. Vagalinski (2011:44) points to physical difficulty, lack of aesthetic reward, and difficulty of establishing construction dates as the main reasons for this deficiency. Roman lime kilns were generally circular or oval in shape and often used pre-excavated pits or were dug into the slopes of hillsides. They were often built with a ledge around the interior of the top of the kiln to keep the raw limestone separated from the wood fuel, meaning the limestone was calcined using radiant or indirect heat. This required burns to last several days and the fuel had to be replenished through one or two stoke holes built into the side

of the kiln (Dix 1979). A series of particularly large Roman kilns near Krivina, Bulgaria dating to the 1st century CE were dug into a thick layer of loess and were pear and oval-shaped (Vagalinski 2011). They were each constructed with a single vaulted stoke hole, through which fuel and limestone were inserted, air entered, and burnt lime was removed. Pollen phytoliths recovered from some of the kilns indicate that oak, sycamore and alder were used as fuel (Vagalinski 2011). It is unclear whether the quicklime was slaked inside or outside the kilns.

Some Roman-Era kilns, like the one excavated at Kom Firin in the western Nile Delta, consisted of three distinct components: a stoking chamber where the fuel was burned and resupplied, a reducing chamber where the limestone was calcined, and a tunnel connecting the two. The Kom Firin kiln possessed the following characteristics: the stoking chamber was oval in shape and measured 1.8 m long by 1.4 m wide; the reducing chamber was fairly rectangular in shape and measured 1.7 m long by only 0.9 m wide; and the tunnel connecting the two chambers was held up by a corbelled vault and was only 0.5 m long (Coulson and Wilkie 1986). The separation of fuel from limestone likely led to a cleaner lime product than if the limestone was directly in contact with the fire, but this meant that ash had to be mixed in with the lime after the firing episodes to induce the Pozzolanic reactions. The indirect heating of the limestone required much longer firing episodes and thus much more fuel per burn.

Until recently there have been only a handful of archaeological features identified as potential lime burning kilns in Mesoamerica, let alone the Maya area specifically (Villaseñor and Barba 2011:82-83). In the 1970s, David Grove and colleagues identified three archaeological features that they believed to be lime-cooking kilns at the site of Chalcatzingo in Morelos (Grove and Guillen 1987; Martín Arana 1987:392-393). These features consisted of pits dug into the earth lined with flat stones set in mud mortar inclining at an angle of approximately 75 degrees.

The largest of the kilns measured 2.8-3.1 m in diameter and reached a depth of 2.3 m below the lip of the pit. Materials recovered from the interior of the kilns included limestone in various stages of calcination. Charcoal recovered from the features was used to date the kilns to the Late Classic Period (ca. 690 +- 80 CE) (Martín Arana 1987:392). Later, the Tepeaca Kiln Project directed by Ronald Castanzo identified 86 kilns, 37 of which were potentially used for lime production, in the Puebla-Tlaxcala Basin (Castanzo 2004; Castanzo and Anderson 2004). Materials recovered from surface surveys led to the dating of the kilns to the Formative through Colonial time periods, with the earliest returning a radiocarbon date of 1010 +- 90 BCE at 1σ (Castanzo and Anderson 2004). In addition to the aforementioned sloping wall kilns discovered at Chalcatzingo, a rectangular pit-kiln was identified at a site in the Tehuacan Valley of Central Mexico in the 1970s (Sisson 1973:98-100).

Studies of lime consumption at Teotihuacan have focused on calculating the energetics required for meeting the metropolis's needs and sourcing the raw limestone to the Tula Valley. While most scholars agree that Teotihuacan acquired its lime from the northern border of the Valley of Mexico (Parsons and Gorenflo 2008:77; Murakami 2010:354) and the Tula Area (Crespo Oviedo and Mastache 1981; Manzanilla 1996:238; Barba and Cordóva 1999:169), they disagree as to the organization of the industry and do not address the physical methods of lime production. As of 1999, no specific lime production areas had been identified in the northern Basin or Tula region (Barba and Cordóva 1999:174) and the absence of any mention of such features in Murakami et al.'s (2013:962) discussion of lime consumption at Teotihuacan suggests that this is still the case.

Turning to the Maya area specifically, bowl-shaped pit-kilns with rounded bottoms were identified at Copán, Honduras (Viel 1983; Whittington 1991) and Dos Pilas, Guatemala

(Johnston et al. 1989) (Figure 4-11). These pit-kilns were only about 0.5-1 m deep in the center and appeared very similar to early pit-kiln technology in the Levant (Schreiner 2002). The similarity in forms between these disparate geographic areas likely reflects the increased efficiency and structural stability of burning the lime in depressed areas as opposed to on flat ground. Also, as demonstrated by my experimental pit-kiln study presented in Chapter 7, repeated lime burnings in the same location loosens the underlying bedrock, which can lead to the excavation of a pit partially for practical reasons.

A series of flat-bottomed, cylindrical pit-kilns dating to the Late/Terminal Classic Period were identified during the survey of the Puuc site of Sayíl in the Late 1980s (Sabloff and Tourtellot 1991). These are most similar to the annular pit-kilns that are the focus of the current study, which makes sense given the geographic proximity between Sayíl and Kiuic. Dunning (1991) ruminated on the frequency of annular structures in the Puuc region and their possible connection to associated tracts of otherwise fertile, but low-phosphorous *kancab* soils. While he did not excavate any of the annular structures at Sayíl, he recovered a core sample from one and apparently conducted some preliminary surface evaluations of others. Based on their proximity to *kancab* soils and the core sample's mixture of what he identified as *sahcab* (or *sascab)* and charcoal, he hypothesized that the annular structures may have been used to produce a type of soil fertilizer (Dunning 1991:25). Producing fertilizer may very well have been one of the burning functions of the annular structures, but it is also possible that the '*sahcab*' sample recovered from the annular structure core at Sayíl was in fact reconstituted calcium carbonate, which would point to the structure's use as a lime production kiln.

Archaeologists working on a highway salvage project near the Prehispanic site of Oxkintok at the northern edge of the Puuc Region also discovered a series of annular structures,

albeit with slightly different construction forms (Ortíz Ruíz 2014). Seven out of fourteen of the identified annular structures were excavated and returned evidence of lime production, with dates ranging from the Late Preclassic Period up through the Colonial Period. Compared with the Bolonchén District annular structures identified at Kiuic and Sayíl, the Oxkintok examples possessed shallower central depressions and much wider double-walls. These discrepancies are discussed in greater detail in Chapter 6. A final identification of annular pit-kilns was made by Gallareta Negrón and colleagues along in the Sierrita de Ticul that marks the eastern boundary of the Puuc Region (Bey, personal communication 11/16/15).

Fauvet-Berthelot (1980:5-7) identified a third type of kiln made up of a "pit within a pit" that dated to the Post-Classic period at the site of Cauinal in Guatemala. Similar examples of this design were uncovered at Pulltrowser Swamp, Belize (Ettlinger 1983:170-173) and possibly at Tula in Central Mexico. Schreiner (2002:94) hypothesized that the central deeper pit would have been stacked with vertical wood fuel while the surrounding, shallower pit contained additional fuel for horizontal heat radiation. Russell and Dahlin (2007) identified seven features believed to be aboveground lime plaster production sites outside the walls of Mayapán. They appeared in the archaeological record as round areas 5-7 m in diameter with much ash, carbon, and partially burned pieces of *chich*. They hypothesized that shallow pits containing the remains of lime slaking episodes in the form of lime products should be found near to these round burning areas, though it is unclear whether this was the case for the Mayapán production areas (Russell and Dahlin 2007:421). Based on the location of these lime production areas, they also suggested that future attempts to identify lime production in the archaeological record should look to the outskirts of settled areas where fuel resources were more readily available. A similar type of open-air firing feature was discovered by MacKinnon and May at Placencia Cay in Belize,

probably for the production of lime from marine shells (MacKinnon and May 1990). Additional identifications of potential lime pit-kilns have been reported by Redfield and Villa Rojas (1934) at Chan Kom, by Freidel and Sabloff (1984:35) on Cozumel, and by Barrera Rubio in the northeast of the Yucatán Peninsula (Barrera Rubio 2013). Considering the amount of lime plaster produced at sites throughout the Maya area from the Preclassic through the Colonial period, the amount of production sites identified to date is surprisingly small. Even at those sites where pit-kilns have been identified they do not appear with as great a frequency as the annular structures in and around Kiuic.

Lime Production and Deforestation

Although I already discussed the potential of lime production to contribute to deforestation in the Maya area in Chapter 3, environmental consequences were a feature of lime production throughout the pre-modern world. Near Eastern archaeologists still debate the intensity of lime production during the early Neolithic. Some researchers argue that lime production was a large-scale enterprise during the PPNB due to the prevalence of lime plaster and the high ratio of burnt lime within the plaster during this early period (Gourdin and Kingery 1975; Garfinkel 1987; Kingery et al. 1988; Ronen et al. 1991; Rollefson and Kohler-Rollefson 1992). There was a greater amount of wood fuel available for lime production during this time before the intensification of agricultural and animal husbandry practices contributed to a denuding of the landscape (Ronen et al. 1991:154). Lime producers likely also contributed to deforestation. Some researchers point to lime production fuel requirements as a significant factor in the disappearance of forests in the Southern Levant by the end of the PPNB (Rollefson and Kohler-Rollefson 1992; Kirch 2005b:422). Kingery et al. (1988) even claim that lime production

was the cause of the complete deforestation of a 3 km radius around the site of ‘Ain Ghazal in the 7th-6th millennia BCE. Once agriculture entered the mix, the tax on environmental resources reached a tipping point. According to Rollefson and Kohler-Rollefson (1992:250):

> “The mosaic effects of the particular aspects of plaster technology, animal husbandry, and local terrain around most 7th millennium Neolithic sites in Palestine/Israel had devastating effects on farming settlements that were tied to restricted sources of fresh water. Such impacts happened as early as 6,500 BC, and Jericho and Beidha were abandoned not as a result of regional desiccation, but of culturally-induced environmental degradation.”

Other archaeologists, however, counter that these PPNB high-intensity estimates were based on misleadingly high estimates of lime-to-aggregate ratios in plasters. They claim that early lime production was not nearly as labor-intensive nor as widespread an industry as previously thought (Goren and Goldberg 1991; Affonso and Pernicka 2001; Goren and Goring-Morris 2008). Regardless of whether lime production was one of the main culprits, much of the Levantine landscape was in fact denuded of fuel by the 6th millennium BCE.

Researchers excavating a complex of Roman-era kilns near Iversheim, Germany have also noted the likely environmental impact of burnt lime production, particularly the felling of trees for fuel. “The kiln operations would have been accompanied by an extensive felling of trees: at Iversheim, on average 60 cu m of wood were needed for each smaller kiln per calcination” (Vagalinski 2011:56). With as many as ten kilns in this production complex, producers would go through as much as 600 cu m of wood per production episode when all kilns were in use. The fact that the Roman military likely operated this lime complex reflects the requirement of a large labor force to supply the raw materials and fire the kilns (Vagalinski 53).

A large labor force would also have consumed a large quantity of wood fuel for other purposes beyond producing lime, leading to further depletion of environmental resources.

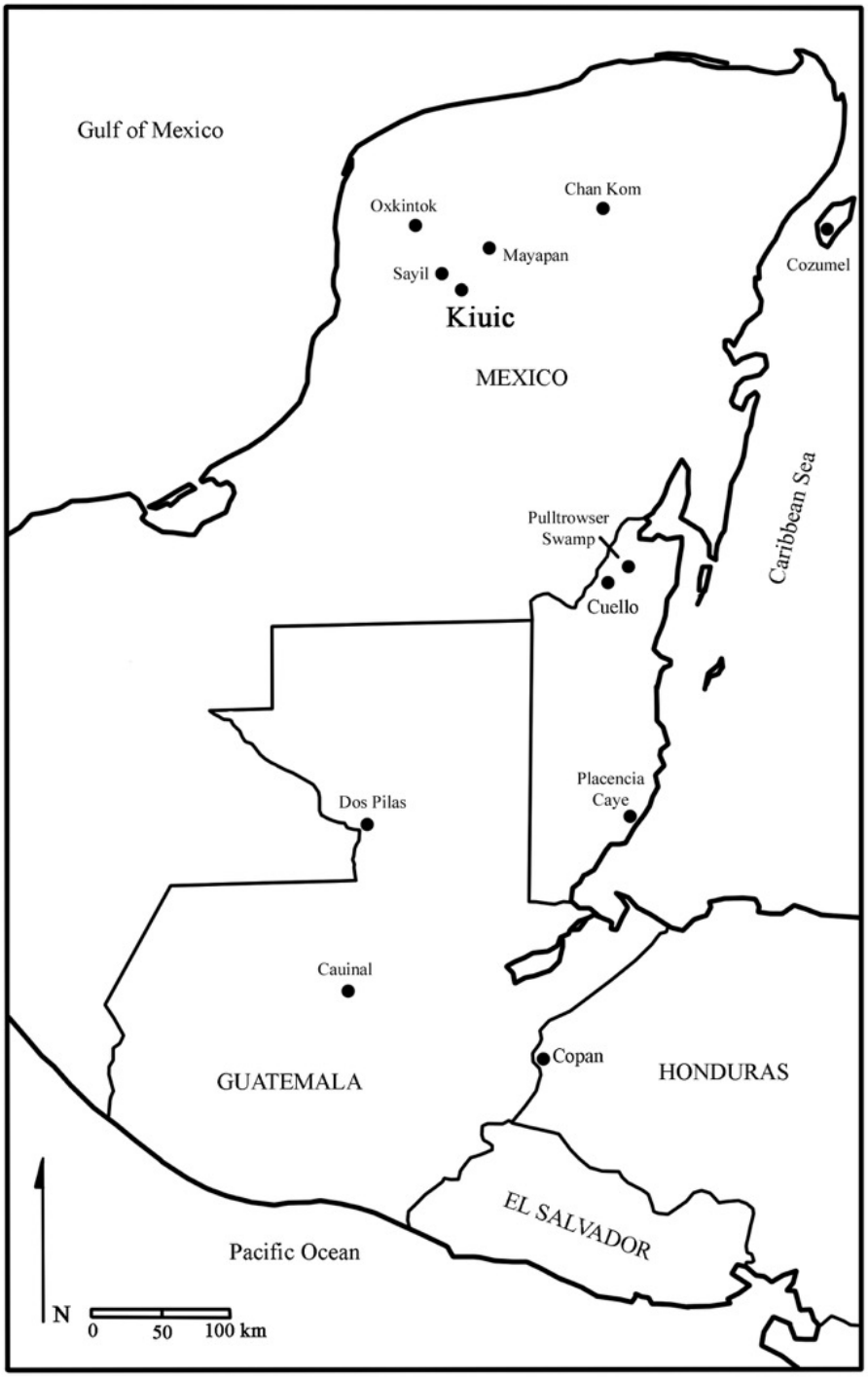


Figure 4-11: Map of the Maya area highlighting archaeological sites where potential kilns have been identified.

Additional Studies of Lime Production

While studies of Prehispanic lime production have been hindered by the difficulty of identifying lime production locations in the archaeological record, archaeologists and conservators have studied Prehispanic lime products to understand consumption and use patterns. For instance, archaeologists have sourced the raw limestone materials necessary for the lime used at Teotihuacan to the Tula Valley to the north (Barba et al. 2009; Barba and Córdova 1999:169; Murakami 2010:354; Murakami et al. 2013:962). The combination of the need for lime and lime products at Teotihuacan and the lack of accessible limestone deposits in the Teotihuacan Valley required the transportation of lime products from the nearest available resource areas. These studies have demonstrated the viability of cathodoluminescence, X-ray Fluorescence and Inductively Coupled Plasma-Optical Emission Spectrometry for sourcing lime plaster to specific limestone quarry regions on an inter-regional scale. Establishing lime provenance can help identify socioeconomic relationships in pre-modern societies on a macro-scale. Unfortunately, micro-scale sourcing of the lime in lime plaster products to specific quarry sites within a given polity or sub-region would be much more difficult given the relative elemental uniformity of limestone deposits within a geographically restricted area like the Eastern Puuc.

While intra-polity sourcing of limestone may be difficult, multi-elemental analyses of lime plaster compositions have been useful for identifying other societal facets such as distinctions between social groups, the nature of labor organization schemes and the chronology of architectural programs. In their study of the lime plaster facades of six buildings at the Piedras Negras site center, Abrams et al. (2012) found that while chemical composition of the lime appeared to be uniform in the construction of each building, there were recognizable differences

in the composition of the plaster between different buildings. They suggested that these discrepancies represented the use of lime calcined from different limestone quarries. In turn they hypothesized that the use of different quarries for different building projects reflected a form of corvée labor in which rulers conscripted different social groups to contribute labor to various construction programs in the site center.

Researchers have also found that certain archaeometric methods allow for the dating of lime plaster samples and thus architectural sequences. Hueda-Tanabe et al. (2004) used archaeomagnetic analyses and magnetic reference curves to accurately date lime plaster floors from Teotihuacan and Tenochtitlan. Other archaeometric techniques such as X-Ray diffraction, cathodoluminescence, stable isotopes analyses, petrography, and scanning electron microscopy have also been employed to identify chunks of burnt lime and carbon within plaster samples. The identification of these burnt lime and carbon samples allows for the direct dating of the construction episode in which the lime plaster is used using radiocarbon analyses (Mathews 2001; Hale 2003; Al-Bashaireh 2008; Chu et al. 2008). Previously believed to be useful only for dating organic materials, the distinctive properties of burnt lime allows for lime plaster to be dated as well. During the lime plaster drying process, the calcium hydroxide slurry hardens and absorbs carbon dioxide (including C-14 atoms) from the air. When the burnt lime in the plaster hardens into reconstituted calcium carbonate, the C-14 begins decomposing and thus comparison can be made in the ratio of C-14 to N-14 in the samples of burnt lime identified within lime plasters (Hale 20013; Chu et al. 2008).

There has also been much research dedicated to the composition of lime plasters in both the Old and New Worlds. Conservationists study what types of aggregates and binders were mixed with burnt lime in pre-modern times not only to understand the characteristics of ancient

technologies and knowledge, but to better inform modern consolidation and preservation efforts as well (Elsen 2006; Michoinová and Rovnaníková 2008). The Prehispanic peoples of Mesoamerica mixed many different organic and non-organic materials with slaked lime to produce plaster and mortar (Littmann 1959, 1960, 1966; Perez Castellanos 2009; Bedolla Arroyo 2010). In Mesoamerica, aggregate materials have been found to include bark extracts (Littmann 1960), nopal cactus pulp (Perez Castellanos 2009), soil, clay, volcanic ash, crushed volcanic rock (Hueda-Tanabe et al. 2004; Bedolla Arroyo 2010), crushed *sascab* (Abrams et al. 2012:1649), and quartzite sand particles (Magaloni 2010:56). In China, historical binders and aggregates have included sticky rice soup, vegetable and fruit juices, egg whites, and animal blood (Yang et al. 2009). Analyses of lime plaster from a 7th-century CE site in Gujarat, India indicate that burnt lime was mixed with sand at a ratio of three-parts sand to one-part lime (Karanth et al. 1986).

The Phoenicians developed the type of mortar known as 'cocciopesto,' which includes aggregates of sand and brick fragments (Zendri et al. 2004), and influenced the continued use of sand as an aggregate throughout the Mediterranean area (Fodde 2008). The Romans took lime mortar to a new level of durability by mixing lime powder with volcanic ash to create the first widely used concretes (Al-Bashaireh 2008:26). Similar studies of aggregate and binder mixtures in the New World have demonstrated that Mesoamericans were also constantly experimenting with different materials in pursuit of higher quality lime products. Recently, Celine Gillot (2014) identified the use of pozzolanic lime mortars at the Maya site of Río Bec in the southwestern Yucatán Peninsula, which demonstrates that this technology did exist at least in some sub-regions of the Prehispanic Maya area. The inclusion of relatively fresh volcanic crystals in ceramics and plasters from around the Maya lowlands indicates that volcanic ash falls blanketed the broader Maya area intermittently over the previous millennia. Geological and meteorological

studies have demonstrated the likelihood that volcanic eruptions in the highlands of Guatemala and Chiapas could have dispersed volcanic ash as for north as the northern Yucatán (Gunn et al 2002:310-311; Ford and Spera 2007:114). The 1982 eruption of the El Chichón volcano in Chiapas demonstrated the feasibility of ash from the southern highlands spreading throughout the Yucatán for use in concrete and/or ceramic production (Macias 2007:213-214; Gillot 2014:6). Today, a material called Portland Cement, a type of artificial hydraulic lime invented in Britain in the 19th century, is the most widely used lime-based concrete in the world (Al-Bashaireh 2008:26; Villaseñor 2010:43).

Chapter 5: Methods and Data

There are three main objectives of this investigation: 1) To identify whether the annular structures identified in and around Kiuic were used as pit-kilns for producing lime powder by the Prehispanic inhabitants of the region; 2) To determine whether the annular pit-kilns used wood fuel more efficiently than open-air pyre methods of production; and 3) To development a model for the socioeconomic organization of the lime production industry. In this chapter I present three main hypotheses formulated to address these research questions, and the methods that I employ to test them. The first hypothesis is fairly straightforward and provides the foundation for investigating the other two. In the second section of the chapter I describe the types of datasets that I use in the investigation.

Hypotheses and Methods

Hypothesis 1: Annular structures were used as pit-kilns to produce lime from limestone.

I developed this first hypothesis after noting evidence of burning in and around the annular structures during preliminary observations. Also, there appeared to be a correlation between the locations of the structures and the locations of surface quarries. If the excavation data indicate that the annular structures were used as kilns to produce lime, it would provide the foundation for the rest of the study's arguments. As discussed earlier, although ethnohistoric evidence indicates the use of open-air pyres to burn limestone down into lime powder, lime kilns have only been identified at a handful of Prehispanic Maya sites to date. Regardless of whether this reflects an actual absence of kilns or is the result of limited archaeological investigations, the

identification of annular structures as lime pit-kilns would mark one of the few positive identifications of Prehispanic lime kiln technology in the Maya area.

I tested my first hypothesis through a systematic excavation program followed by isotopic, multi-elemental, and contextual analyses. A sample of nine annular structures was chosen for excavation from 53 structures identified in the study area. These nine structures spanned the inner, intermediate, and outer zones of the Kiuic polity. They included structures located within residential compounds, outside compounds, and others that were fairly isolated from other archaeological features. The main goals of the excavations were to uncover the original forms of the annular structures, record any visual evidence of burning episodes within the structures, and gather materials for laboratory-based analyses. If the surface rings of the annular structures were found to surround central depressions with evidence of burning on the interior walls this would support the hypothesis that they were used to cook materials, possibly in a pit-kiln-like fashion. Additional evidence for burning would include burnt ceramic sherds, pieces of charcoal, and/or ashes mixed in with the soil. If I recovered materials related to lime production such as *chich*-size pieces of limestone, burned or partially-burned small pieces of limestone, lime powder, calcined lime, and/or lime plaster or stucco, it would suggest that the firing structure was used for lime production. If these structures were used as kilns but not specifically for the production of lime, I would still expect to find evidence of burning such as ash, charcoal and burnt earth within the annular structures. However, instead of materials related specifically to lime production, I would find other materials such as ceramic wasters, food residues, and/or a plethora of other materials.

The excavations of the annular structures followed the same procedures used by the other sub-projects subsumed within the Bolonchén Regional Archaeology Project. First, the annular

structure and its immediate surroundings were cleared of vegetation. Next, a grid was set up that encompassed the entirety of the annular structure and part of the surrounding context, dividing the excavation area into 2 m by 2 m squares. After the grid for the first annular structure proved to be unnecessarily large, I changed the extent of the grid for Annular Structures 2-7 to encompass only the extent of the annular structure and used test-pits to obtain contextual reference material. For Annular Structures 8 and 9 I returned to a more extensive grid system in order to better understand the forms and construction stages of these structures. Once the grids were in place, workers collected any cultural materials from the surface of the grid area, and then 3-5 teams of two workers excavated each square of the grid one level at a time. Levels were determined at first by arbitrary 15 cm intervals and then by visible changes in the makeup of the soil and fill of the unit. Using unit excavation forms, I recorded the depth below the datum of each corner and the center of the unit at the start and finish of each level. I also noted any cultural and natural features encountered, as well as changes in the fill. I took photographs of all of the units before and after excavation of each level, and sketched the architectural features in order to record both floor, wall profile and cut views of the annular structures.

Aside from the excavation of Annular Structure 1, the central depressions of the structures were excavated independent of the grids as their own excavation pits, or *pozos*. This allowed for the excavation of the entire central depression as one unit and thus maintained a consistent depth below the datum within the structure's walls throughout the excavation process. While excavations of Annular Structure 1 began with the central depression divided among the grid squares, after three excavation levels I combined those parts of the grid that covered the interior of the structure into *Pozo* 1. In addition to the central pit and the units excavated as part of the grid, I also excavated a series of test-pits and test-trenches around some of the annular

structures to gain a better contextual perspective and obtain some comparative materials. Throughout the excavations I recovered several categories of material, including pieces of limestone, *sascab*, reconstituted calcium carbonate (or stucco), ceramic sherds, and soil samples were collected in plastic bags. Charcoal samples were excavated solely using trowels to avoid contamination and sealed immediately in aluminum foil before being placed in plastic bags. Each bag was labeled, recorded and carefully catalogued for storage in the storage facility at the Millsaps Puuc Archaeological Research Center (MPARC) in Oxkutzcab.

By systematically taking apart these ring-like mounds, I was able to better understand their original forms and gain insight into their construction processes, which shed light on how they were used for the burning of materials. In addition to uncovering the basic forms of the annular structures, by excavating to the lowest internal levels of the structures and test-pitting in their immediate surrounding contexts I recovered macro- and micro-artifacts that helped to identify what types of materials were processed within the structures. I also collected soil samples from within and immediately outside the annular structures to compare with control soil samples recovered from locations slightly more distant from the structures.

The second part of the testing program to address my first hypothesis involved a series of laboratory-based analyses on the materials recovered from the excavations. Working with Dr. James Burton, director of the Archaeological Chemistry Laboratory at UW-Madison, I performed stable carbon- and oxygen-isotope analyses and inductively coupled plasma-optical emission spectroscopy (ICP-OES) of the limestone, *sascab*, and soil samples. The carbon- and oxygen-isotope tests were used to determine whether the samples of *sascab* recovered from within the annular structures were naturally occurring *sascab* or reconstituted calcium carbonate. If the specimens are determined to be reconstituted calcium carbonate, this would indicate that

the annular kilns had reached at least 800° C for at least 20 hours, the necessary temperature and duration to calcine limestone into quicklime. The resulting quicklime was likely slaked in situ to form hydrated lime powder and then removed for use. Any remaining hydrated lime would eventually become a slurry after extensive rainfall episodes. The plaster would then dry and harden into a layer of pure lime plaster that resembles *sascab* in appearance and texture. The temperatures and cooking duration necessary to calcine limestone are far greater than those necessary for cooking foodstuffs in a pit oven or *piib*. Ethnographic research of *piib* use has shown that even the longest duration cooking episodes do not last more than eight hours and the lower quantity of fuel used would not maintain temperatures consistently hot enough to calcine limestone (Salazar et al. 2012).

The stable carbon isotope analyses measured the ratio of C^{13} to C^{12} isotopes (or $\delta^{13}C$) in the *sascab*/plaster samples. Previous studies (Létolle et al. 1992; Murakami et al. 2013) have demonstrated that the $\delta^{13}C$ level in naturally occurring limestone is generally close to $0‰$ while the $\delta^{13}C$ level in lime plasters (i.e., lime that has recarbonated into calcium carbonate) is much lower. This is due to the fact that natural limestone was formed under ancient oceans and absorbed CO_2 isotopes from water. Reconstituted calcium carbonate has gone through a process in which it loses its original CO_2 isotopes and absorbs new CO_2 isotopes from the air (Létolle et al. 1992; Burton, personal communication 8/12/15). Depending on the degree of decalcination or decarboxylation of the original limestone, lime plasters may have a $\delta^{13}C$ level as low as $-21‰$. A similar phenomenon is observed in the ratio between O^{16} and O18 (or $\delta^{18}O$), where the lower the level equals the greater the amount of decarboxylation and then recarbonation of the materials (Létolle et al. 1992; Murakami et al. 2013). Thus, if I found that the limestone and *sascab* samples had low $\delta^{13}C$ and $\delta^{18}O$ levels, it would indicate that the materials had been

reconstituted as calcium carbonate. This in turn would suggest that they had previously existed as quicklime (CaO) and then lime powder ($Ca(OH_2)$) before hydrating and recarbonating into calcium carbonate ($CaCO_3$), meaning that the firing episode within the annular structure had reached kiln-like temperatures.

Inductively coupled plasma-optical emission spectroscopy (ICP-OES) involves heating the sample to a very high temperature to the point where the elements within the sample emit characteristic colors. The light emitted by the elements in the sample is then focused on a monochrometer and captured by a detector that records the intensity, and therefore the amount, of each element present (Price and Burton 2011). I used ICP-OES on limestone, *sascab*, and soil samples to determine the following: 1) Whether high levels of ash were present within the kiln, which would further provide evidence for burning episodes; 2) Whether the *sascab*/plaster samples had high or low levels of Magnesium, which would provide another way of distinguishing between the natural and the reconstituted material; and 3) To record any elemental anomalies that might indicate the type of fuel that was used in the burning process, or any materials that may have been fired in addition to limestone. Multi-elemental analyses of the soil composition could also indicate what materials may have been mixed with the lime after it was slaked to produce mortar and stucco. Some of the charcoal samples were preserved well enough to distinguish the likely genera of woods used, if not the specific species. Differences in the types of fuel used in different kilns could have had implications for understanding changes to fuel resources and the time period that the kilns were in use as well as provide data to compare with my experimental data.

An additional method for examining the functions of the annular structures was the analysis of their contexts in relation to other archaeological features that may have been related

to the Prehispanic limestone processing industry. I expected that if the annular structures were used as pit-kilns to produce lime they would have been built near other features of the limestone processing industry. These would include limestone quarries, outcrops of the grade of limestone preferred for making burnt lime, piles of *chich*, and/or water storage features. Proximity to other archaeological features would cut the transportation effort for assembling the raw materials necessary for the lime burning process. Quarries and outcrops provided the raw limestone, piles of *chich* likely represent pieces of limestone broken down in anticipation of burning episodes, and water storage features provide access to the water necessary for the slaking process. A correlation with the location of the high grade of limestone known as *saakel bach tuunich* in particular would suggest a link between the annular structures and lime production. Ethnographic data indicate that this type of limestone would have been most desired for making lime. *Saakel bach tuunich* is fairly widespread throughout the landscape, but not evenly so. Thus, a high correlation between the location of annular structures and *saakel bach tuunich* provides another line of evidence suggesting their use for making lime.

If the data indicated there were little or no correlations between annular structures and other features of the limestone processing industry, this would necessitate investigating other possible burning functions for the annular structures. Other possible functions might have included pottery production, food preparation and/or trash burning. Excavation data combined with multi-elemental analyses would be the most productive methods to identify evidence of pottery production. Pottery production would likely have resulted in the discarding of ceramic 'wasters' in the vicinity of the pit-kilns, though ethnographic research in the region has indicated that ceramic producers may have kept production areas clear of these type of artifacts (Arnold, personal communication 7/1/2015). Multi-elemental analyses of soil and rock samples recovered

from within the pit-kilns would be the most viable techniques for addressing the possible burning of food and/or waste materials in the pit-kilns. If it turned out that most annular structures did not exhibit evidence for burning episodes, then I would explore possible alternative functions such as open-air water catchment features or storage pits. The use of the annular structures for burning episodes would necessarily preclude these other functions if the different activities were seasonal endeavors.

Hypothesis 2: Annular structure technology was developed to use fuel more efficiently than open-air pyres.

If the Kiuic annular structures were in fact kilns, the structures could potentially represent a distinct local innovation with implications for resource management strategies. Considering the relatively rapid growth and decline of Puuc society during the Late and Terminal Classic Periods, which included population and construction booms, increased lime production may have stressed local fuel resources. Thus, I hypothesized that the most likely reason for their local development was to conserve fuel during the lime production process. To test this hypothesis, I constructed and fired an experimental annular lime kiln modeled on the Prehispanic structures to produce comparative fuel efficiency data. Additionally, I used charcoal samples and ceramic sherds recovered from the excavation portion of the investigation to develop a chronology of use for the structures. This allowed for an examination of whether annular structure construction and use coincided with the period of demographic and architectural growth.

The first part of the investigation program involved experimenting with lime powder production in order to determine the potential benefits of using the annular structures to produce lime as opposed to using open-air pyres. Through my excavations and archaeometric analyses I

gained insight into the original forms of the annular structures and the types of fuel that were used in the firing process. Based on these findings I oversaw the construction of an annular structure modeled on one form of Prehispanic structure design as far as was practical. I then fired a pile of limestone to produce lime replicating the hypothesized Prehispanic firing process. I recorded such variables throughout the experiment as: the amount of materials and labor needed to construct the annular structure, the amount and types of materials and labor needed to prepare the kiln for firing, the rate at which the fuel was used, the total amount of fuel necessary, the temperature of the kiln throughout the firing process, and the time necessary to calcine the limestone into lime. The firing produced a series of data that I could then compare with the results of experimental open-air pyre calcination recorded by Morris et al. (1931) at Chichén Itzá, Russell and Dahlin (2007) at Mayapán, and Gallareta and Ciau at Labná (2003). By comparing these datasets, I was able to address the issue of whether the annular structure did indeed represent a technological innovation that improved fuel and labor efficiency with regard to lime production in the Puuc, which would provide a possible motivation for its development.

The second key to testing this hypothesis involved obtaining data concerning the time period in which the annular structures were built and used. To address this temporal aspect of the development and use of the annular structures, I recovered ceramic and charcoal samples from within and around the annular structures. Ceramic chronologies from this area of the Puuc allow for the dating of archaeological features to a general time period, such as: the Early Classic Period (Chiic Complex: ~300-600 AD); the Mid-Late Classic Period (Yuc Complex: ~600-800 AD); the Terminal Classic Period (Ceh Complex: ~800-950 AD); and, the Postclassic Period (Zodz Complex: 950-1300 AD) (Kohut 2015; Gunn 2015). Dating charcoal samples recovered from within and around the annular structures would provide an even more detailed diachronic

assessment of the use of annular structures and thus provide indirect evidence regarding the growth and decline of the local lime production industry. Knowing when the kilns were in use would help inform such issues as whether the annular kiln technology developed at a time of environmental stress in the Bolonchén district. If the development of annular structures correlated with a period of ecological stress, this would suggest another possible motivation to discover more resource-efficient techniques for lime production.

I would also expect that if the Prehispanic inhabitants of the Puuc relied more heavily on annular structures for lime production due to concerns for fuel conservancy, then my experimental annular kiln would be more efficient for lime production than the standard open-air pyre with regard to at least one of the following variables: total fuel consumption per total product output, total labor hours required per total product output (including multiple firings), and/or total time required for production per total product output. If the annular structures were not more efficient than open-air pyres for producing lime from limestone, then I would expect that my experimental annular kiln would not prove to be more efficient with regard to any of the variables tested. If radiocarbon and ceramic dating results proved to be inconclusive or the dates did not match up with the Late and Terminal Classic periods, then I would reevaluate the possible primary motivations for the development of the annular kiln technology.

Hypothesis 3: The lime production industry was decentralized.

Finally, I drew on the widespread and disparate locations of the annular structures throughout the community to hypothesize that lime production was largely decentralized. Based on more intensive spatial and contextual analyses, I expected to find that certain corporate groups controlled access to specific lime kilns and may have been able to meet their own lime

consumption needs. If the lime production industry were largely decentralized with no specific groups completely controlling production, I would expect to find a fairly even distribution of annular structures throughout the study area. I would also expect that there would not be any clustering of annular structures in or around the public architecture of the site center or even away from the site center that would be more easily controlled or overseen by central authorities. Additionally, I would expect for there to be no storage structures in the vicinity of the public architecture of the site center that may represent locations for the storage of lime surpluses. The absence of these overt markers of centralized control would not preclude central government or elite oversight of certain pre- and post-production stages of the lime processing industry. I also use the spatial and contextual analyses to search for patterns in annular pit-kiln distribution that provide more details as to the socioeconomic organization of the lime industry.

To test this hypothesis, I analyzed the spatial and contextual characteristics of the 53 annular structures identified within my study area compared with the residential and public architectural compounds. Using proximity and contextual spatial analyses, I examined the spatial organization of the lime production industry to ascertain whether specific corporate groups may have controlled lime production or at least access to specific annular pit-kilns. The nature of control over lime production has implications for the forms of economic exchange that might have been in use in the Prehispanic Kiuic community. For example, a large proportion of the annular structures located in close proximity to certain but not all residential compounds would indicate that certain corporate groups produced lime while others did not. Knowing that these non-lime producing groups required lime for at least dietary and architectural purposes, they had to acquire the lime from the lime-producing groups. Restricted production of craft materials used by all members of the community would suggest some sort of exchange system was in place in

the Prehispanic Kiuic polity for lime distribution. If the annular structures were found to cluster around or within public architectural compounds, this might indicate direct control of the lime production industry by the community's governing authorities and thus reflect a centralized redistribution system. However, proximity cannot be seen as an explicit indicator of control and this issue is addressed in more detail in Chapters 8 and 9. Furthermore, different grades of limestone produce varying grades of lime powder and spatial correlations between annular structures and outcrops of certain grades of limestone, especially *saakel bach tuunich*, may indicate the purposeful location of annular structures near the necessary raw materials for lime production.

Annular structures located within or nearby to elite residential compounds were most likely either operated by or at least overseen by the residents of that compound. Annular structures located in close proximity to lower status residential compounds were conversely most likely operated, if not owned, by residents of these compounds. It is also possible that several households shared access to annular structures located in their midst. Small corporate groups would most likely have required only one lime-producing kiln to supply their annual lime consumption needs. If multiple annular structures were identified within close distance of one or a few residential compounds, this would suggest that the pit-kilns might have been used for other purposes instead of or in addition to lime production or that these corporate groups were purposely producing surplus lime for exchange. This would have further implications for the organization of the lime industry in relation to domestic and political economies in the Kiuic polity.

It is more difficult to tease out the social significance of the annular structures that are far removed from any residential context. It is possible that these structures, such as the two

outer zone structures excavated during the 2014 field season to the west of the Kiuic valley, were operated on a seasonal basis and temporary camps may have been constructed nearby during the dry season. Another possibility is that small-scale corporate lime production operated in a similar way to salt production in Aztec Central Mexico, where workshops were located far from residences out of necessity and to reduce the hazards of production (De León 2009). Those elite residential compounds located close to the public and palatial architecture of the site center likely maintained stronger social ties to the governing authorities of the site if they themselves were not in fact the governing authorities. While it would be incorrect to correlate distance from the site center directly with degree of control over production, it is likely that lime production at annular structures located farther away from the site center were more difficult to regulate.

To address the labor, resource use, and potential small-scale corporate self-sufficiency aspects of the burnt lime industry organization, I estimated the production and consumption rates for the small corporate group that occupied the Pixoy architectural compound immediately to the northwest of the site center. Elliot Abrams pioneered work on architectural energetics, "the quantification of cost of construction of architecture into common units of comparison," or "energy in form of labor expenditure," (Abrams 1994:2) in the Copán Valley. Working off of the analytical 'architectural energetics' method developed by Abrams, and incorporating ethnographic data gathered by Russell and Dahlin (2007), I quantified the time and labor investment devoted to the extraction and processing of limestone. I estimated the capacity of the Pixoy annular structure and tallied the quantity of architectural features within the Pixoy Group. I combined these with ethnographic estimations of lime consumption for dietary and construction purposes to estimate how many lime production episodes were required to meet internal corporate group lime consumption needs.

I also used ethnographic and experimental data related to limestone processing to provide additional lines of evidence for understanding the organization of the lime production industry. I expected that the ethnographic data would be able to identify the most desirable grades of limestone for producing lime and that I would then be able to observe a correlation between the locations of annular structures and the high-grade outcrops. This would indicate an in-depth knowledge of minor variations in limestone composition and hence the ability to identify different grades limestone. While it was impossible to directly apply these ethnographic data to Prehispanic contexts, they provided the closest modern analogues for the Prehispanic burnt lime industry. Thus, the ethnographic information could provide indirect insights into the degree of skill and knowledge required to efficiently produce lime. The experimental construction and firing of a lime kiln modeled on the Prehispanic annular pit-kilns provided additional data with which to evaluate the organization of the Prehispanic industry, especially with regard to labor and resource consumption requirements.

Alternative Hypotheses and Outcomes

Preliminary studies at Kiuic have indicated that the annular structures did serve a pyrotechnological function, even if excavations did not turn up evidence of lime production specifically (Gallareta Negrón et al. 2014). Excavations of similar annular structures at Oxkintok (Ortíz Ruíz 2014) and Sayíl (Sabloff and Tourtellot 1991; Dunning 1991) have uncovered evidence for lime burning within. Possible alternatives to limestone burning include cooking other materials such as ceramics, refuse, and/or foodstuffs, or ritual activities requiring fire. Any burning-related function would establish the annular structures as a distinctive pyrotechnological invention in the Puuc region, and would demonstrate the importance of this adaptation for

managing fuel resources. Therefore, whether or not the annular structures were used to cook limestone, food, ceramics or other materials, the investigation of this special oven or kiln technology increases our understanding of Prehispanic Maya technology and resource management.

If the annular structures were not pyrotechnological in nature, their distinctive form and prevalence in the Puuc region would still indicate that they were an important feature of the local Prehispanic sub-regional culture. Alternative possibilities for their function include use as storage facilities for water, maize, or other environmental resources, or as residential or ceremonial structures. Investigation of the former set of alternatives has implications for daily life in the Puuc and resource management, while the latter would increase our understanding of an impressive and potentially local architectural tradition. Therefore, even if evidence does not support the lime kiln hypothesis, a thorough investigation of the structures and their surrounding contexts would still yield novel information regarding a significant aspect of Prehispanic Puuc culture and contribute to our growing understanding of sub-regional variation within the broader Maya area. I discuss the viability of these alternative functions further in Chapter 8 in relation to the data gathered during the investigation.

If this kiln technology was not unique to the Puuc then a systematic study of the functions and forms of the annular structures could provide beneficial information regarding the lime industry throughout the Prehispanic Maya world. If a review of the published literature indicated that the structures were uniquely prevalent in the Puuc, but the experimental annular kiln did not prove to be more fuel- and/or time-efficient than open-air pyres, I would explore other possible reasons for their invention. Other possible explanations include their use for combatting high

winds during the firing process or providing a more efficient method for hydrating the calcium oxide into calcium hydroxide following the firing process.

A final factor that needs to be considered is that some lime producers in the Late and Terminal Classic Kiuic community may have still used the open-air production technique alongside the annular pit-kiln method. This would affect the inferences that I draw about the economic organization of the lime production. Russell and Dahlin (2007) argue that based on their study of lime production at Mayapán aboveground pyres would leave a "readily identifiable" (Russell and Dahlin 2007:421) archaeological signature of partially burned stones, charcoal and ash most likely arranged in a 5-7 m-diameter circle. If these areas were repeatedly used, traces of plaster and/or slaked lime would build up over time. They identified seven such lime production locales on the outskirts of Mayapán. If lime production areas would be truly as easy to identify as Russell and Dahlin claim, then they would most likely have been identified during the Labná-Kiuic inter-site survey that involved ground-truthing of the entire corridor. However, the lack of identification of these larger, repeated use sites does not mean that small-scale producers were not firing limestone using smaller, more ephemeral above-ground pyres. These smaller-scale burns would be very difficult to identify in the archaeological record, even with intensive and extensive survey ground coverage. I include the possibility of multiple production techniques in my discussion of the socioeconomic organization of lime production in Chapters 8 and 9.

Datasets

In this section I describe the four main types of data used to test my hypotheses regarding the functions of the annular structures and the organization of the lime production industry.

These include: spatial and contextual data provided by Gallareta Negrón and colleagues' (2014) inter-site survey; excavation data uncovered from the systematic investigation of nine annular structures; experimental data generated from the construction and firing of an annular kiln modeled on the Prehispanic structures; and ethnographic data regarding local knowledge and practices surrounding limestone processing.

The Labná-Kiuic Inter-Site Survey

The 9 km^2 inter-site survey completed by Gallareta Negrón and colleagues (including myself) between the archaeological sites of Labná and Kiuic provides the starting point for many of my analyses (Gallareta Negrón et al. 2014). Firstly, the survey identified the locations of the 53 annular structures that are the main focus of my project and provided the data for choosing a representative sample of nine structures for excavation. My study area is the part of the inter-site survey that would most likely have been part of the Prehispanic Kiuic polity. As discussed in the previous chapter, I divided my study area into inner, intermediate, and outer zones based on distance from the ceremonial site center, discrepancies in architectural concentrations, and on topographic distinctions. The geographic divisions also reflect differences in the prevalence of annular structures (Table 4-2). In addition to the annular structures, the survey identified hundreds of other archaeological features such as residential architecture, quarries, and cisterns that provide data for my spatial and contextual analyses of the socioeconomic organization of the lime industry (Table 5-1). Several of the Prehispanic features identified during the survey were likely related to the lime production industry. These features include the following:

1) The aforementioned annular structures, which are hypothesized to be lime kilns and are the central focus of this study.

2) Limestone quarries and *sascaberas* (quarries of a specific type of softer, whiter limestone found below the uppermost layer of bedrock). While more difficult to distinguish amidst the forest overgrowth, large limestone quarries are visible where sections of limestone outcrops have been cut away and/or cave-like overhangs are present. Quarries normally take circular or semi-circular shapes, while *sascaberas* are most often visible as holes or caves that penetrate the uppermost layer of bedrock to access the softer stone below. These quarries served as the fount for the literal building blocks of the Prehispanic edifices as well as the raw materials used to produce lime powder. The proximity between quarries and annular kilns is one of the lines of evidence used to suggest their use in lime production.

3) Piles of *chich*, or small limestone rocks. These piles may appear as natural features at the base of hills in the Puuc region, as small pieces of limestone have been dislodged from the hillsides and rolled down to accumulate into mounds at the bottom. *Chich* piles that occur away from the base of a hill are not natural features and were therefore constructed or modified by human agency. These human-constructed *chich* piles may appear as isolated features or in groups of as many as 20 mounds. One of the main reasons for accumulating small limestone rocks into a pile is to prepare to use them for some sort of construction or lime production activity. *Chich* was used for such purposes as the construction fill for platforms and double-walled structures and the fist-size and smaller pebbles were burned down to create lime powder. Thus, the identification of *chich* piles located away from the bases of hills throughout the survey area would indicate the presence of activities related to the Prehispanic construction industry, and when viewed in combination with other lime industry features would represent another way to shed light on the organization of Prehispanic lime production.

Table 5-1: Table showing the number totals for the different archaeological and topographic features identified in the study area.

Type of Feature	**Outer**	**Intermediate**	**Inner**	**Total**
Annular Structure	11	35	7	53
Quarry	4	11	3	18
Sascabera	0	11	2	13
Chich Mound(s)	10	6	0	16
Haltun	3	0	1	4
Residential group w/ at least one vaulted structure	0	6	21	27
Residential group w/o vaulted structure	0	30	24	54
Total	28	99	58	185

4) *Haltúns* or *chultúns*, which are both sources of water. *Haltúns* are natural depressions in the surface bedrock that fill with a measure of standing water during the rainy season. *Chultúns* are human-made reservoirs used to collect water during the rainy season for use during the dry half of the year. While the process may take place naturally through absorption of water vapor from the air, water in one form or another is necessary for slaking the quicklime produced from the calcination of limestone. The proximity of *haltúns* and/or *chultúns* to hypothesized lime production areas would indicate whether the industry was a seasonal enterprise, dependent upon a stored water supply, or potentially a year-round initiative taking advantage of naturally occurring water sources.

5) Though not human-made or –modified features, limestone outcrops were important features of the landscape related to the lime production industry. While the the members of the Labná-Kiuic inter-site survey did not specifically note the locations of the high-grade limestone known as *saakel bach tuunich*, I recorded whether or not there was a *saakel bach tuunich* outcrop close to the annular structures that I surveyed in my study area. Based on my

ethnographic interviews with local workers, *saakel bach tuunich* appears to be widespread throughout the landscape, though not necessarily evenly distributed. Thus, identifying the proximity of *saakel bach tuunich* outcrops to annular structures was particularly important for linking the pit-kilns to the lime production industry.

Excavation and Archaeometric Data

Throughout the excavations of the nine annular structures and their contexts, I focused on collecting several categories of artifacts and ecofacts. These materials included: limestone, *sascab*, and stucco samples; ceramic sherds; charcoal samples; and soil samples. Each of these materials could be used to shed light on the functions of the annular structures and the processing of resources. In addition to the recovery of artifacts and ecofacts, the excavations provided evidence of the construction forms of the various annular structures. Excavating the surface walls of the structures as well as their central depressions led to the discovery of a wide variation in the shapes and sizes of the annular structures in and around Kiuic. This allowed for the investigation of the relationship between annular structure form and such factors as socioeconomic status, possible alternative functions, and distance from the inner site center.

Following the excavations, I performed a series of analyses on the limestone, stucco/*sascab*, soil, and charcoal samples recovered from the annular structures. I used Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) to analyze the elemental compositions of the limestone and soil samples in the University of Wisconsin-Madison Archaeological Chemistry Laboratory. I sent stucco/*sascab* samples to the Environmental Isotope Laboratory at the University of Arizona for stable oxygen and carbon isotope analyses in order to determine whether the samples were naturally occurring *sascab* or reconstituted calcium

carbonate. I also consulted with Dr. Christopher Morehart at Arizona State University to try to identify the species of trees represented by my eleven charcoal samples. Finally, I sent six charcoal samples to the Accelerator Mass Spectrometry Laboratory at the University of Arizona to be radiocarbon dated. These combined archaeometric analyses provided evidence that the annular structures were used as kilns for producing lime during the period of increased population and construction activity at Kiuic. An in-depth description of the excavations of the nine selected annular structures is presented in the following chapter.

Experimental Data

In order to test the practicality and resource-efficiency of the annular pit-kiln technology, I oversaw the construction of a single-walled annular pit-kiln modeled on the Prehispanic ones excavated during the 2014 field season. The kiln experiments produced crucial data regarding: the labor time required to construct a simple annular structure; the collection and assembly of materials necessary for a firing episode; the duration of a firing episode; fuel-efficiency rates; the generation of smoke pollution; the importance of weather and seasonal considerations; the slaking and subsequent collection of the resulting lime powder; the effect of firing episodes on the interior of an annular structure; and the characteristics of partially burned pieces of *chich*.

All of these data were then compared with the data generated by the aboveground pyre firing episodes reported by Morris et al. (1931), May Ciau and Gallareta Negrón (2003) and Russell and Dahlin (2007). A comparison of the variables from these disparate datasets shed light on the possible reasons for developing the annular kiln technology for lime production in the first place, most importantly potential increased resource efficiency.

Ethnographic Data

Ethnographic data concerning local Yucatecan knowledge of limestone grades provided a final line of evidence significant for this investigation of Prehispanic local lime production. These data were used to evaluate the potential familiarity that Prehispanic lime producers may have had with different grades and types of limestone. Obviously, modern knowledge does not equal Prehispanic knowledge, but these data provide the closest thing to emic data to which we currently have access. I gathered ethnographic data from two main sources: the local residents of the contemporary towns of Yaxhachen and Kancab, and the ethnographic fieldwork conducted by Dean Arnold in the region in the 1960s (Arnold, personal communication 7/1/2015). The goal was not to equate contemporary knowledge of limestone processing with that available to local residents over a millennium earlier, but to provide a modern analogue for what degree of expertise *may* have been involved in lime production in the past. This ethnographic research also provided the basis for identifying the *saakel bach tuunich* grade of limestone that is most desirable for making lime. Evaluating correlations between annular structures and *saakel bach tuunich* was a key component of my spatial and contextual investigations regarding lime industry organization.

First, I gathered evidence regarding four general categories of limestone from my excavation assistants from the local towns of Yaxhachen and Kancab. They indicated that these four categories were the only grades of limestone with which they were familiar. The second, more extensive corpus of data was gathered by Dr. Dean Arnold during interviews with local potters in the nearby town of Ticul in Spring 1965 that were familiar with lime production. Although he has not yet published this information, Dr. Arnold was gracious enough to allow me

to incorporate his data into my investigation (Arnold, personal communication 7/1/2015). These data included a full twenty different names for different types and grades of limestone.

Chapter 6: The Annular Structures and Prehispanic Lime Production

Before analyzing the organization of lime production in the Kiuic community it was crucial to uncover physical evidence supporting the hypothesis that the annular structures were indeed used to produce lime. Although relatively shallow Prehispanic lime pit-kilns have been identified in other sub-regions of Mesoamerica (Castanzo 2004; Grove and Guillén 1987), and lime-covered surface depressions have been identified as Prehispanic lime production areas in the Maya area (Redfield and Villa Rojas 1934; Russell and Dahlin 2007), overall there have been relatively few lime kilns identified in the Maya area (Abrams and Freter 1996; Abrams 1996). Similarly, there is neither ethnographic nor ethnohistoric evidence supporting the use of kilns for producing lime by the Maya.

Through the systematic excavation of nine annular structures (Figure 6-1) I recovered the following lines of evidence for their use as lime kilns by the Prehispanic Maya: evidence for multiple burning episodes within the structures, layers of reconstituted lime stucco/plaster near the floors of the structures interspersed with layers of carbon and burnt rock, and the presence of partially-burned pieces of limestone scattered around the exteriors of the structures. Spatial and contextual data gathered during the Labná-Kiuic inter-site survey (Gallareta Negrón et al. 2014) and my own supplementary surveys also support the hypothesis that the annular structures functioned as lime kilns. These combined datasets provided the basis for making inferences about the lime production industry was organized within the Prehispanic Kiuic socio-economy.

In the first section of this chapter I describe the systematic excavations of the nine selected annular structures, and present the data recovered from these research programs regarding their construction forms and contexts. In the second section of the chapter I draw upon

both the excavation data and survey data regarding the other annular structures identified in the study region (Appendix A) to create a working typology of annular structure construction forms. In Chapter 8 I combine the contextual and physical data recovered from these excavations with the spatial and archaeometric data to summarize the case for the annular structures being used as kilns to produce lime.

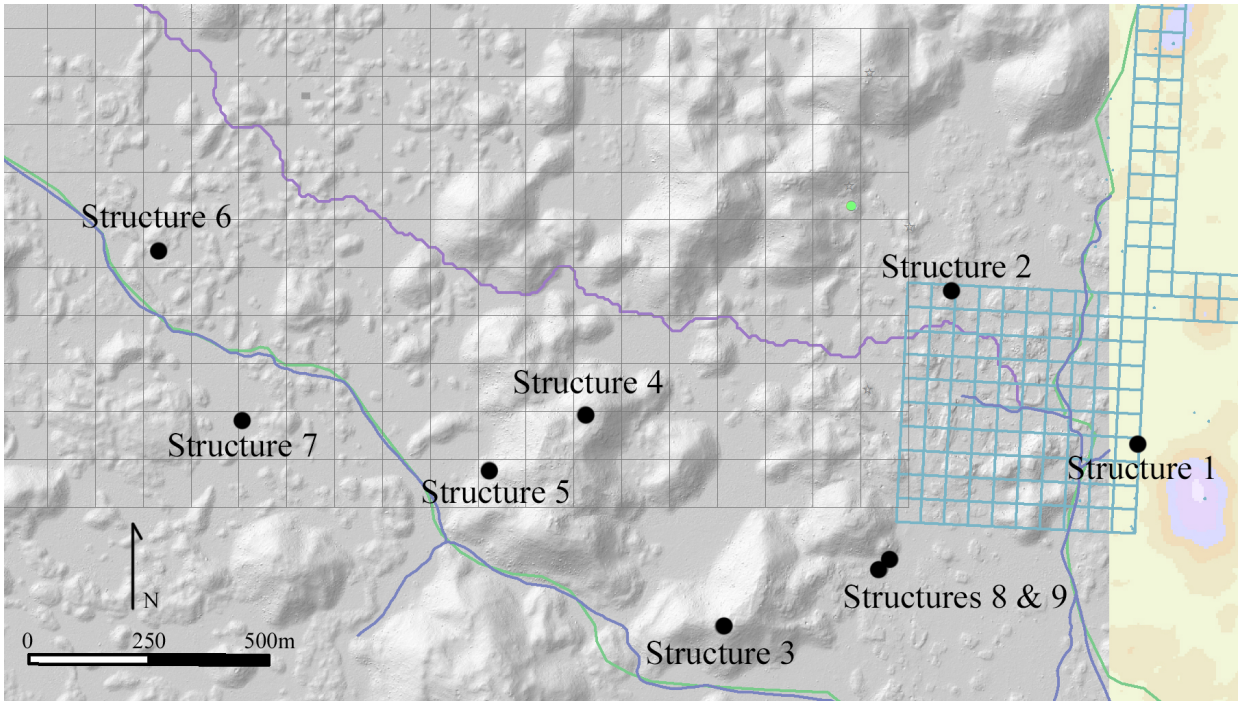


Figure 6-1: Map showing the locations of the nine excavated annular structures (adapted from Gallareta Negrón et al. 2014).

The Systematic Excavations of Nine Annular Structures

Annular Structure 1 (N0880 E1255)

Location: Annular Structure 1 is located in the southeastern sector of the Kiuic site core with reference to the site map created by William Ringle and colleagues in 2001 (Figure 6-2). More specifically, it is located approximately 150 m to the east-southeast of the elite residential Harbin

Group and 250 m to the southeast of the civic-ceremonial Yaxche Group at the site center. It is located on a leveled terrace halfway down the northern slope of a low hill that contains a platform supporting two vaulted structures at its apex immediately to the south. There are other residential groups with vaulted structures located approximately 50 m to the west and north of the annular structure, as well as a vaulted residential complex atop the hill immediately to the southeast of the annular structure. There are also two simple foundations of non-vaulted structures located about 20 m to the east of the structure. A second annular structure (N0795 E1245) similar in size, shape and context is located approximately 70 m to the south, near the base of another slope. A third, much larger annular structure (N0810 E1140) is located approximately 115 m to the southwest of Annular Structure 1.

With regard to the immediate context of Annular Structure 1, a small *sascabera* was located approximately 5 meters to the west on the same hill-slope terrace as the annular structure (Figure 6-3). A test pit was placed within this *sascabera* and there was no evidence recovered for burning within or around this feature. Test pits excavated around the perimeter of the annular structure revealed that the bedrock of the hill sloped alongside and through the annular structure, suggesting that the level terrace on which the annular structure was situated was a human-made or -modified feature along with the structure. A layer of topsoil as thick as 1.2 m mixed with small-to-medium sized stones had accumulated atop the bedrock to the west of the annular structure between the double walls and the small *sascabera*. The hill continued its slope downward to the north and east of the annular structure, reaching a level surface approximately 3 m below the boulders of the structure's double wall. The entirety of the surface of this slope was littered with *chich*-size pieces of limestone, many of which exhibited evidence of having been burned (Figure 6-4). At the base of the slope, the terrain flattened out forming a nearly level area

approximately 50 m wide, which separates the hill-slope of Annular Structure 1 from a vaulted architectural compound to the north.

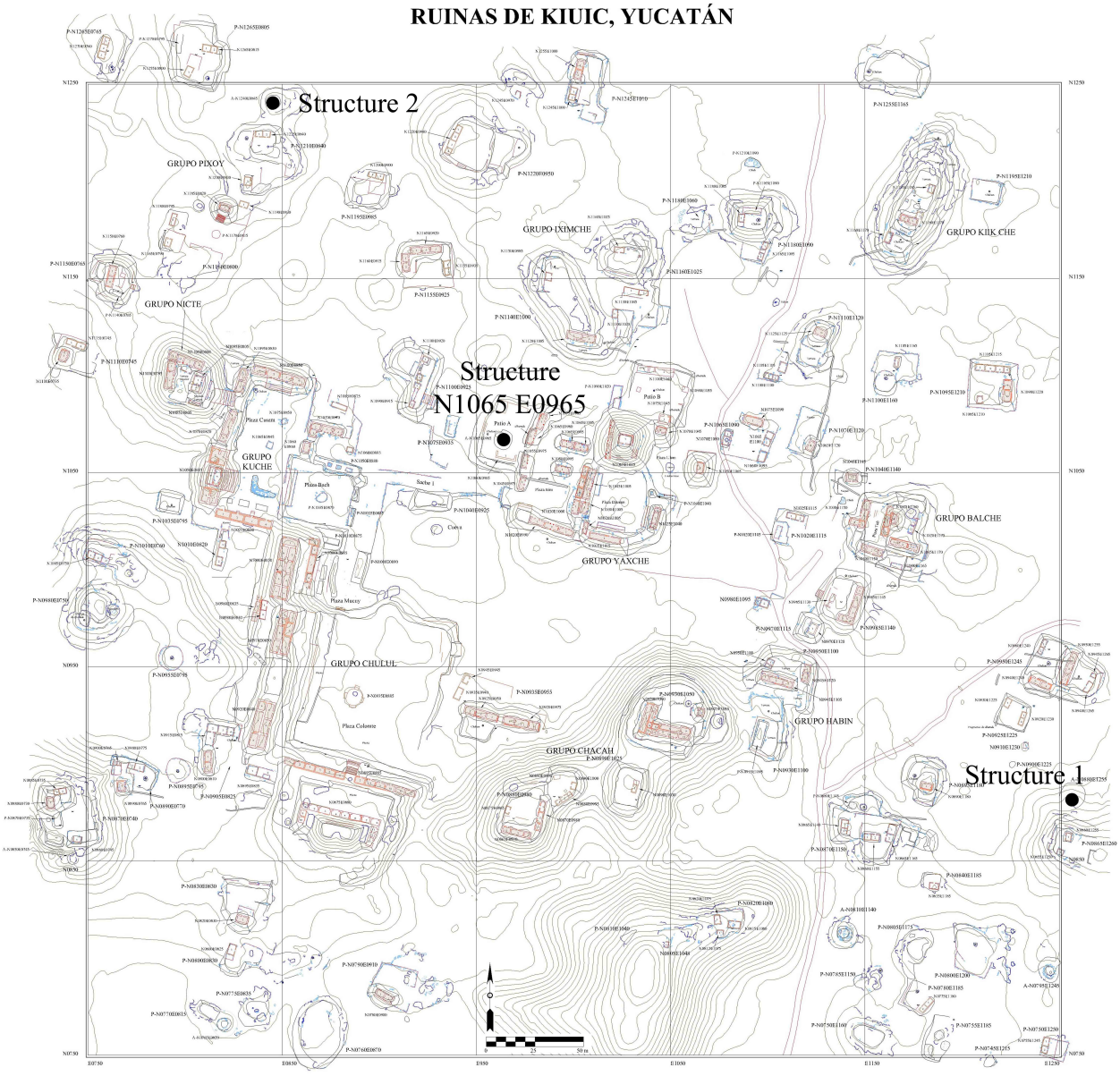


Figure 6-2: Map of the Kiuic site center showing the locations of Annular Structures 1 and 2, and the peculiar annular structure excavated by Stephanie Simms in 2008 (Map by William Ringle and colleagues, Gallareta Negrón et al. 2014).



Figure 6-3: Photograph of the small *sascabera* located immediately to the west of Annular Structure 1.



Figure 6-4: The scatter of burned *chich* that litters the slope to the north and northeast of Annular Structure 1.

Construction Form: The structure possesses a double wall consisting of two concentric rings made up of large coarsely cut boulders (Figure 6-5). The fill in between the concentric rings is made up of medium, small, and *chich*-size stones mixed with earth and ceramic sherds. Due to the slope of the hill, parts of the walls have collapsed, including part of the interior south wall, which has slipped into the central depression of the structure and some of the largest boulders from the exterior north wall, which have fallen down the slope north of the structure. Nevertheless, the original double wall shape of the structure is still visible on its western side, where the concentric arcs of boulders are well preserved. While it is unclear whether other vertical rows of boulders were originally stacked atop the single layer still visible, the quantity of large stones recovered from inside the central depression and around the exterior of the structure suggest that the double walls of the structure originally consisted of at least two layers of boulders. It does not appear that the walls were fit together using any type of mortar, as no mortar-like materials were recovered from around the outside of the ring, nor within the double wall. The diameter of the central depression measures 2.2 m N-S by 2.4 m E-W and the thickness of the double wall varies between 0.75 and 1.25 meters bringing the overall structure diameter to approximately 4-5 meters (Figure 6-6).

Excavation: I excavated Annular Structure 1 in June 2014. A grid was set up that encompassed the entirety of the structure and included parts of the surrounding context. In addition to the grid units, I excavated six additional test pits in order to better understand the context in which the structure was built and used. Excavations in the interior of the structure revealed that below the surface arc of large boulders, the walls of the structure descended almost completely vertically. The walls below the surface arc of boulders consisted of a layer of fill comprised of smaller

boulders and stones mixed with earth (Figures 6-7 and 6-8). One meter below the level of the surface boulders I discovered another smaller ring of boulders with a diameter of about 1.75 m (Figure 6-9). Only the western, northwestern and northern parts of this small ring remained intact, forming a semi-circle that may have been completed by the bedrock wall found in the southern and eastern parts of the pit. Below the layer of fill, the southern and southeastern interior walls consisted of the bedrock of the hill on which the structure is located. Due to the topographic situation, the northern and western walls of the structure arrived at this layer of bedrock at a slightly deeper level and possessed a wider layer of earthen and rock fill between the surface arc and the bedrock. The identification of the smaller ring of boulders and bedrock within the central shaft suggested that the double walled annular structure visible on the surface represented a later phase of construction.



Figure 6-5: Photograph of Annular Structure 1 looking North after the first level of excavations.

The lower bedrock layer of the interior walls was more friable and darker in color than the bedrock found in the outcrops that breached the surface nearby the annular structure suggesting that the interior of the structure was exposed to multiple burning episodes. The evidence for burning continued in the layer of *sascab* and/or stucco encountered below the bedrock, approximately 2.5 meters below the surface ring of boulders. In addition to the continued friability of the walls in the *sascab*/stucco layer, I recovered samples of charcoal that were most likely remnants of an Prehispanic burning episode within the central pit. The first layer of *sascab*/stucco encountered below the bedrock measured between 0.5 and 1 m in width and was very friable. Below the layer of soft *sascab/*stucco was a layer of harder *sascab*/stucco in both the walls and floor of the pit. While the softer layer possessed a slightly grayish tint, perhaps as a result of being mixed with ash, the harder layer was pure white. Samples of the *sascab*/stucco were recovered from the floor and walls of the structure to test whether this material was in fact naturally-occurring *sascab* or reconstituted calcium carbonate.

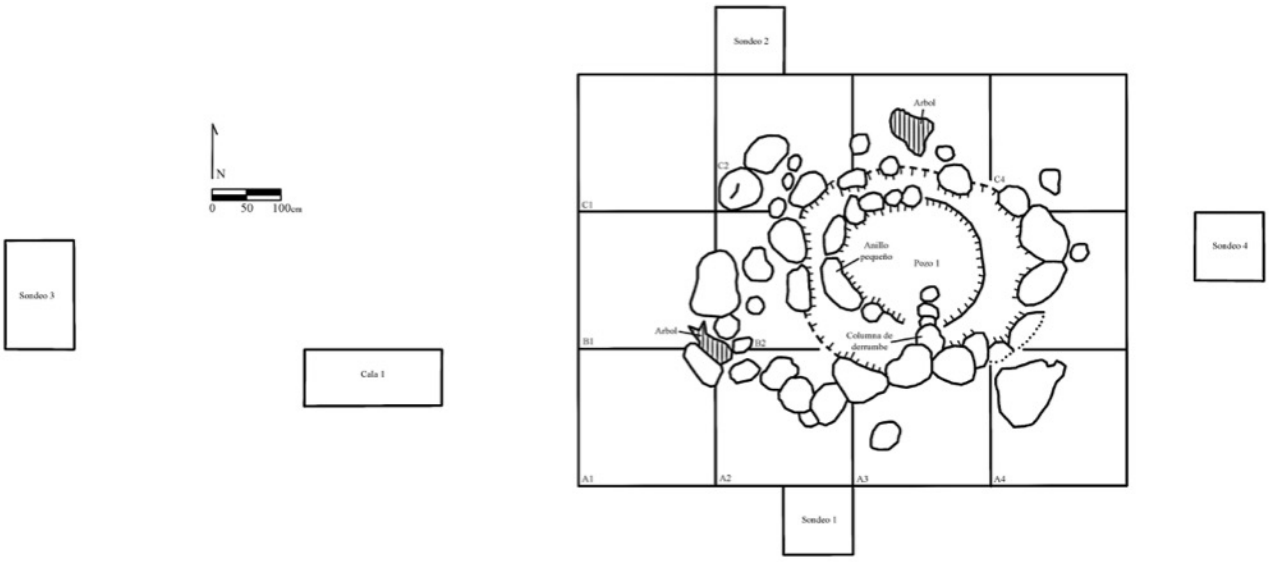


Figure 6-6: Aerial view sketch of the excavation area for Annular Structure 1.

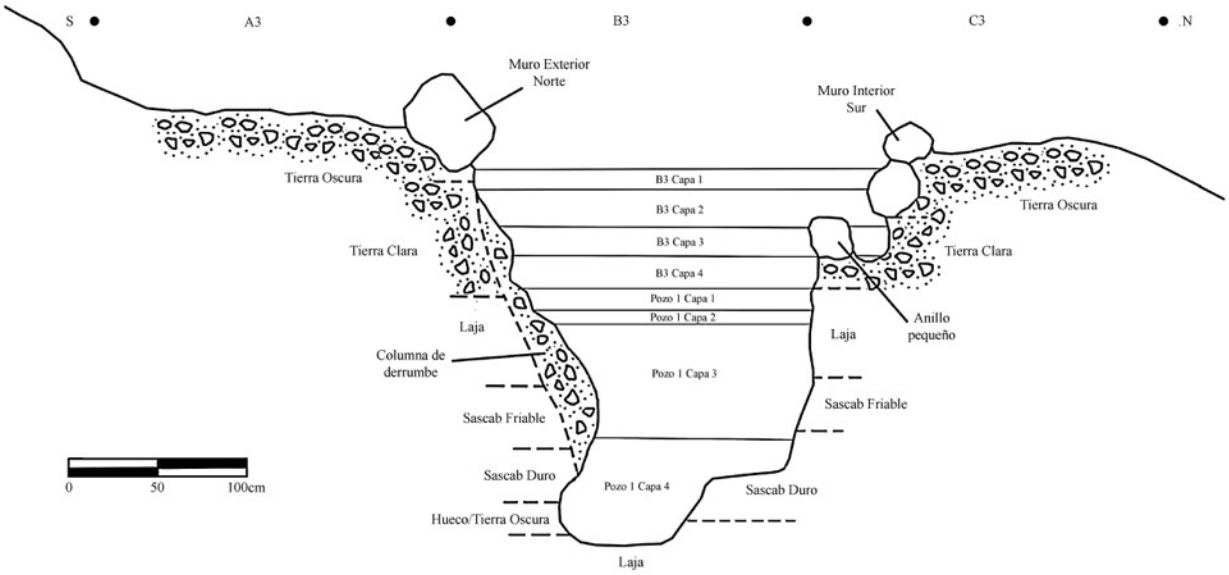


Figure 6-7: North-south profile cut sketch of Annular Structure 1.

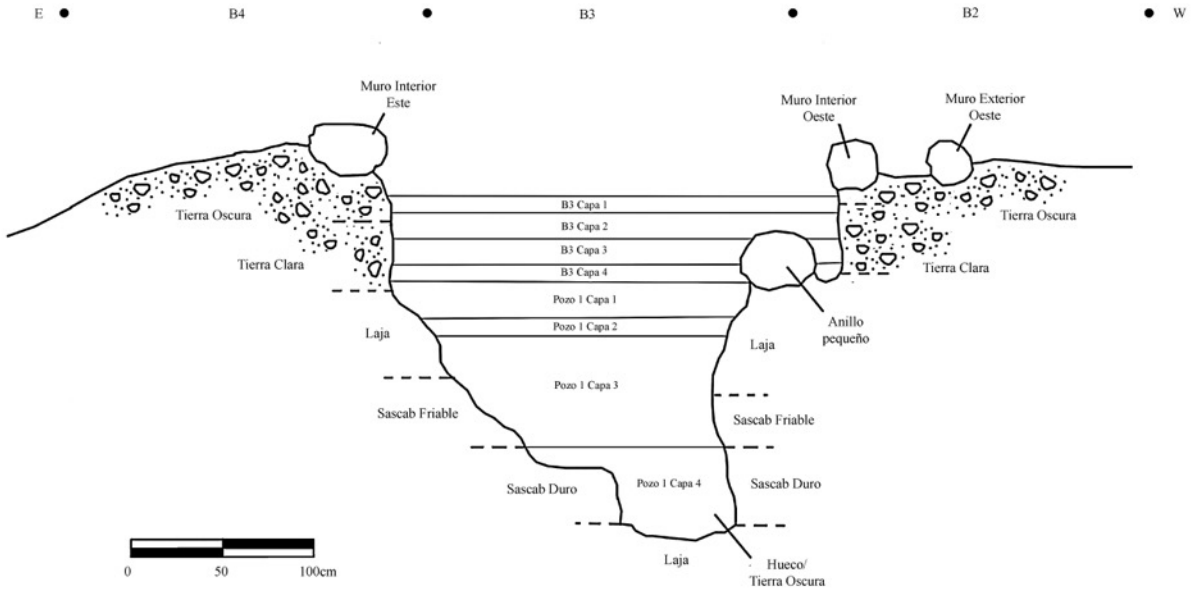


Figure 6-8: East-west profile cut sketch of Annular Structure 1.



Figure 6-9: Photograph of the smaller, original ring discovered below the later phases of construction of Annular Structure 1.

The harder layer of *sascab*/stucco varied between 0.5 and 0.7 m in thickness and maintained a steady level of durability throughout. Excavations through this harder layer led to the discovery of a small hole at the base of the southwestern arc of the inner shaft that represented a part of the central depression that had never been completely refilled. The hole intruded into the northeastern wall of the central depression, suggesting that the original excavators of the central shaft were determined to recover as much *sascab* as possible from the pit. Alternatively, the excavation of this side hole could have been a by-product of firing episodes in which the *sascab* was loosened during firing episodes and then removed to avoid it getting mixed in with the subsequent batch of lime powder. This pattern was observed in several other annular structures. A large amount of ash and blackened earth were encountered in the

hole, which appeared at a depth of 3 m below the surface ring of boulders and continued to a depth of 3.7 m. The black soil might have represented disintegrated pieces of charcoal, as the darkened appearance of the hole provided further evidence for burning episodes taking place in the central depression (Figure 6-10). The fact that this evidence for burning was located below the levels of *sascab*/stucco indicates that the layers of white material encountered above it were in fact reconstituted calcium carbonate. This in turn suggests that temperatures in the pit reached high enough levels for long enough duration to calcine limestone.



Figure 6-10: Photograph of the hole at the northeastern base of the central depression of Annular Structure 1 showing the blackened, burnt appearance of the soil.

Prior to excavation, the surface within the annular structure gradually sloped toward the center of the circle forming a bowl. Excavations in the center of the pit recovered much dark soil near the surface, but the fill became lighter further down in the central depression changing from

dark brown to light brown to light grayish brown until eventually it mixed with *sascab* powder and became more white than brown. The first relatively hard floor was reached at a depth of approximately 3 m below the surface ring in the form of the hard *sascab*/stucco layer. Below the 0.5-0.7 m thick layer of hard *sascab*/stucco, I encountered a second layer of bedrock that represented the original floor and lowest limit of the structure's central depression (Figure 6-11). Throughout the upper levels of the excavation, the fill was mixed with a large quantity of boulders and stones that represented part of the double-ring wall collapse. The fact that several large stones were found in the lowermost layers of the pit, immediately above the layer of hard *sascab*/stucco suggested that the collapse of the interior walls began when the pit still remained open to the air and that over time through either gradual erosion or a series of collapse events, the uppermost layers of the original structure fell in and filled the central depression. Seeing as how the structure was built on the slope of a hill, most likely to take advantage of the hard bedrock to serve as one side of the kiln, natural events such as flooding and/or landslides may have contributed to the infilling of the pit.

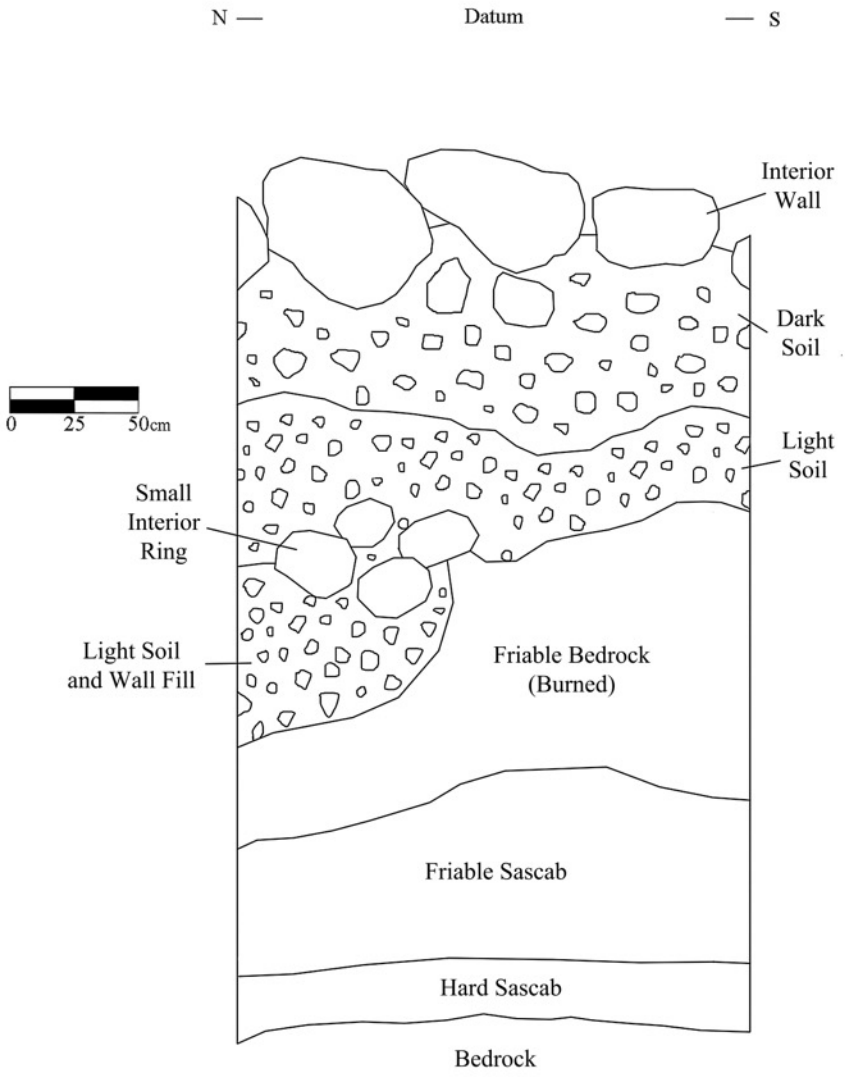


Figure 6-11: Profile sketch of the eastern wall of the central depression of Annular Structure 1.

Annular Structure 2 (N1240 E0845)

Location: Annular Structure 2 is located in the elite residential group known as the Grupo Pixoy in the northwestern sector of the Kiuic inner site core with reference to the map created by William Ringle and colleagues in 2001 (Figure 6-2). I excavated the structure during the 2014 summer field season. The Pixoy Group is notable for including a small pyramid structure, the only other at Kiuic aside from the central pyramid within the civic-ceremonial Yaxche Group.

Annular Structure 2 is located at the northeastern edge of Pixoy, about 15 m to the north of a platform with a vaulted structure and a chultún and 50 m to the north of the small pyramid. There is another platform with two vaulted structures located 50 m to the northwest of the ring structure but it is unclear if this platform group should be included as part of the Pixoy Group or another adjacent residential complex. A large quarry (15 m long by 10 m wide) is located less than 8 m to the northwest of the annular structure and the proximity suggests a link between the two features (Figure 6-12). Additionally, a small *haltún* (a natural depression in the bedrock that seasonally fills with water) is located approximately 7 m to the northeast of the annular structure. Water collected in the *haltún* could have been used to slake quicklime produced in the annular structure, especially if the goal was to produce large quantities of lime in a relatively short period of time and waiting for absorption of natural moisture was not an option. Taken together, the annular structure, the quarry, and the *haltún* might be viewed as a lime powder production complex and the presence of the quarry and *haltún* might have factored into the decision to construct the annular structure in this part of the Pixoy Group.

Construction Form: Another factor influencing the location for the construction of the annular structure may have been the natural topography of the area. The structure was built at the edge of a limestone outcrop with high concentrations of *saakel bach tuunich* and the highest part of the annular structure's ring is approximately 2.75 m higher than the flat land surrounding the outcrop to the west and north. The surface around the structure slopes away to the north, west and southwest, while the outcrop continues at an elevated level to the east and southeast. Similar to Annular Structure 1, the central depression of Annular Structure 2 was cut into the side of a bedrock slope presumably to take advantage of the bedrock for use as one side of the interior of

the structure. In the case of Annular Structure 2, the southern and eastern interior walls were mainly cut from the bedrock of the limestone outcrop (Figures 6-13 and 6-14). Also similar to Annular Structure 1, the Pixoy annular structure was constructed of a double wall of large rough-cut boulders on the surface. On the southern and eastern sides where the bedrock was closer to the surface, the boulders of the double ring were placed directly on top of the bedrock, while several vertical rows of boulders formed the double wall on the sloping sides.



Figure 6-12: Photograph of the quarry located just to the northwest of Annular Structure 2 in the Pixoy Group.

The northern and western interior walls of the structure consisted of multiple layers of medium and large size boulders, the base level of which rested atop the bedrock at a lower depth (Figure 6-15). The exterior of the double walls also possessed multiple vertical rows of large boulders, and excavations immediately to the north of structure found a system of retention walls forming mini terraces that protected the structure from collapsing down the slope to the north (Figures 6-16 and 6-17). At the highest preserved level, the double wall averaged 0.75 m in thickness and the space between the two concentric rings of large boulders was filled with earth, small and medium limestone rocks, and ceramic sherds. The central depression of the structure measured 3.2 m in diameter and was nearly completely circular (Figure 6-18). The interior of the

northern part of the double wall was well preserved, maintaining 4-5 vertical rows of medium and large size boulders at the beginning of the excavation (Figure 6-19). This wall of stones was constructed to join with the slope of the bedrock on the eastern side of the structure and continue the arc of the ring that was cut into the slope of the outcrop. The northern and western interior walls of the structure were made up of these larger boulders down to a depth of about 2 m below the surface of the ring where the wall reached the level of the bedrock. It is unclear whether additional vertical rows of boulders originally sat atop the double wall ring, but the amount of large stones recovered from inside the central depression and the amount that apparently rolled down the exterior slope suggest that there was at least one additional layer of boulders atop the double-ring of the structure.

Excavation: At the start of the excavations the central depression reached a depth of 1.2 m below the surface, indicating that the double ring of the annular structure did originally surround a well-like shaft. Carefully excavating the central depression, I first encountered a layer of dark brown surface soil that became lighter as the excavation went deeper. The fill of the central pit included stones of all sizes, representing collapse from the higher levels of the interior walls. Eventually the brown soil began to mix with *sascab* and/or stucco, turning it whiter until the fill consisted completely of *sascab*/stucco at a depth of about 3 m below the surface of the ring. In certain areas the *sascab*/stucco possessed a grayish tint, most likely resulting from multiple burning episodes and mixing with ash. As was the case with Annular Structure 1, the interior walls of Annular Structure 2 crossed through the surface layer of bedrock into the layer of softer *sascab*/stucco below. The *sascab*/stucco level appeared in the south and east walls first, at a depth of approximately 2.75 m below the surface of the ring and then on the northern and

western sides by a depth of 3 m. The interior walls at all levels, including the boulders of the north wall, the bedrock layer and the *sascab*/stucco layers all displayed signs of having been burned, including friable textures and darker coloring (Figure 6-20).



Figure 6-13: Photograph of the southeastern interior wall of Annular Structure 2 showing the bedrock cut.

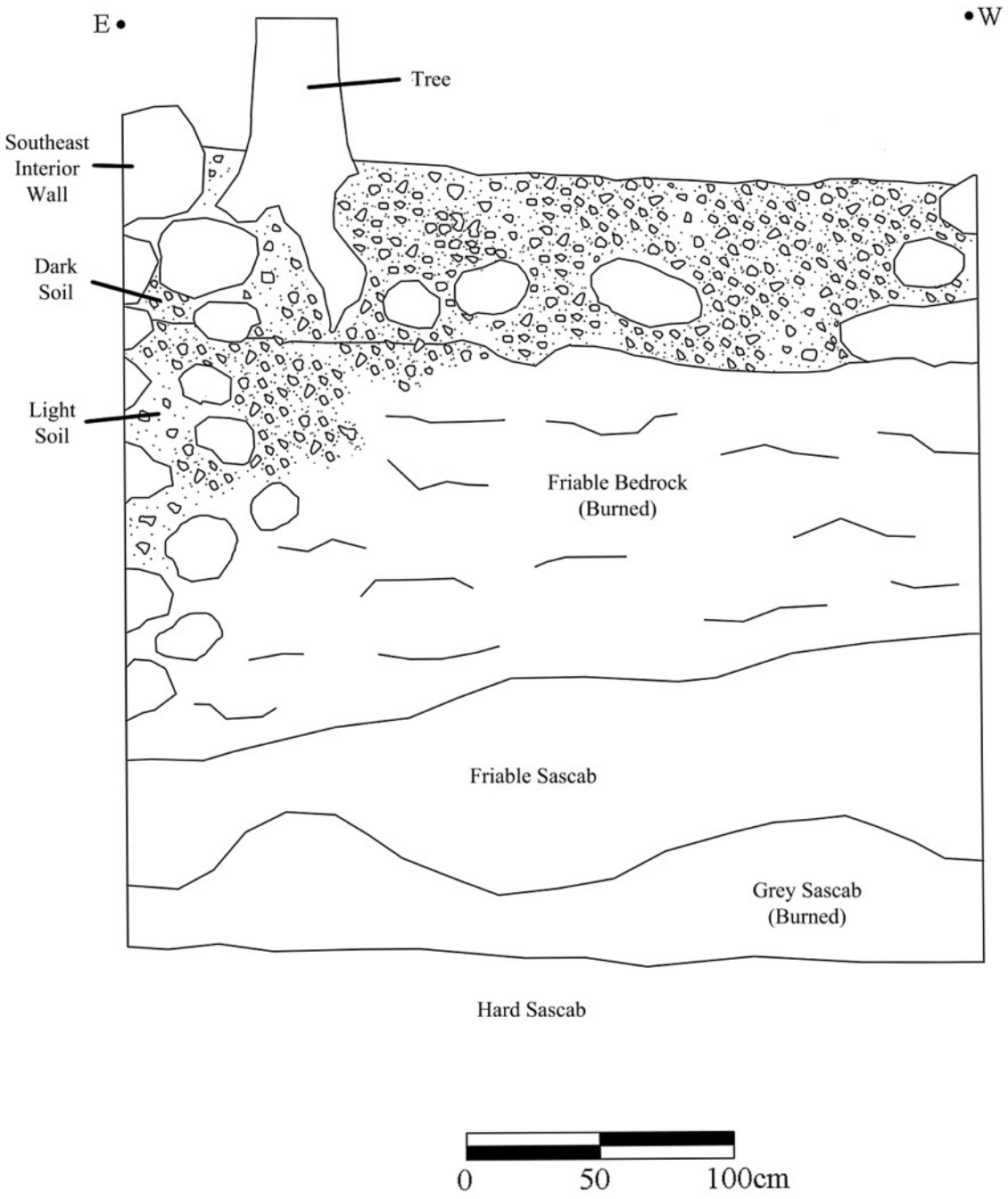


Figure 6-14: Profile sketch of the southern interior wall of Annular Structure 2.



Figure 6-15: Photograph of the northern portion of the interior wall of Annular Structure 2.

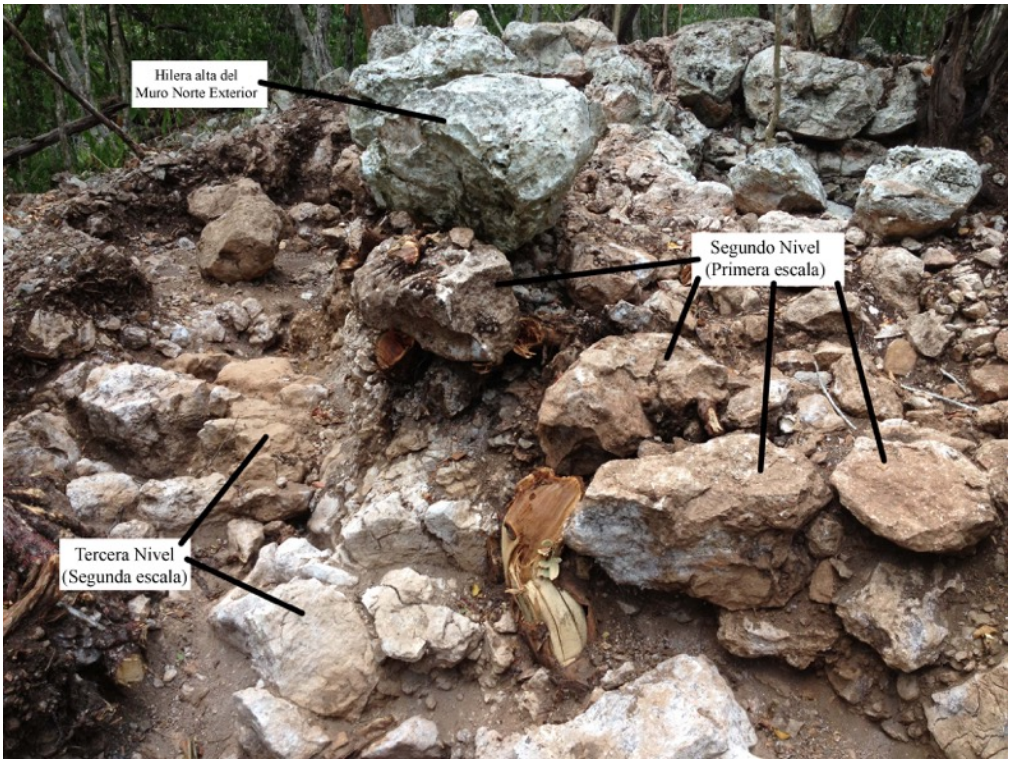


Figure 6-16: Photograph of the exterior of the northern portion of Annular Structure 2 showing the multiple 'terrace/steps' of the retention wall system.

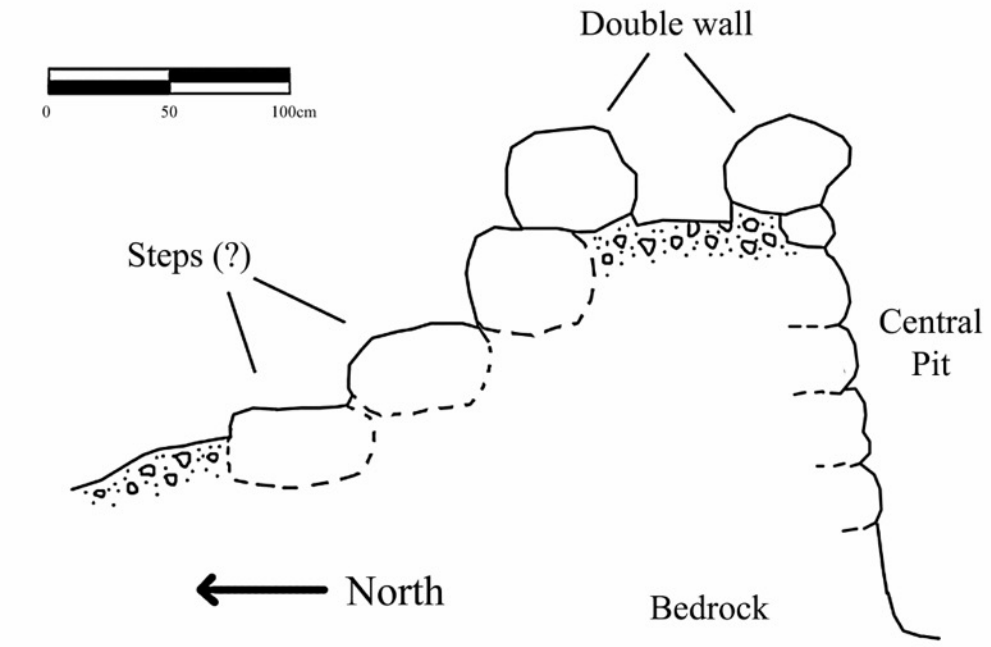


Figure 6-17: Profile cut sketch of the terrace/step retention system of the northern exterior portion of Annular Structure 2.

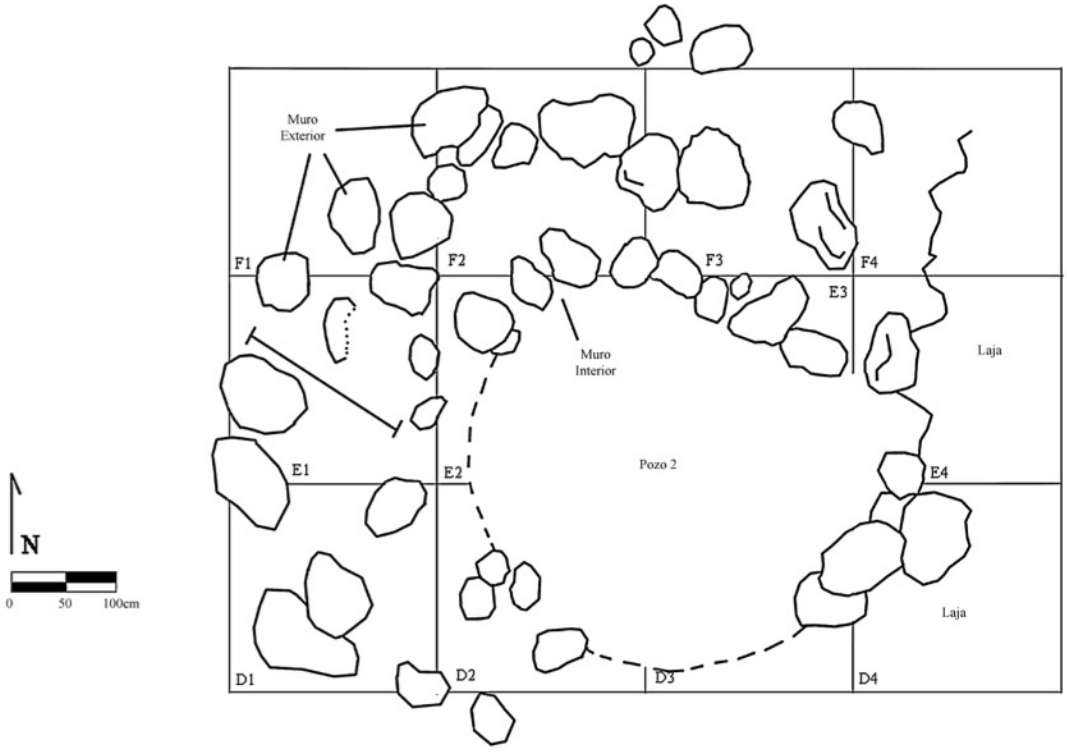


Figure 6-18: Aerial view sketch of Annular Structure 2 as it appeared in the archaeological record.

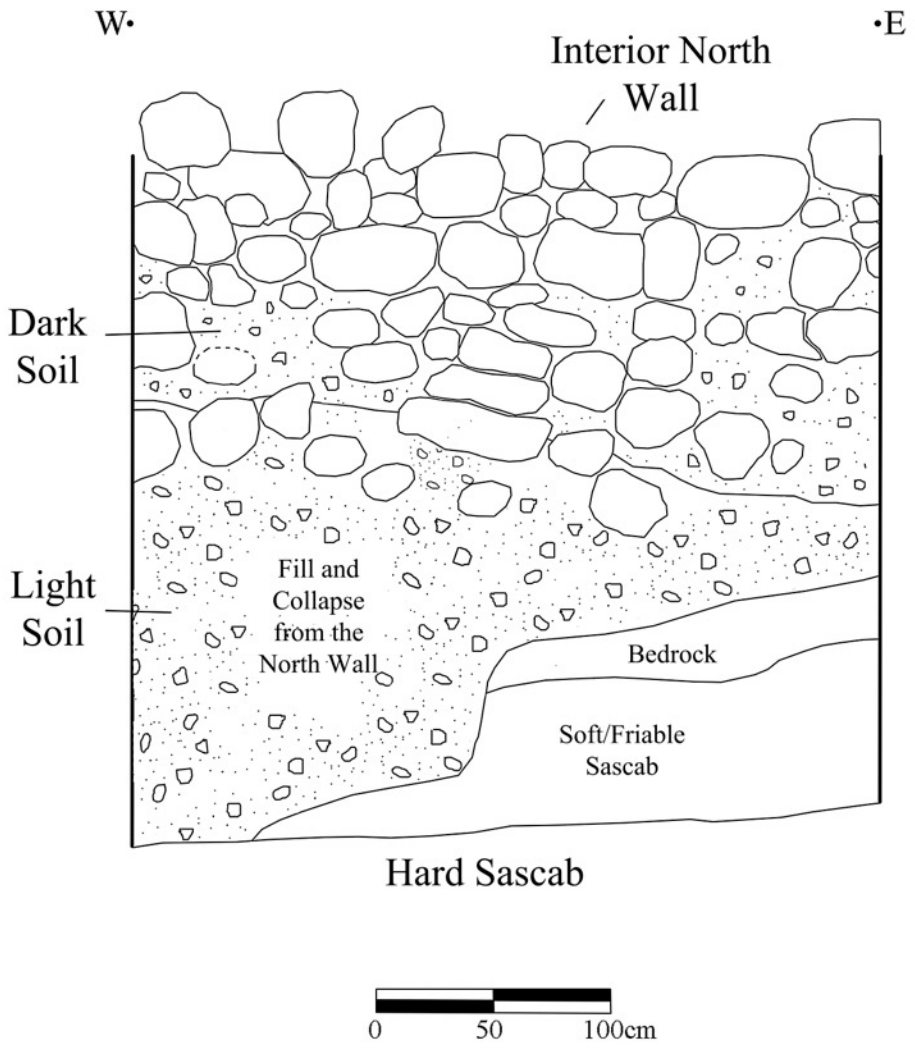


Figure 6-19: Profile drawing of the northern interior wall of Annular Structure 2 showing the multiple vertical layers of boulders sitting atop fill and bedrock.

Below the layer of soft, powdery *sascab*/stucco, I encountered a very hard layer of *sascab*/stucco at an average depth of 3.2 m below the highest point of the structure. This harder layer almost resembled a stucco floor and samples were recovered to test whether this material represented naturally occurring *sascab* or reconstituted calcium carbonate. Immediately below this first layer of hard *sascab*/stucco, which proved to be only a few centimeters thick, lay an

even thinner layer of blackened earth and *sascab*/stucco and an equally thin layer of reddish-orange earth and *sascab*/stucco (Figure 6-21). Samples were taken from these layers in order to test whether small amounts of charcoal could be recovered from these layers. Beneath the blackened and reddish-orange layers was another layer of hardened, white and gray *sascab*/stucco. This thicker layer measured approximately 0.75 m in width and directly overlay the lower level of bedrock that represented the final floor of the structure at a depth of 4 m below the surface ring of the structure (Figures 6-22 and 6-23). It appears that this hardened *sascab* represents a layer of lime that had been slaked and then dried to form a layer of hardened stucco or plaster. The final depth of the central pit was well below the surface level of the flat terrain surrounding the limestone outcrop.

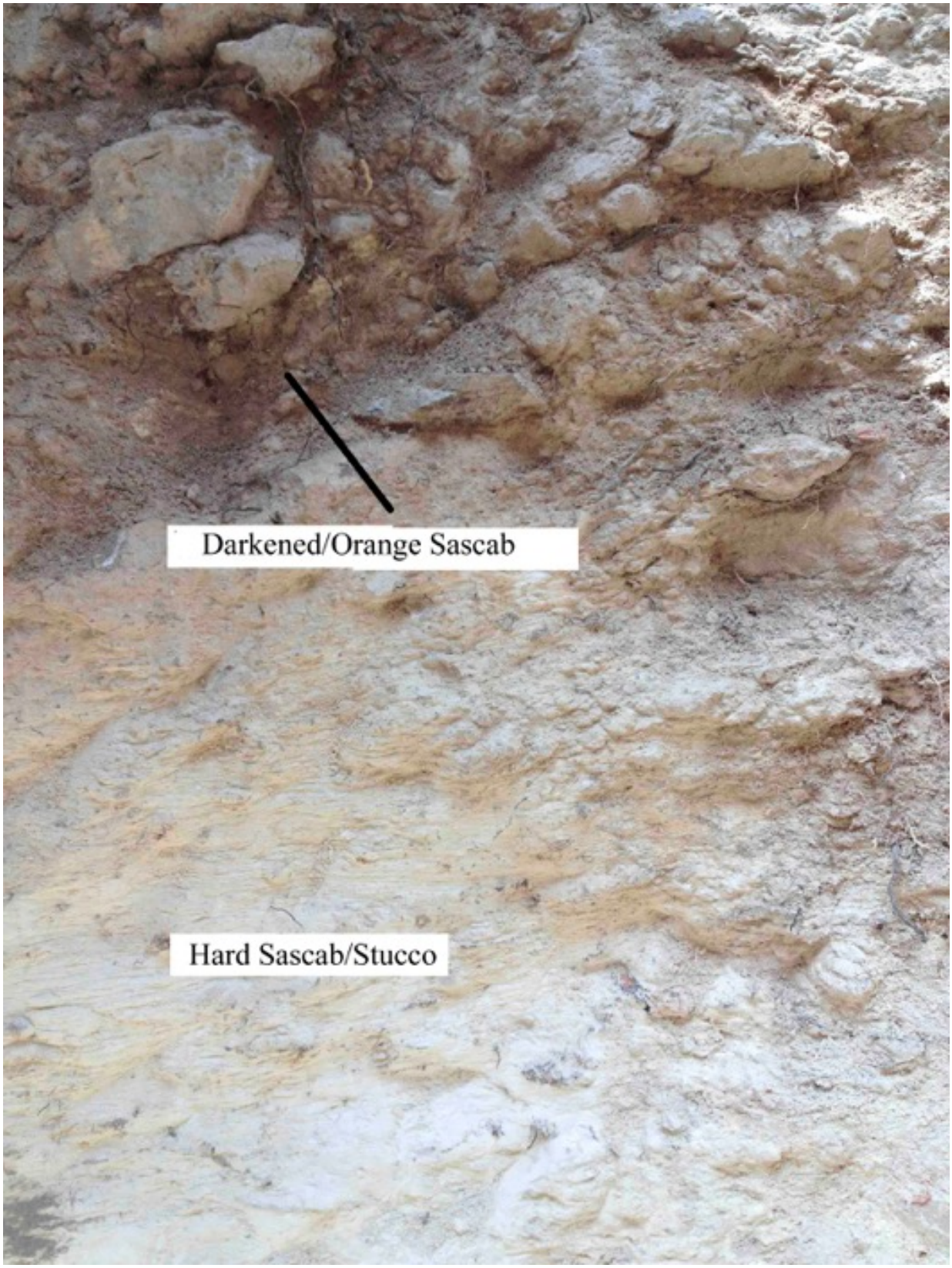


Figure 6-20: Photograph of the southwestern interior wall of Annular Structure 2 showing the different layers of *sascab*/stucco with evidence of burning.

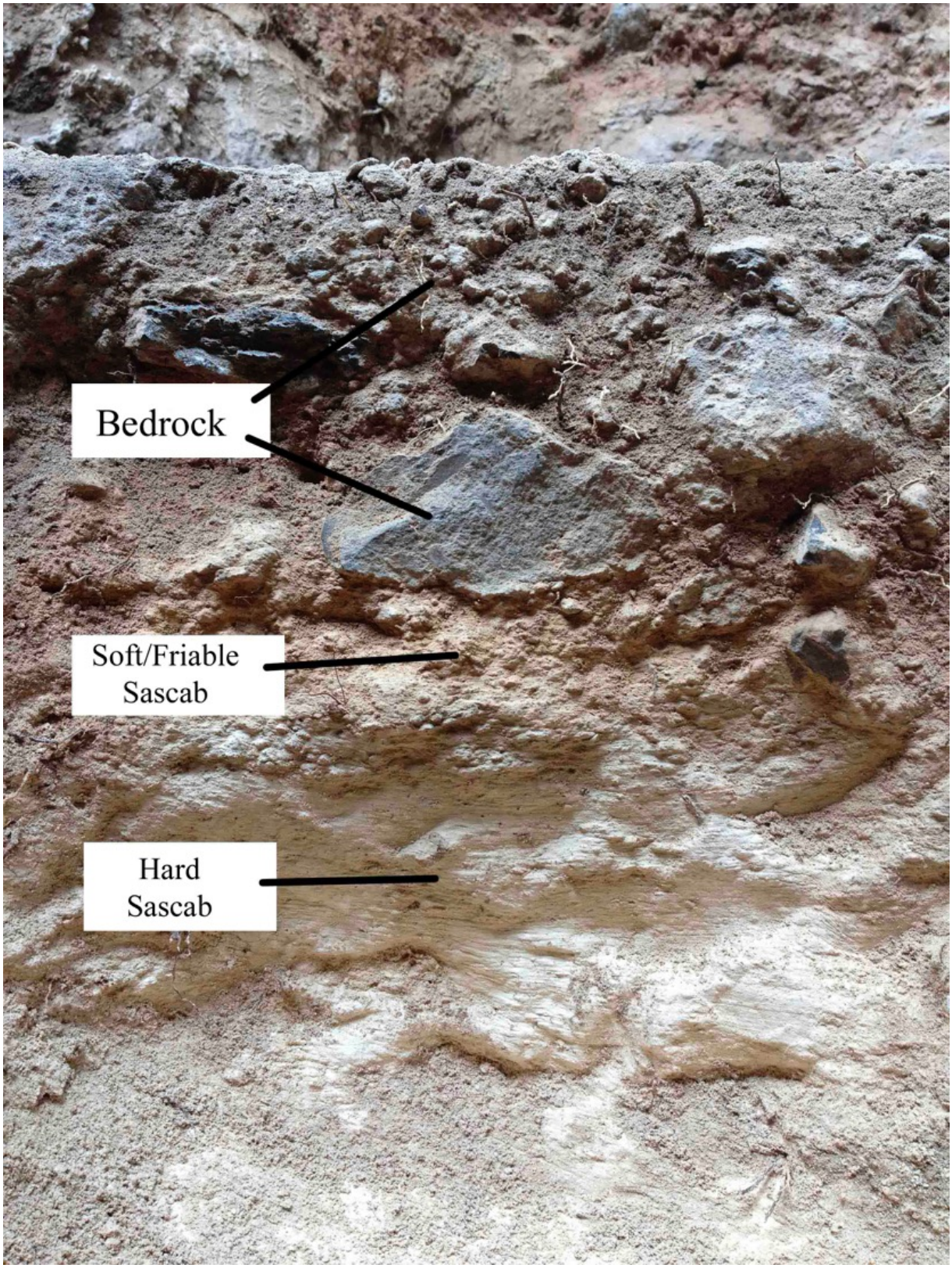


Figure 6-21: Photograph of the southern profile of Sondeo 8 within Annular Structure 2 showing the different layers of burned rock and *sascab*/stucco.

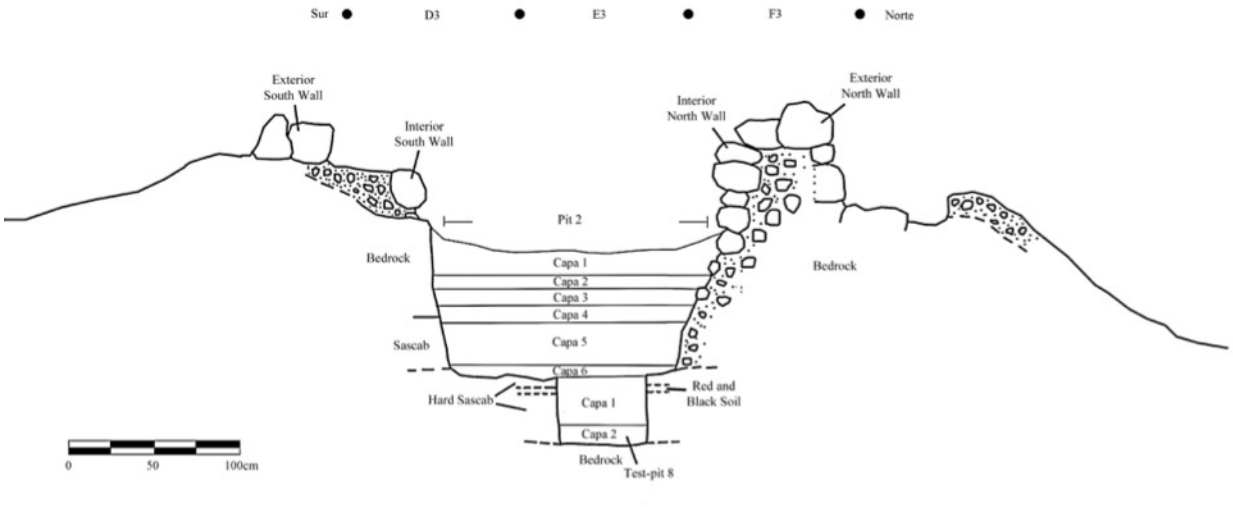


Figure 6-22: South-North profile cut drawing of Annular Structure 2 looking west.

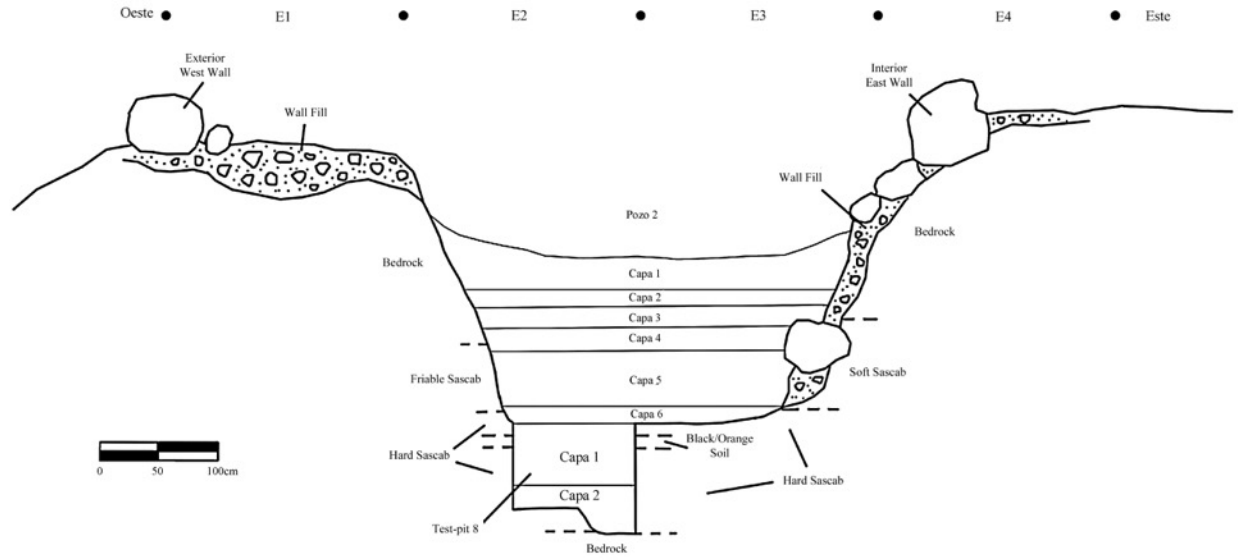


Figure 6-23: West-East profile cut drawing of Annular Structure 2 looking North.

Annular Structure 3 (GPS 2227)

Location: Annular Structure 3 is located within the intermediate zone on top of a hill named *Box Peek' Pocpocxic* (BPP) approximately 0.75 m to the southwest of the Yaxche Group and immediately to the southeast of the hill where elite residential compound of *Escalera al Cielo* (EAC) is located (Figure 6-24). Researchers first mapped a group of Prehispanic structures atop the apex of this hill in 2002 (Gallareta Negrón et al. 2003), and then I completed my own preliminary survey of the complex during the 2012 summer field season. A final survey of the hill was completed in 2014 as part of the Labná-Kiuic inter-site survey. Annular Structure 3, the only structure of its kind on the apex of this hill, was built at the southwestern extremity of the group where the terrain starts to slope down to the southwest. The closest Prehispanic features to the annular structure are two platform groups located at a distance of 15 m to the northeast that support multiple-room residential structures, several *metates*, and a *chultún*. Whereas the EAC structural complexes include several vaulted residential and civic-ceremonial structures, the BPP hill group where Annular Structure 3 is located only includes one vaulted structure at its highest point and then several platforms supporting non-vaulted structures. It has been hypothesized that the Prehispanic inhabitants of EAC were members of the socio-economic elite (Simms et al. 2012; Gallareta Negrón et al. 2014), and the discrepancy in architecture suggests that the inhabitants of BPP were of lower socio-economic status. In addition to the platform groups on the apex of the hill, an additional cluster of platforms and non-vaulted structures extends over a lower, northeastern spur that juts off the base of the hill. This northeastern group possesses its own annular structure, which has not yet been excavated.

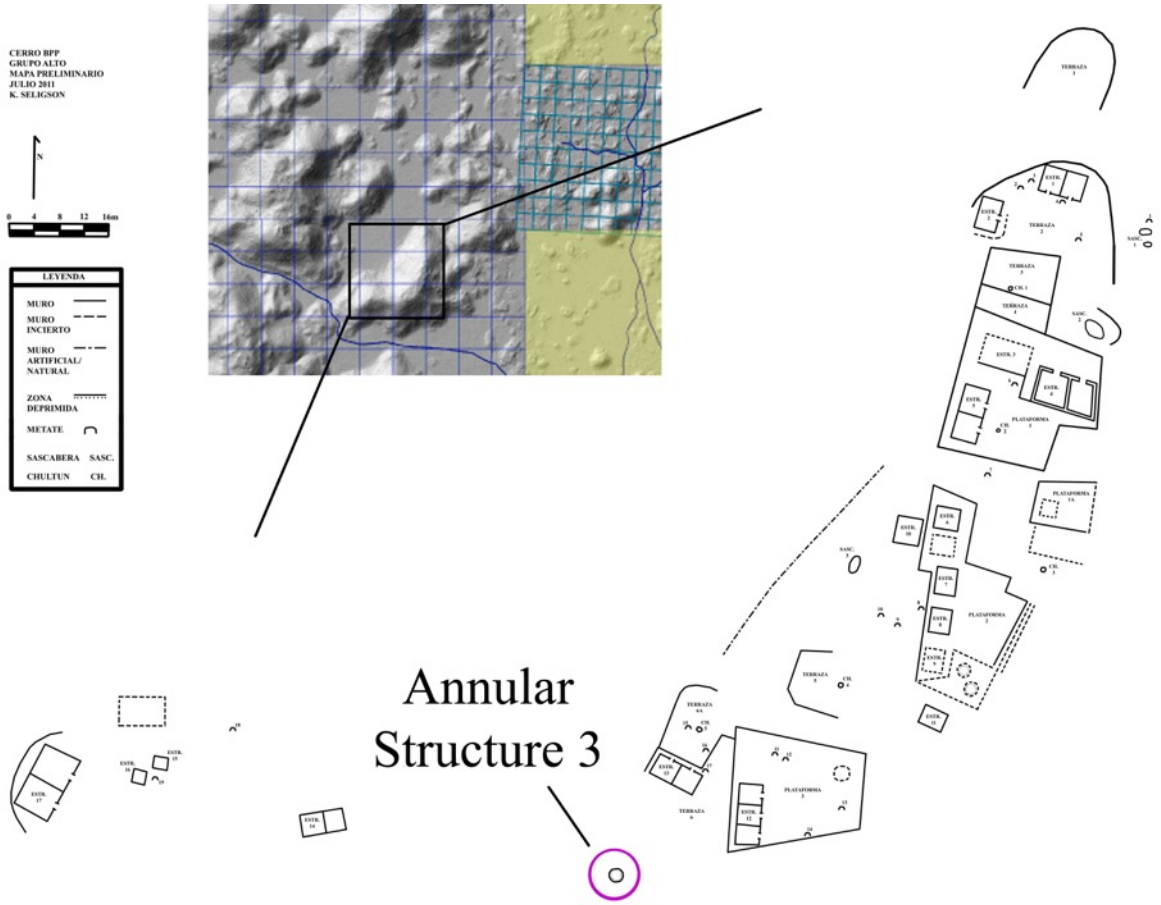


Figure 6-24: Map showing the location of Annular Structure 3 within the BPP hilltop group and in relation to the larger Kiuic western intermediate zone (Seligson 2012, in Gallareta Negrón et al. 2013).

Construction Form: Annular Structure 3 has a diameter of 2.56 m North-South and 2.44 m East-West and its top-most levels consist of a ring of large rough-cut boulders (Figure 6-25). As was the case with Annular Structures 1 and 2, the builders of this annular structure took advantage of the bedrock slope of the hillside to use as one side of the annular structure. In this case, the interior eastern wall of the structure was composed of the limestone bedrock of the hill that slopes from northeast to southwest. The bedrock slopes gently upward to the northeast outside the central depression of the structure until it reaches the nearby group of platforms. The northern, western, and southern walls of the ring are composed of crude large and medium size

boulders. Unlike the first two annular structures excavated, Annular Structure 3 does not possess a double-ring, at least not one that is visible in the archaeological record. Due to the natural topography, the base of the western wall is lower down than those of the northern and southern walls. In order to combat the slope of the hill the western wall contains more construction materials. Many of the larger stones that originally formed this wall have since collapsed slightly down the slope to the west (Figure 6-26). The quantity of the construction material suggests that the western wall most likely included an adjoining retention wall in addition to multiple vertical rows of stones. It is unclear whether there was originally a ring of boulders atop the bedrock of the east wall, but the recovery of many such stones from within the central depression suggests that it was a possibility. It is also likely that at least one or two vertical rows of stones have fallen from the northern and southern walls, both into the interior of the structure and down the slopes surrounding the structure. The rough stones used in the construction of the surface ring of the structure were not quite as large as those identified in the first two annular structures and the lack of a defined double wall gives Annular Structure 3 a cruder appearance than the others.



Figure 6-25: Aerial view drawing of Annular Structure 3.



Figure 6-26: Photograph of the western wall of Annular Structure 3 showing the large boulders used to construct this side of the structure that have since collapsed outside the structure.

Excavation: Annular Structure 3 was excavated during the 2014 BRAP summer field season. Excavations in the central depression of Annular Structure 3 began with the removal of a layer of dark brown surface soil, which gave way to slightly lighter fill mixed with stones of all sizes that probably represented the collapse of the uppermost levels of the ring walls. The bedrock of the east wall became very friable and exhibited evidence of having been burned immediately below the level of the surface soil. At a depth of 1.5 m below the highest point of the ring, excavations encountered a floor of bedrock made up of slightly different levels that resembled overlapping shelves. The surface of these bedrock shelves was tinted dark gray, most likely resulting from burning. In the middle of the central depression was an oval opening to a *sascabera* or partially-

collapse *chultún* that was cut through the surface bedrock. The mouth of the *sascabera*/*chultún* measured 1.4 m North-South by 1.1 m East West and the bedrock of the neck was approximately 20 cm in thickness before giving way to the open cavity below (Figures 6-27–6-30).



Figure 6-27: Photograph of the central depression of Annular Structure 3 showing the overlapping shelves of the surface bedrock and the opening to the *sascabera*/*chultún*.

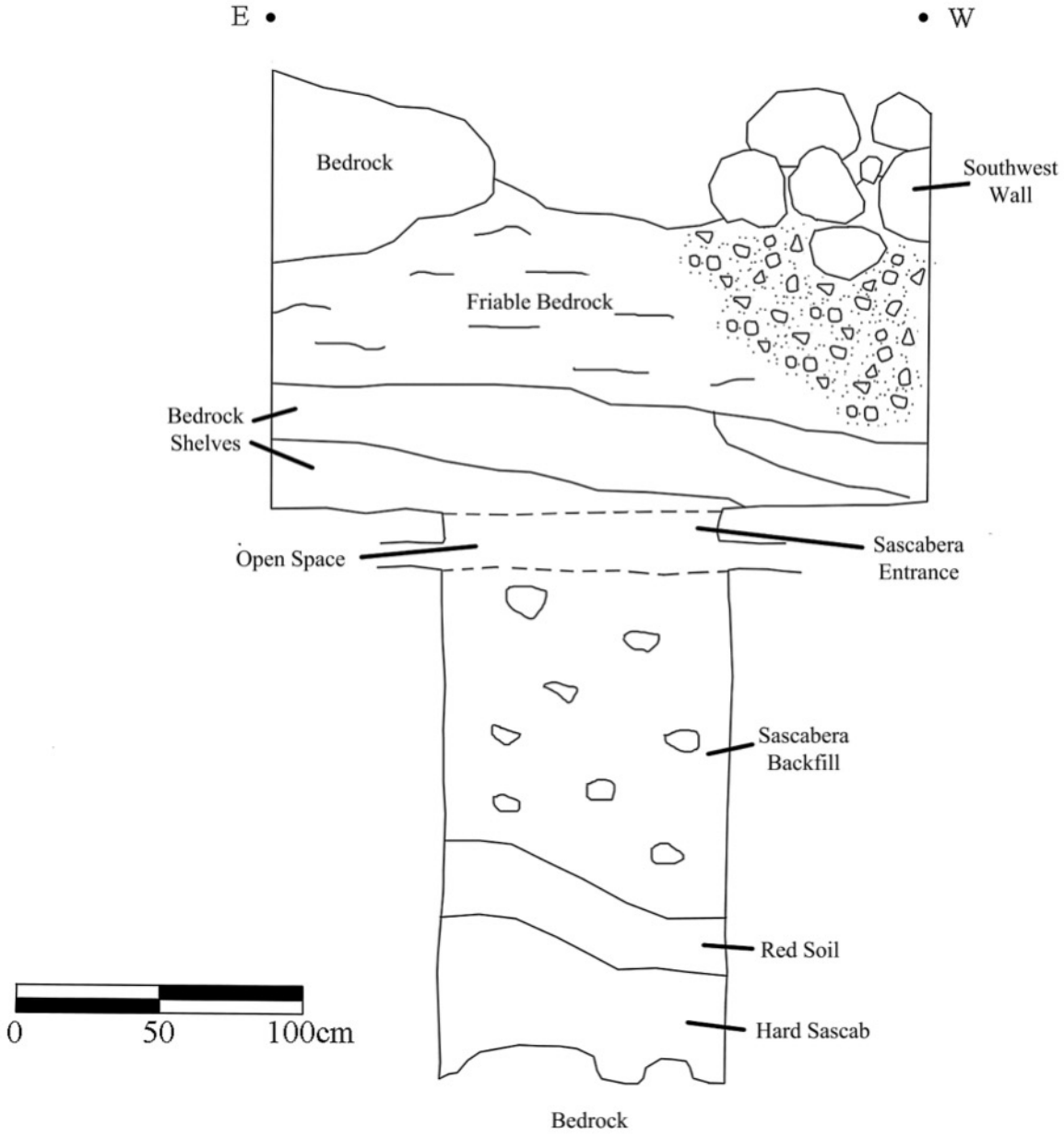


Figure 6-28: Profile drawing of the Northern side of Pozo 3 showing the upper levels of the central depression of Annular Structure 3 as well as the underlying *sascabera*/*chultún.*

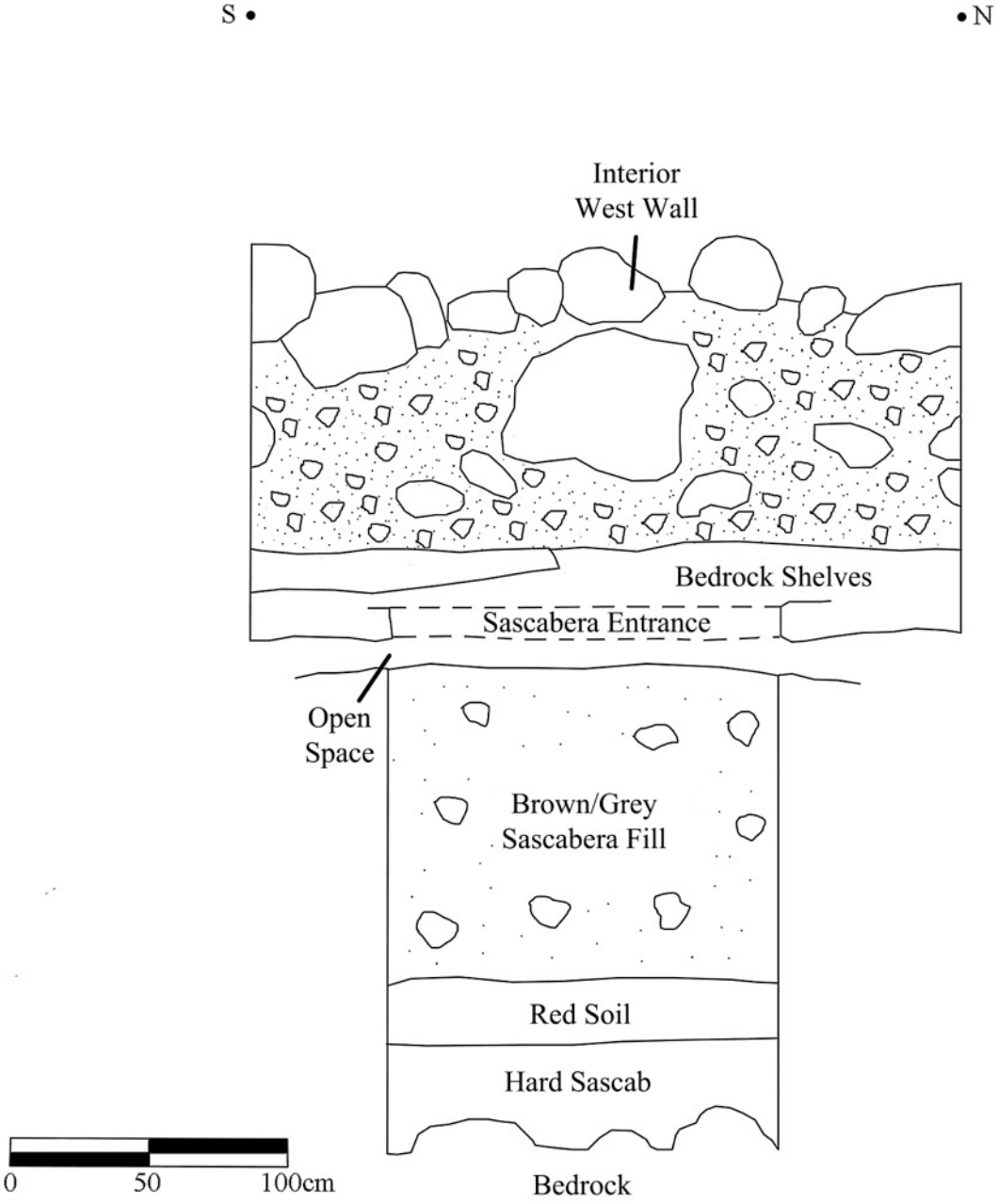


Figure 6-29: Profile drawing of the Western side of Pozo 3 showing the upper levels of the central depression of Annular Structure 3 as well as the underlying *sascabera*/chultún.



Figure 6-30: Final aerial view drawing of Annular Structure 3.

The *sascabera*/*chultún* was nearly completely filled with debris and soil from the surface. I excavated a unit directly down through the opening of the pit, following the dimensions of the *sascabera*/*chultún* entrance. The fill within the subterranean cavity consisted of fine, light colored soil mixed with stones of all sizes. In the thin open space between the top of the fill layer and the ceiling of the cavity, I could see that the cavity continued for several meters to the south

and west. At a depth of 2.75 m below the highest part of the ring (1.25 m below the entrance to the cavity) excavations identified a layer of burnt reddish soil and rock that sloped from east to west and measured 10-15 cm thick. Below this burnt layer, the fill consisted mainly of powdery *sascab*/stucco until a depth of 2 m below the entrance to the cavity when it gave way to a level of very hard *sascab*/stucco. This firmer layer only measured approximately 10 cm in thickness and sat immediately on top of the lower level of bedrock that formed the floor of the *sascabera*/*chultún* (Figures 6-31 and 6-32). The firmness of this last layer of *sascab*/stucco resembled the hard layers of *sascab*/stucco discovered at the lowest levels of the first two annular structures, and most likely represented the reconstituted calcium carbonate that had originally been calcine, then slaked during the lime production process.

Excavations around the exterior of the annular structure reached the level of bedrock within 50 cm of the surface, indicating that the ring structure was most likely constructed immediately on top of the bedrock. The presence of a full *sascabera* or *chultún* within the confines of the annular structure's ring suggests that the structure was built after the cavity was already excavated. Evidence for burning both below and above the opening to the *sascabera*/*chultún* indicates that similarly to the first two annular structures, Annular Structure 3 may have served multiple purposes over its use-life: in this case as a source for raw materials and potentially water storage before potentially being used to produce lime.

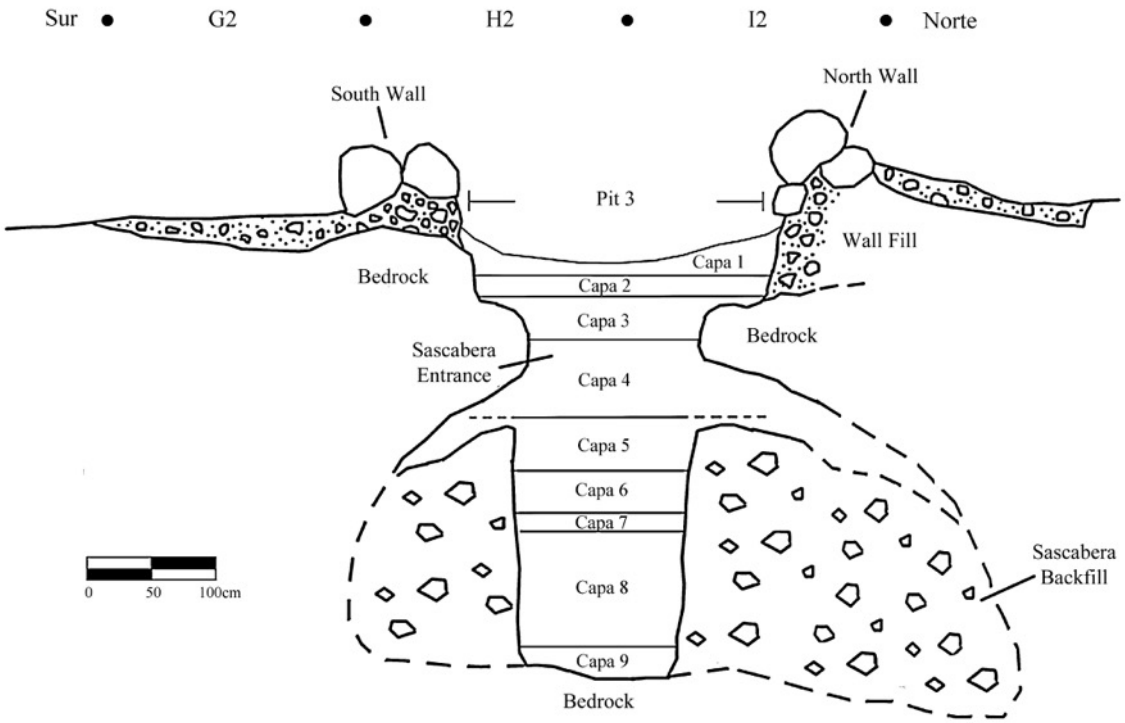


Figure 6-31: South-North profile cut drawing of Annular Structure 3 looking West.

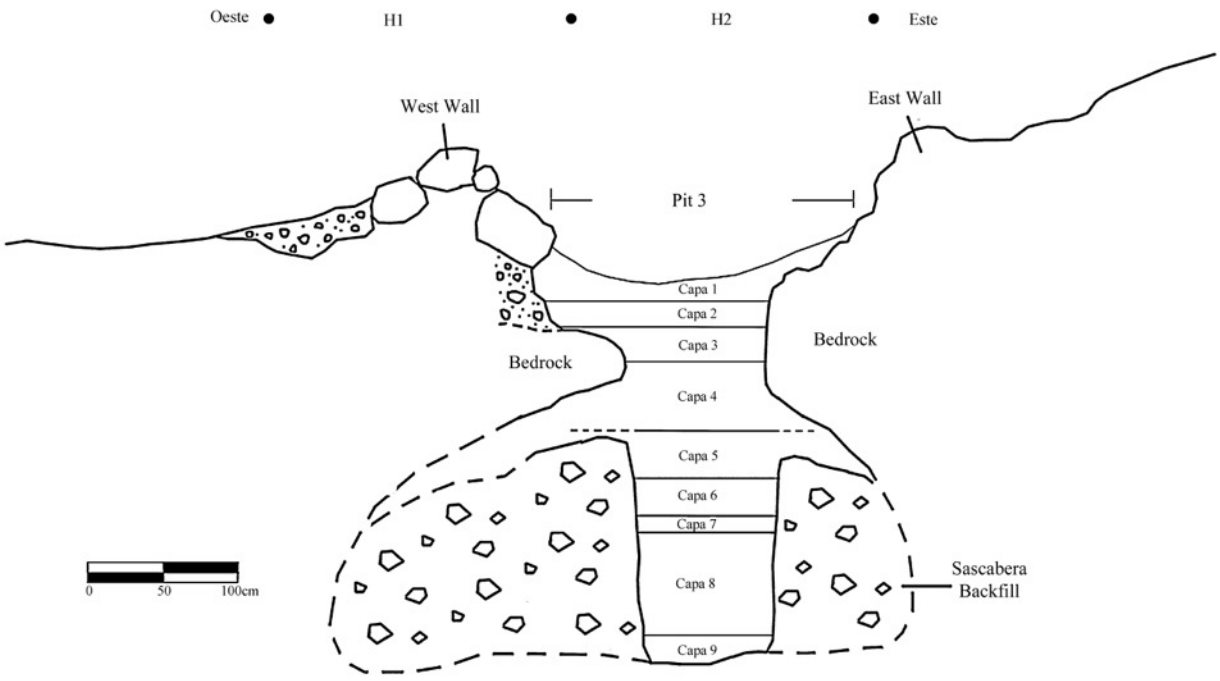


Figure 6-32: West-East profile cut drawing of Annular Structure 3 looking North.

Annular Structure 4 (S2795 E3330)

Location: Annular Structure 4 is located on top of the hill known as *Escalera al Cielo* (EAC), where BRAP project members have been excavating several structures of an elite residential group since 2007 (Gallareta Negrón et al. 2014). EAC is located approximately 1.5 km to the southwest of the Kiuic site center in the intermediate zone of the Kiuic polity. The hill's apex runs roughly North-South and the EAC archaeological complex consists of two main compounds with vaulted architectural, and several smaller non-vaulted groups. Annular Structure 4 is located on the northernmost promontory of the apex of the hill, about 90 m to the northeast of the vaulted residential group called EAC Norte (Figure 6-33). Aside from the annular structure, the northern promontory supports two platforms with non-vaulted two-room structures at a distance of 30 m to the southeast, and a possible lone rectangular platform 20 m to the northeast. Annular Structure 4 is the only ring structure, and thus likely the only kiln, on the entire EAC hilltop.

Construction Form: At the start of the excavations, the part of the structure visible on the surface appeared to have more of a quadrangular than a circular shape (Figure 6-34). As excavations continued the interior walls of the structure appeared to be slightly more rounded than the surface first made them appear, but the internal dimensions of Annular Structure 4 proved to be irregular compared with the relatively circular shape of the first three annular structures excavated. While the entirety of the fill debris from the southern and eastern walls could not be removed due to the way that these walls had collapsed, it was still apparent that their original shape did not form a perfect circle. At the time of the excavation, the boulders that made up the uppermost levels of the north wall were slowly being pushed toward the center of the structure by roots extending from a large tree located just to the northwest of the structure. Aside from the

depression in the center, the structure was identified as an annular structure by the ring of medium-sized boulders surrounding the central depression. Despite the fact that there was a smaller quantity of boulders forming the surface ring and the immediate topography was different from that of the first three annular structures (Annular Structure 4 is surrounded by relatively level ground) data recovered from within the structure demonstrated its similarities to other annular kilns. The amount of large stones recovered from within the central depression indicated that the ring of medium-sized boulders outlining the annular structure most likely supported at least one more vertical row of stones in the past.

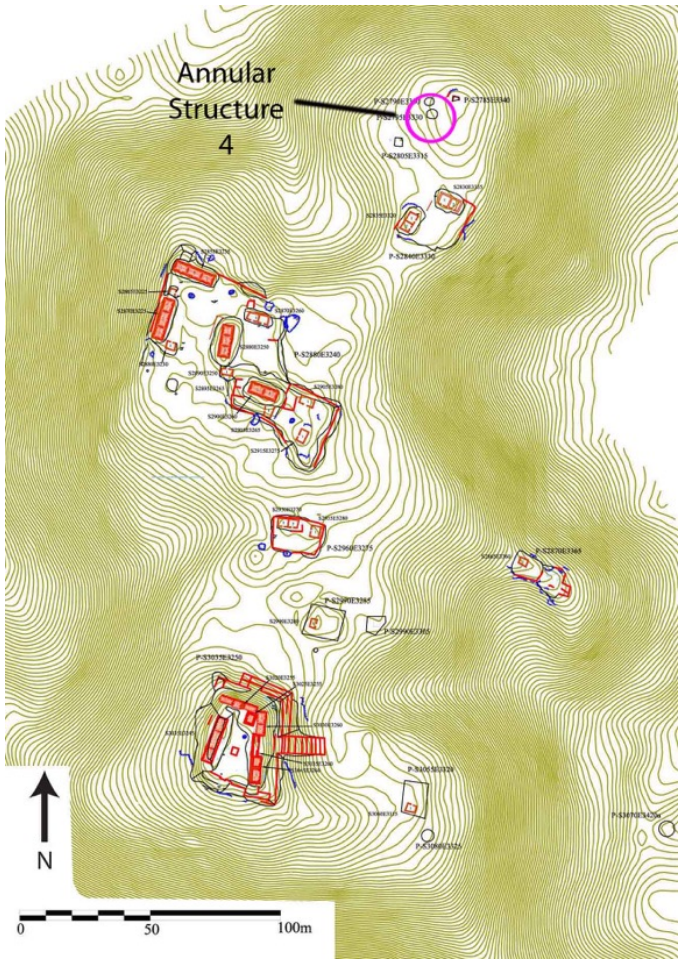


Figure 6-33: Map showing the location of Annular Structure 4 atop *Escalera al Cielo* (Gallareta Negrón et al. 2014).

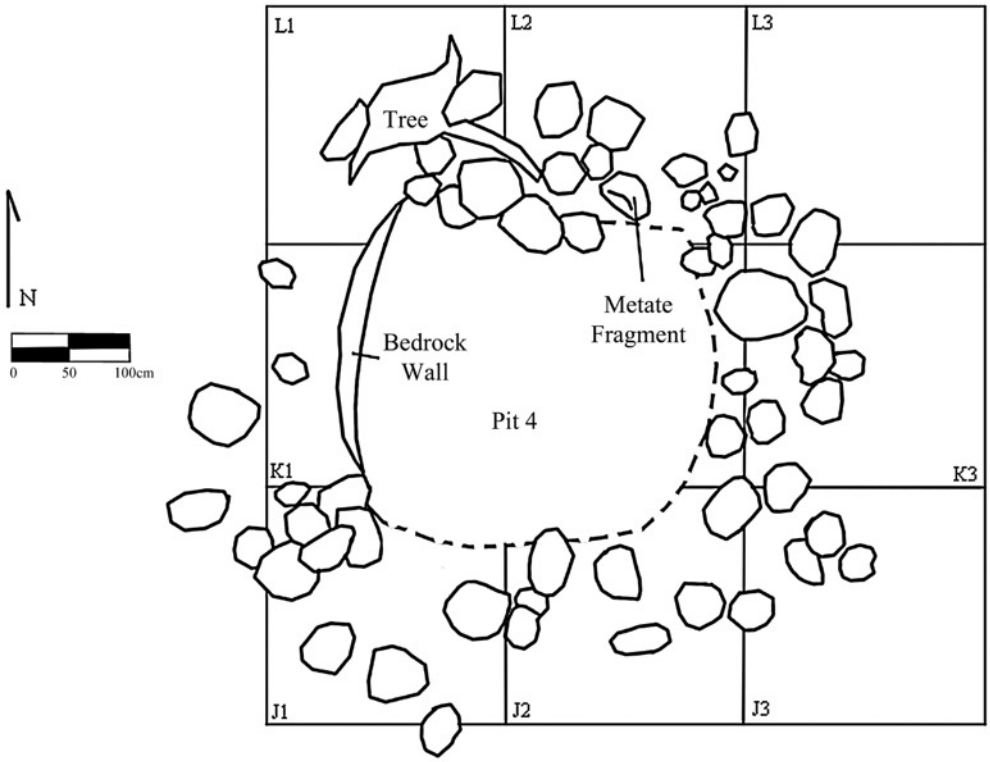


Figure 6-34: Aerial view drawing of Annular Structure 4.

Excavation: Annular Structure 4 was excavated during the 2014 BRAP summer field season. One of the reasons for the irregular shape of Annular Structure 4 was discovered through the excavation of the western interior wall of the structure. I found that the line of medium-sized rough cut boulders that made up the extant portion of the western surface ring of the structure lay directly atop a layer of surface bedrock. Below the boulders, the bedrock was cut vertically but it was unclear whether this cut was natural or human-modified. It possessed a peculiar shape, descending nearly vertically for approximately a meter before cutting deeper into the wall in what at first appeared to be the mouth of a cave. However, after less than a half a meter, this cave opening switched direction again and the bedrock began to slope toward the center of the structure. Thus the bedrock of the western wall either contained a natural fissure, or the builders

of the annular structure created a very narrow and shallow recess into the western interior wall of the structure (Figure 5-35 - 5-37). In addition to this recess, the western wall was peculiar in that it ran roughly south to north and it did not possess the curve or arc found in the walls of the first three annular structures excavated. While the other walls of Annular Structure 4 did cut through the bedrock level, they also contained a thicker layer of stones and fill in their uppermost levels (Figures 5-38). Where the southern and northern walls of the structure abutted the western wall they formed nearly 90-degree angles, giving the structure its less than circular appearance.



Figure 6-35: Photograph of the western interior wall of Annular Structure 4 showing the unusual cut into the bedrock wall.

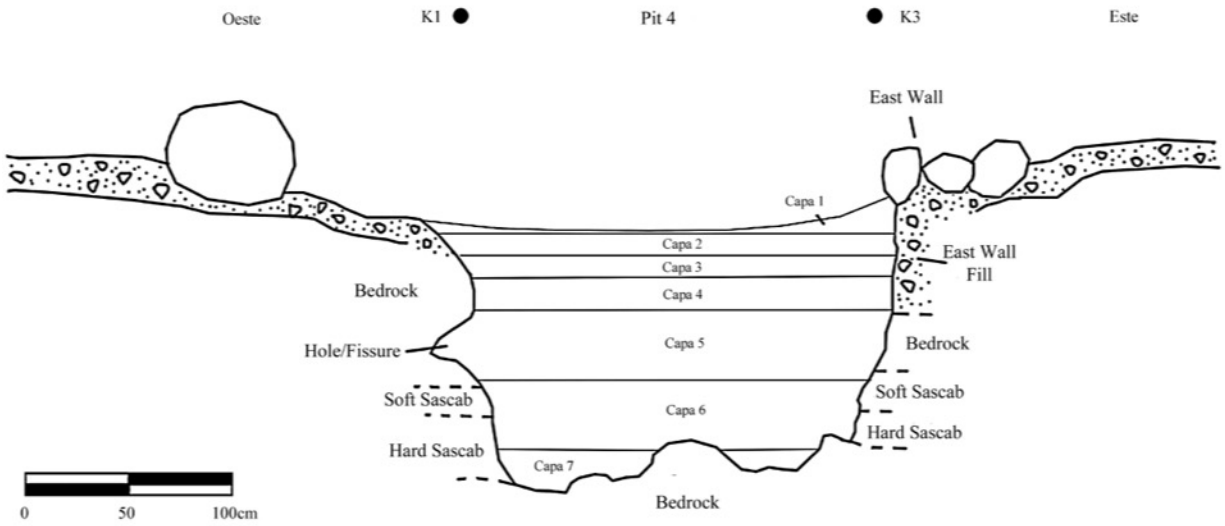


Figure 6-36: West-East profile cut drawing of Annular Structure 4 showing the unusual fissure in the western wall.

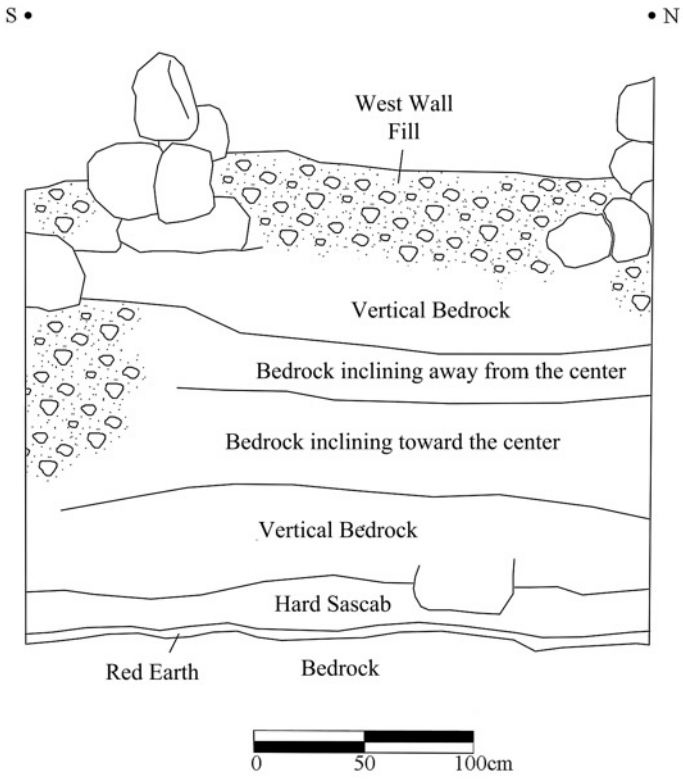


Figure 6-37: Schematic profile drawing of the western interior wall showing the layers of construction including the unusual fissure in the bedrock.

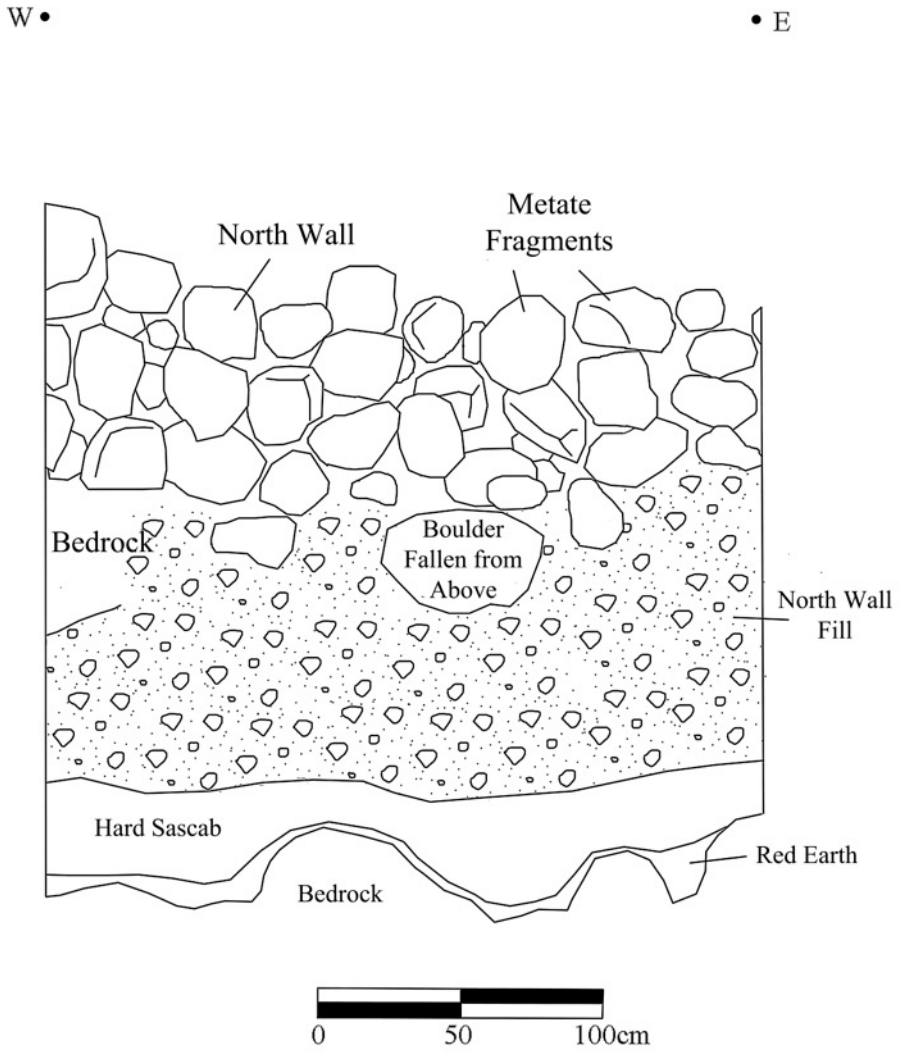


Figure 6-38: Profile drawing of the Northern interior wall of Annular Structure 4.

Due to the smaller quantity of large boulders scattered around the outside of the structure and the lower frequency with which they were recovered from within the structure's central depression compared with the other annular structures, it appeared that the surface ring of the structure did not possess more than one or two vertical rows. Unlike Annular Structures 1 and 2, and more like Annular Structure 3, this annular structure did not possess a thick double wall, but instead had a single horizontal ring of medium and large boulders marking its extent on the

surface. The bedrock was very close to the surface on all sides surrounding this surface ring, suggesting that the structure was originally constructed immediately atop and through the bedrock. The central depression was cut through the uppermost bedrock layer to the layer of *sascab* below. Small, darkened *chich*-size stones that appear to have been burned were scattered on the surface all around the structure.

The soil fill recovered from within this annular structure possessed more of a reddish hue than the coffee-brown soil recovered from the other annular structures, despite the fact that the thin soil cover surrounding the structure was predominantly dark brown. Like the other structures, however, the soil became lighter as excavations sunk deeper, eventually giving way to pinkish-colored soft *sascab* and/or stucco. The fill was mixed with stones of all sizes and ceramic sherds, most likely representing the collapse of the inner walls of the structure. Below the layer of soft, friable *sascab*/stucco excavations uncovered a hard layer of dark red soil. A similar layer of darkened/reddish earth and stone had been encountered below the soft *sascab*/stucco layer during the excavation of Annular Structure 2. This very thin layer of red earth and *sascab*/stucco in Annular Structure 4 was caked to the underlying layer of harder *sascab*/stucco and proved to be very hard as well. The underlying layer of hardened *sascab* sat atop the bedrock of the floor of the structure. The texture and appearance of the red material indicated that it had a high clay content. The discrepancy between this clayey material and the thin, non-clayey soil atop EAC suggests that it was deliberately transported atop the hill to be used in the kiln, perhaps for insulation purposes. Examples of clay used to coat the interior of an annular structure were recovered during the excavation of Annular Structure 8. The red clayey layer appeared at an average depth of 2.5 m below the level of the surface ring and exhibited obvious evidence of burning (Figure 6-39).



Figure 6-39: Photograph of the layer of reddish soil/clay near the floor of Annular Structure 4.

As mentioned above, the precarious positioning of large boulders within the north and south walls precluded the complete excavation of these sides. However, from the visible edges of both walls and the debris recovered from within the central depression, it was apparent that the original annular structure was wider North-South than the pit opened during excavation. The profile of the excavation pit demonstrates how the north wall in particular was originally more recessed and consisted of at least a few larger boulders that have since fallen into the central depression (Figure 6-40). While the fissure/hole in the west wall of Annular Structure 4 departed from what was seen in the excavations of the first three annular structures, the evidence recovered from the floor of the structure and the relatively well-preserved east wall indicated that

this annular structure had more similarities in construction form than differences. The excavations in the central depression encountered levels of wall collapse and fill, bedrock with evidence of burning, a soft/friable *sascab*/stucco layer, and a hardened layer of *sascab*/stucco immediately overlaying the lower level of bedrock.

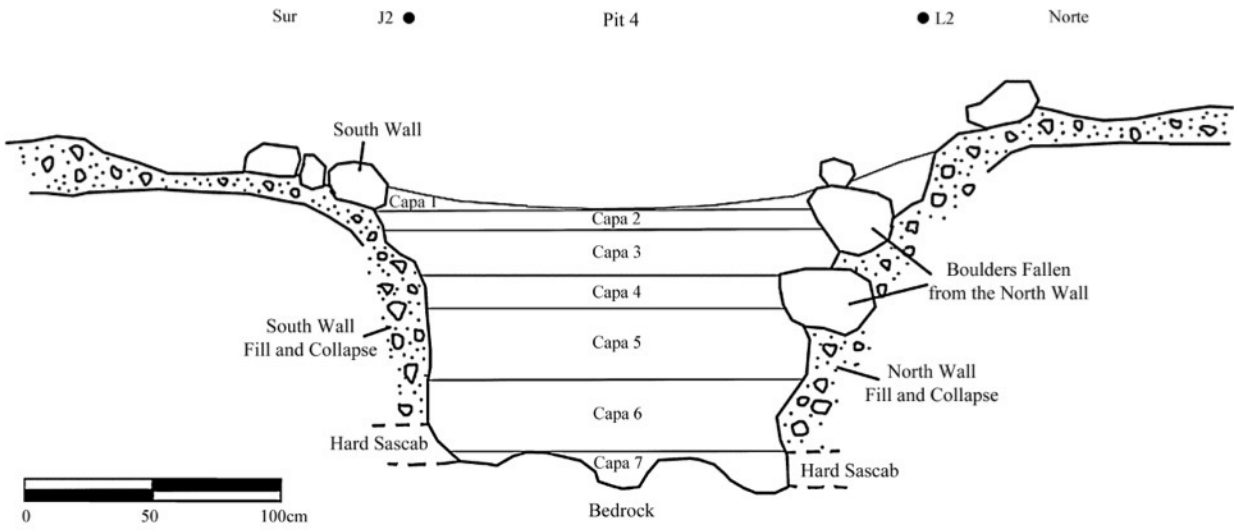


Figure 6-40: South-North profile cut drawing of Annular Structure 4 looking West.

Annular Structure 5 (GPS 2113)

Location: Annular Structure 5 is located at the western base of the EAC hill, in between the groups EAC Norte and EAC Sur with respect to latitude (Figure 6-1). While the land to the west of EAC is part of the outer zone of the study area, the proximity of this annular structure to the EAC complexes and no other Prehispanic features argues for it being included in the intermediate zone of study. The nearest Prehispanic feature (not including the structures atop EAC) is a small *pasel* foundation located approximately 60 m to the north. Aside from these features, the structure is relatively isolated, making it the first annular structure excavated under

these circumstances. The land levels out just to west of the annular structure and contains relatively deep patches of soil that would likely have made this area appealing for agricultural pursuits in the past.

Construction Form: Annular Structure 5 has a nearly circular ring, measuring 2.05 m North-South and 2.1 m East-West from interior wall to interior wall (Figure 6-41). Due to its location on sloping ground, the western wall of the structure contains more construction material in an analogous situation to Annular Structure 3 (Figure 6-42). While the structure does not appear to have had a double concentric wall like Structures 1 and 2, the west wall probably consisted of at least two horizontal rows of boulders to combat the natural incline and serve as a retention mechanism. Additionally, it most likely possessed either two or three vertical rows of stones to bring it even with the single row of boulders located slightly up the slope on the eastern side of the structure. The northern wall also appears to have been slightly thicker than the southern wall, again resulting from the need to shore it up against the hill-slope (Figure 6-43). The entirety of the ring of boulders sits directly atop the bedrock, which lies immediately below a thin 25-50 cm layer of soil (Figure 6-44).

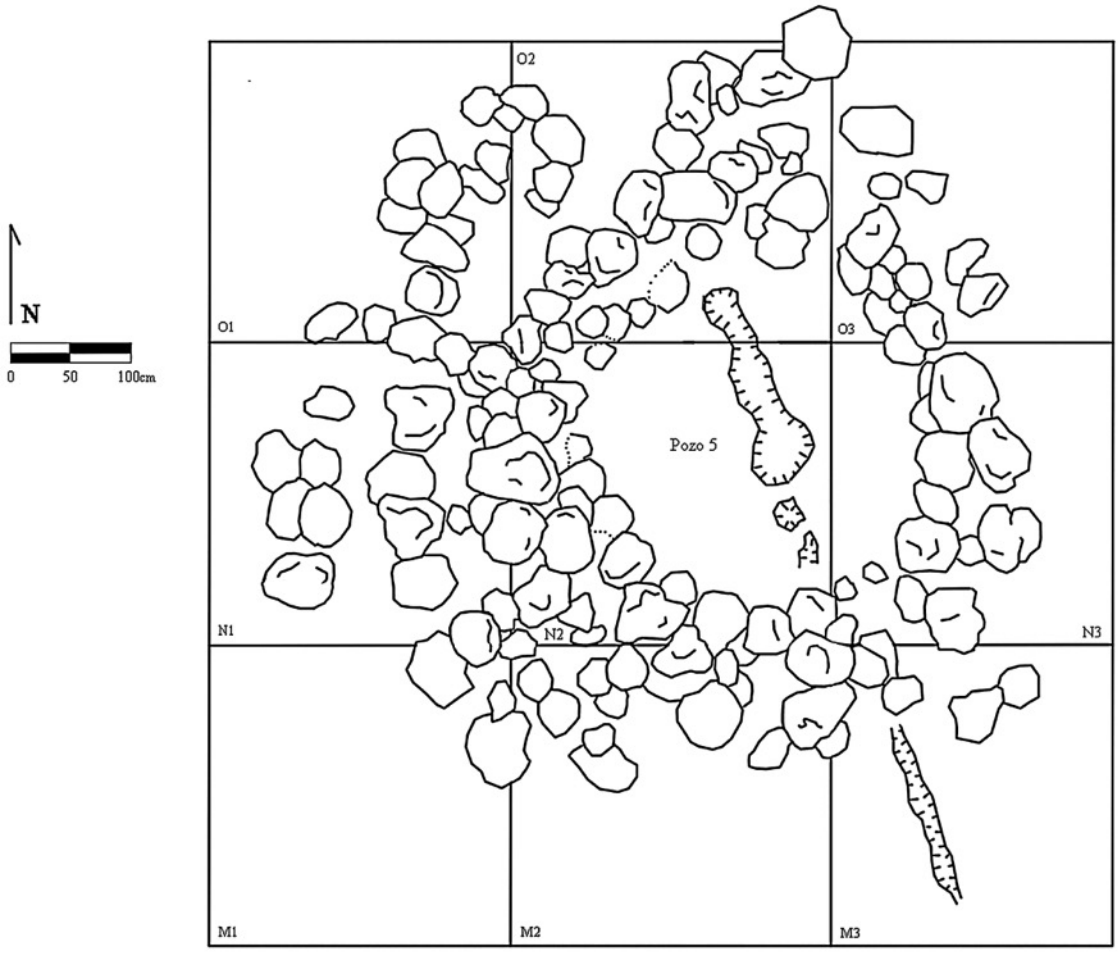


Figure 6-41: Aerial view drawing of Annular Structure 5 showing the greater amount of construction material used in the western side of the structure.

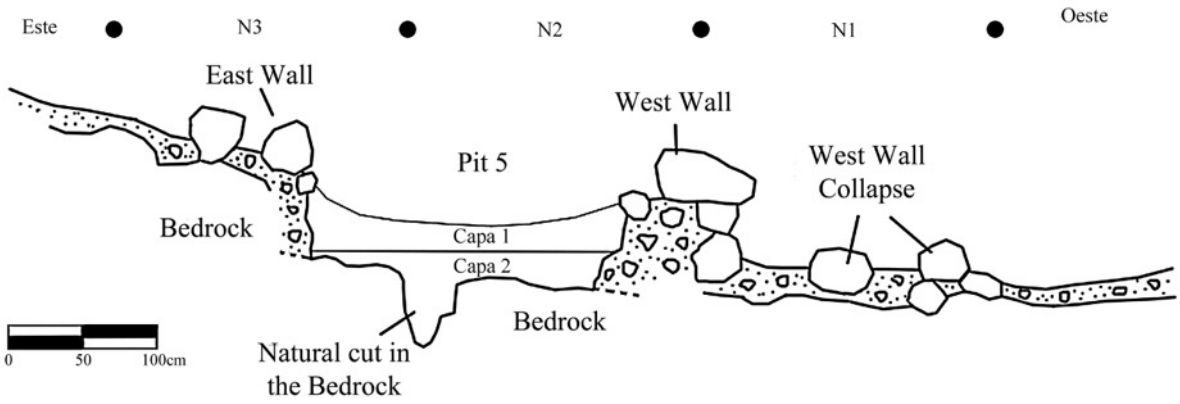


Figure 6-42: East-West profile cut view of Annular Structure 5 showing the greater amount of construction material used in the western side of the structure.

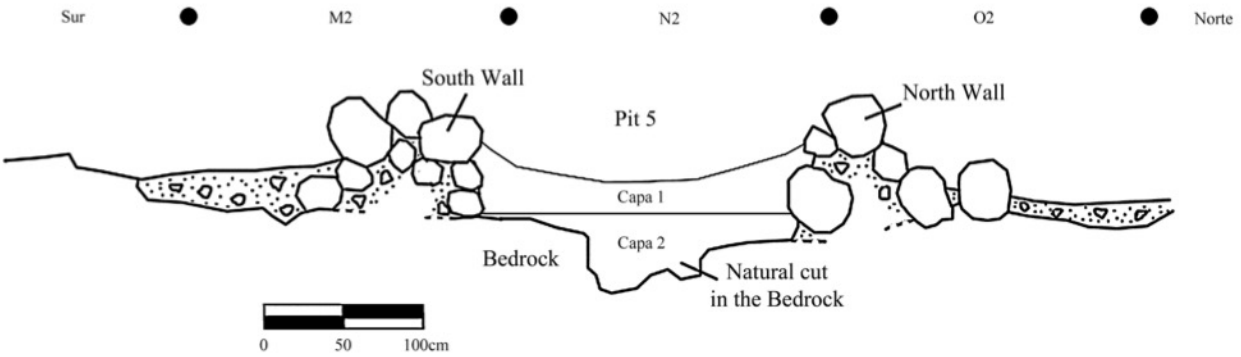


Figure 6-43: South-North profile cut drawing of Annular Structure 5 showing the extra construction materials that have collapsed from the Northern wall.



Figure 6-44: Photograph of Annular Structure 5 post-excavation showing the placement of the ring stones directly atop the surface bedrock.

Excavation: Several features of Annular Structure 5 differed from the other ring structures excavated during the 2014 and 2015 summer field seasons. First, Annular Structure 5 contained two nearly complete ceramic vessels, one inside the other, abutting the interior of the northern wall at a depth of only 1 meter below the top of the ring and only 30 cm below the surface of the topsoil (Figures 6-45 and 6-46). Likewise, only a thin layer of soil separated the vessels from the bedrock internal floor of the structure. These vessels did not appear to represent a purposefully placed offering and represented the only instance of nearly complete ceramic vessels being recovered from an annular structure to date. Similarly to the other annular structures, the fill within the central depression consisted of dark brown soil near the surface that became slightly lighter as excavators descended. However, unlike the other annular structures, the central depression of Annular Structure 5 arrived at, but did not cross through, the surface layer of bedrock. Instead of an entrance to a *sascabera* or at least cutting through the bedrock to arrive at the *sascab* layer below, it appears the builders of this structure burned materials directly on the surface bedrock, which exhibited the dark grey color of burnt rock. The interior walls of the ring boulders also exhibited the color and texture indicating that they had been exposed to multiple firing episodes. Thus, while Annular Structure 5 did possess several features similar to the other excavated annular structures, it was the only structure excavated during this investigation that did not cross through the top layer of bedrock. This raises the possibility that it was used to burn other materials besides limestone and used for purposes other than producing lime.

The final peculiar feature of Annular Structure 5 was a natural trench or fissure in the bedrock that cut through nearly the entirely of the central depression from the northwest to the southwest (Figure 6-47). The fracture had an average width of 30 cm wide and a depth of 40 cm. Like the flat, sloping bedrock of the surface, the bedrock walls within the fracture also exhibited

evidence of having been burned. Even more interesting is the fact that the natural trench in the bedrock continued under the southeastern wall of the ring and extended approximately one meter outside the structure. Excavations of the southeastern wall of the structure revealed a natural small bridge of bedrock that spanned the fissure beneath the ring wall and formed a short tunnel. The medium size boulders of the southeastern wall were placed atop this natural bedrock bridge, keeping the tunnel below clear (Figures 6-48 and 6-49). The evidence for burning within the structure suggested that this tunnel was deliberately kept open to allow the passage of air into the structure, presumably to maintain a fire. It is even likely that the builders of the structure located it where they did in order to take advantage of the natural ventilation system offered by the fracture in the bedrock. A similar situation was discovered in the excavation of Annular Structure 8. Again, the lack of *sascab* shed doubt on this structure being used primarily to produce lime powder, but this ring structure was undoubtedly used for cooking some type of materials. It is possible that Annular Structure 5 was a young lime-burning kiln that had only been used a certain amount of times before use ceased, which prevented the surface bedrock from being loosened up enough to begin to excavate the central depression of the structure through to the *sascab* layer.



Figure 6-45: Photograph of the two ceramic vessels recovered from just inside the northern wall of Annular Structure 5.

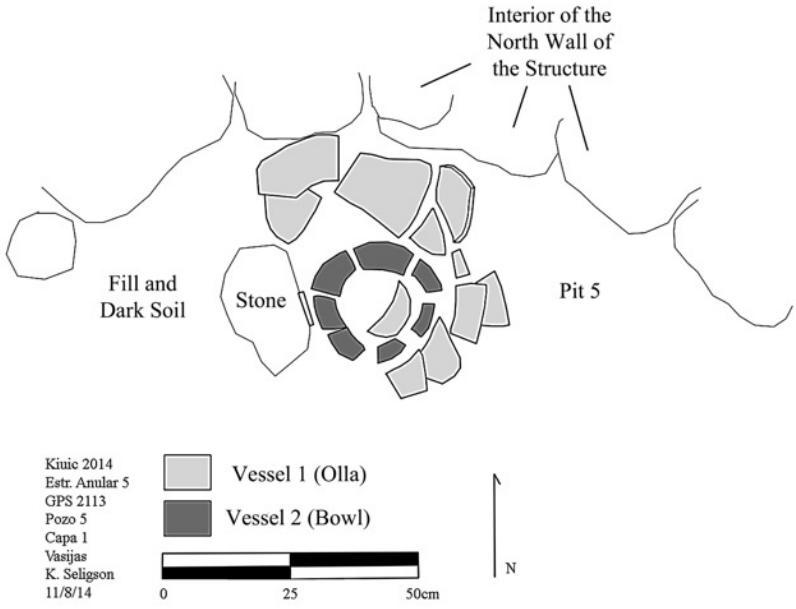


Figure 6-46: Drawing of the ceramic vessels found just within the northern wall of Annular Structure 5.



Figure 6-47: Photograph of the natural fissure in the surface bedrock within Annular Structure 5.



Figure 6-48: Photograph of the natural fissure in the surface bedrock of Annular Structure 5 running underneath the southeastern wall of the structure.



Figure 6-49: Photograph of the tunnel formed by the natural fissure and natural bedrock bridge below the southeastern wall of Annular Structure 5 that may have served as a ventilation system.

Annular Structure 6 (GPS 1863)

Location: Annular Structure 6 is located on relatively flat terrain surrounded by slightly elevated outcrops of limestone in the outer zone to the west of Escalera al Cielo (Figure 6-1). A fairly large *haltún* (4.9 m long by 2.9 m wide, more than 1.75 m deep) is located immediately to the south of the structure (Figures 6-50 and 6-51). It is not likely a coincidence that the two features are located so close together. The nearest Prehispanic architectural feature to the annular structure is a *pasel* foundation located approximately 75 m to the northwest. There is a quarry about 90 m to the northeast on the other side of an elevated patch of limestone outcrops, but it would hardly be a convenient trek from the quarry to the annular structure. Aside from the presence of the numerous limestone outcrops around Annular Structure 6 that could have provided raw materials for lime production or construction, the large *haltún* is the only obvious

factor influencing the construction of the large annular structure in this location. Despite the presence of these many outcrops, the builders of Annular Structure 6 did not use a slope for construction in a similar fashion to Structures 1, 2 and 3. Annular Structure 6 was excavated into relatively level bedrock, supporting the notion that the *haltún* was the most important factor influencing the location of the construction.



Figure 6-50: Photograph of the *haltún* located immediately to the south of Annular Structure 6.

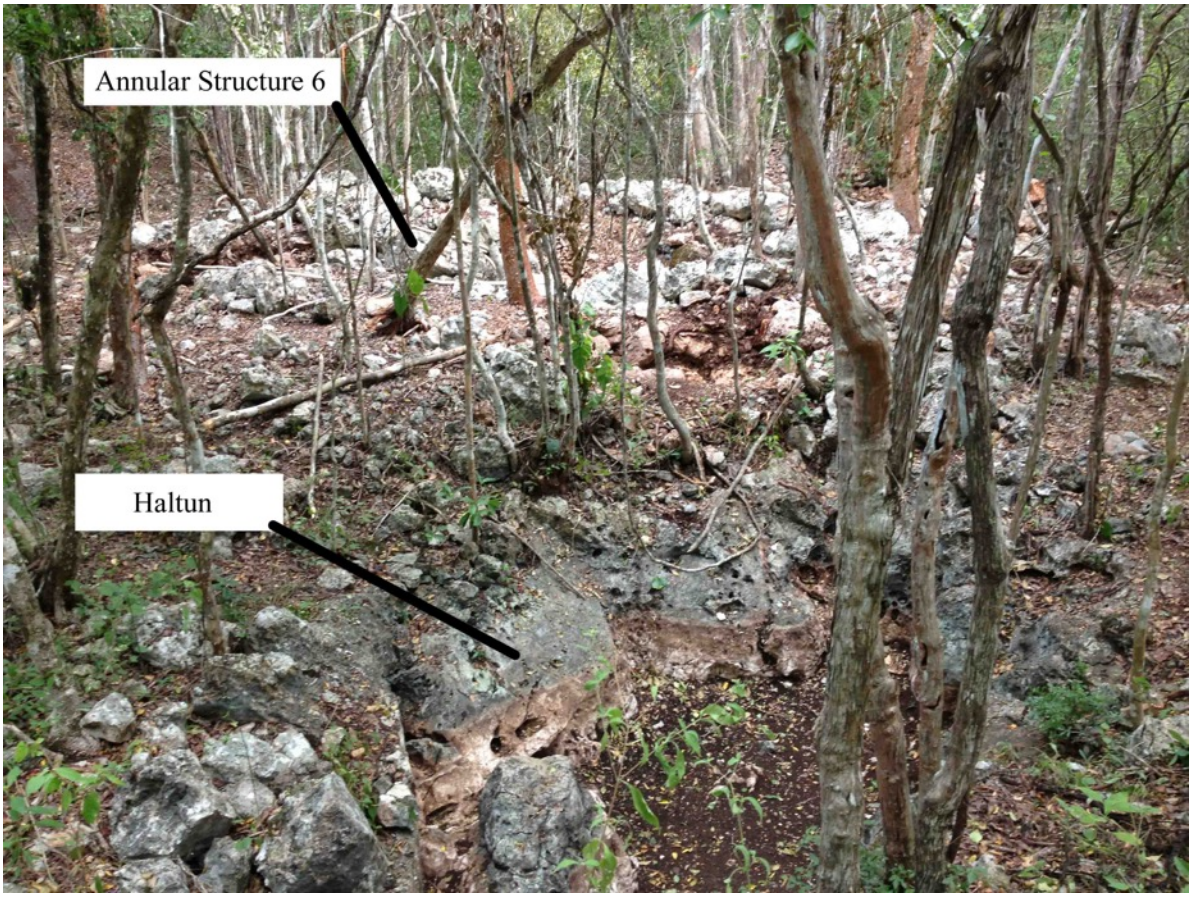


Figure 6-51: Photograph of the proximity of Annular Structure 6 to the *haltún*.

Construction Form: Annular Structure 6 was the largest annular structure excavated during the 2014 and 2015 field seasons. It was most similar in construction form to Annular Structures 1 and 2 in that it was constructed of a double ring of boulders surrounding a deep central depression. The central depression measured 3.3 m North-South by 3 m East-West at surface level and the thickness of the double walls varied between 0.5 and 1 m wide. Additionally, on some sides of the structure it appeared that there was a third, smaller wall represented by stones of a slightly smaller size. It is possible that this outermost ring marked the extent of fill used to shore up the inner walls of the structure. The diameter of the structure including this exterior ring averaged 10 m, which would make this structure by far the largest yet identified and more similar in form to structures excavated at Oxkintok (Ortíz Ruíz 2014) (Figure 6-52). The double

wall that surrounds the central depression was constructed of very large boulders, some measuring over a meter in length and close to a meter in width. Many of the stones from the interior ring had fallen into the central depression, making the excavation of this structure particularly difficult (Figures 6-53 and 6-54). The quantity of stones recovered from within the pit suggests that there was at least one additional vertical row of stones atop the double wall. The fill between the two rings of large boulders consisted of smaller stones and earth, much of which had collapsed into the central depression. Although much of the interior walls and fill had fallen inside the central pit, there was still a depression measuring 1.25 m deep at the beginning of the excavations and enough stones remained in place in the arcs to demonstrate that the structure's original form was nearly circular.

Excavation: Due to the precarious position of several large boulders within the northern half of the central depression, excavations focused on uncovering the Southern, Western, and Eastern interior walls of the structure. The fill in the central depression consisted of dark brown soil in the uppermost layers that became lighter in the lower levels until it became more white than brown as it mixed with *sascab* and/or stucco. Stones of all sizes that had collapsed from the interior upper walls of the structure were encountered throughout the excavations. Based on those walls that remained relatively intact and on the amount of fill recovered from the central pit, it was determined that the interior walls of the structure originally consisted of between 2 and 4 vertical rows of large stones in the uppermost layer. These rows of boulders sat atop a layer of bedrock, through which the central depression was cut. The upper bedrock layer of this annular structure was thicker than that of the majority of the other excavated annular structures, beginning at an average depth of 1.3 m below the top of the interior arc and continuing for over 2

m down. At first, the bedrock layer was cut to gradually slope inward, but then at an average depth of 3.2 m below the top of the arc the bedrock began to descend completely vertically. Due to the angling of the uppermost layer of bedrock, the diameter of the central depression shrunk to 2.2 m East-West (Figures 6-55 and 6-56).

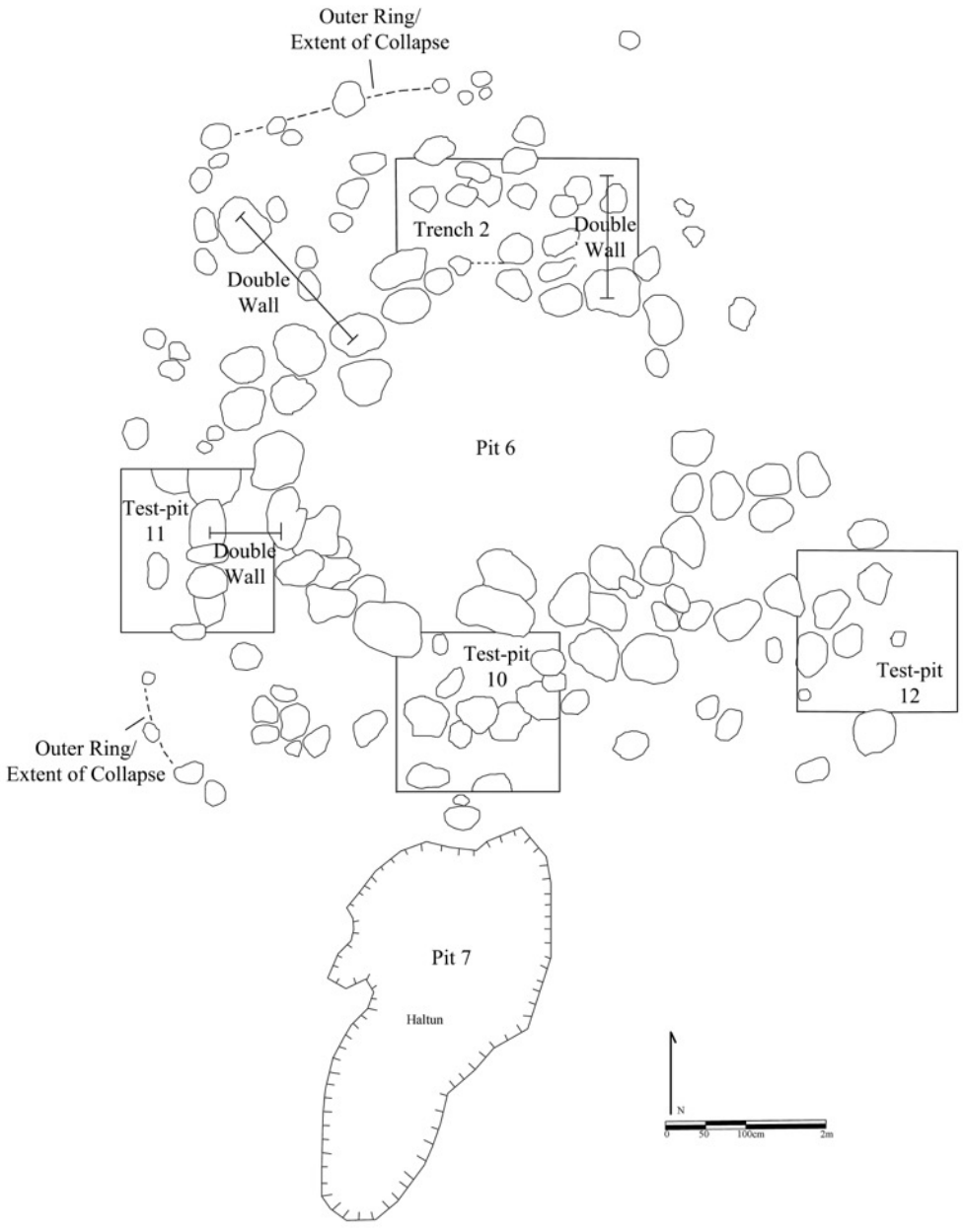


Figure 6-52: Aerial view drawing of Annular Structure 6 and the adjacent *haltún.*



Figure 6-53: Photograph of the interior of Annular Structure 6 near the beginning of excavations.



Figure 6-54: Photograph of the very large boulders from the interior walls of Annular Structure 6 that had collapsed into the central depression.

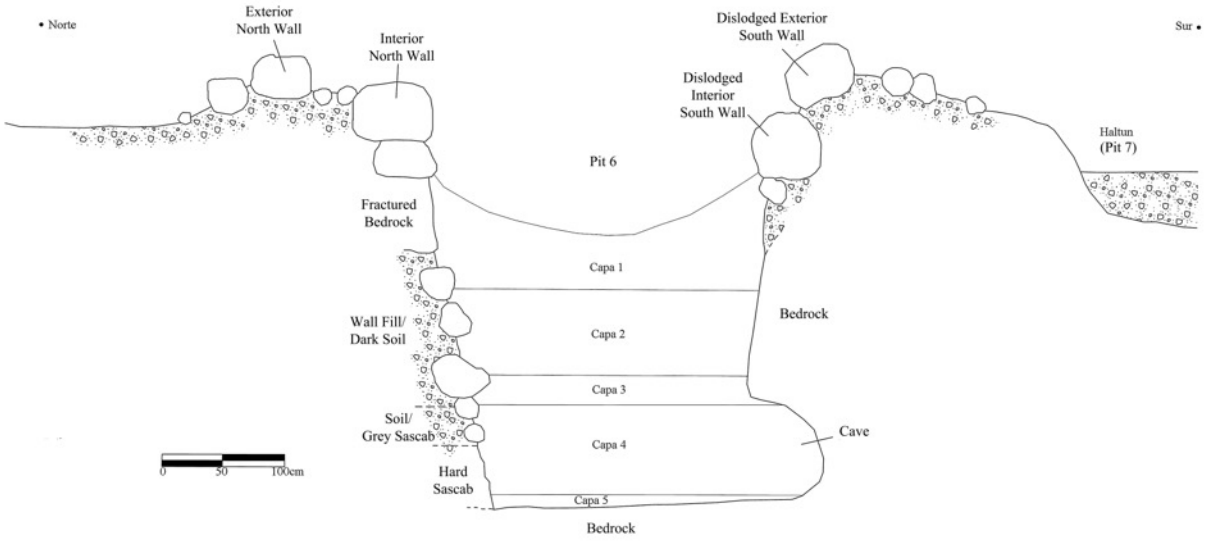


Figure 6-55: North-South profile cut drawing of Annular Structure 6 looking East.

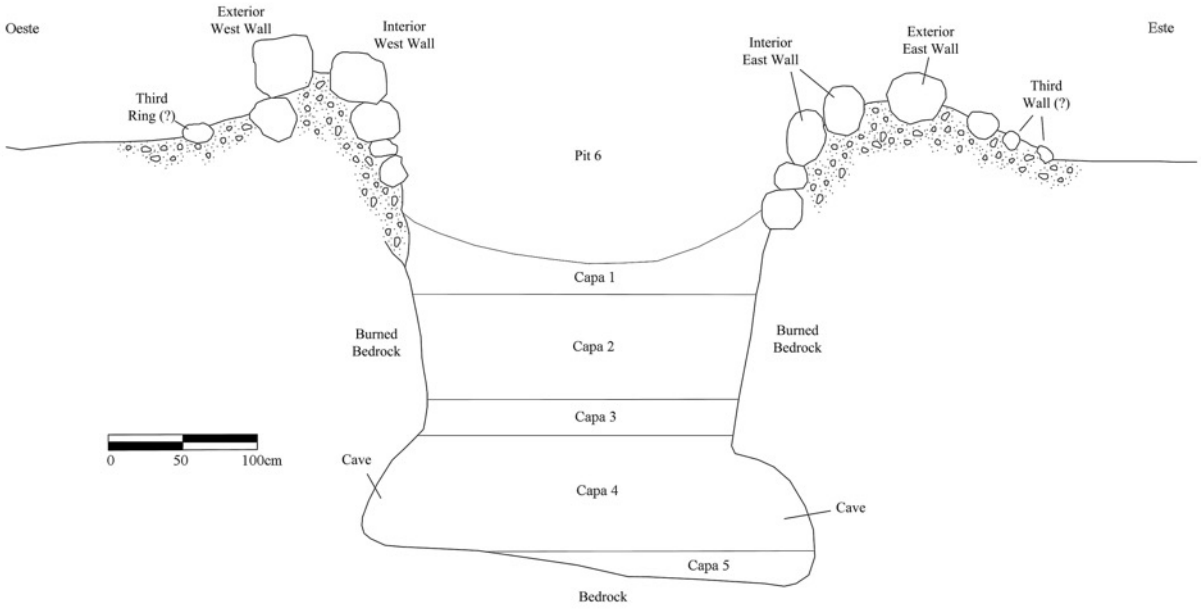


Figure 6-556: West-East profile cut drawing of Annular Structure 6 looking North.

At a depth of 3.5 m below the top of the ring, the bedrock walls began to slope away from the center of the depression, forming a cave-like recess at the level of the *sascab* layer. This recess spanned the entire circumference of the excavated part of the structure interior, and

although the debris from the north side could not be removed it appeared that the recess continued through this area completing a full circle. The fill in the center of the depression at the level of this recess was very light as the soil was mixed with much fine *sascab*/stucco. Approximately 40 cm below the level of the beginning of the recess was a layer of very hard *sascab*/stucco that proved to be about 10-15 cm thick. As posited for the other annular structures that reached a hard layer of *sascab*/stucco*,* it appeared that this layer represented reconstituted calcium-carbonate that had passed through the cycle of decarboxylation, hydration, and carbonation. Below this hard layer of *sascab*/stucco, I found a layer of softer grayish *sascab*/stucco and then another layer of even harder *sascab*/stucco. Beneath this second, harder layer, which measured less than 10 cm in thickness, excavations reached the lower level of bedrock that formed the floor of the annular structure. The recess in the walls appeared to represent the remains of a small *sascabera* from which the builders of the annular structure harvested *sascab*. The final depth of the floor of the annular structure averaged about 4 m below the top of the ring. The depth of the interior depression and the size of the double wall ring made this annular structure most similar in form to Annular Structures 1 and 2, despite the spatial context being markedly different (Figures 6-57-6-60).

In addition to the central pit, I excavated five additional test pits around the outside of the structure, including one in the center of the *haltún*. These external test-pits demonstrated the true width of the surface ring of the structure and demonstrated that the fill from the double-ring surrounding the central depression extended all the way to the outer third ring. The test-pit in the *haltún* confirmed that it was indeed a deep natural depression (~1.75 m below the surface) and not a human-excavated quarry.

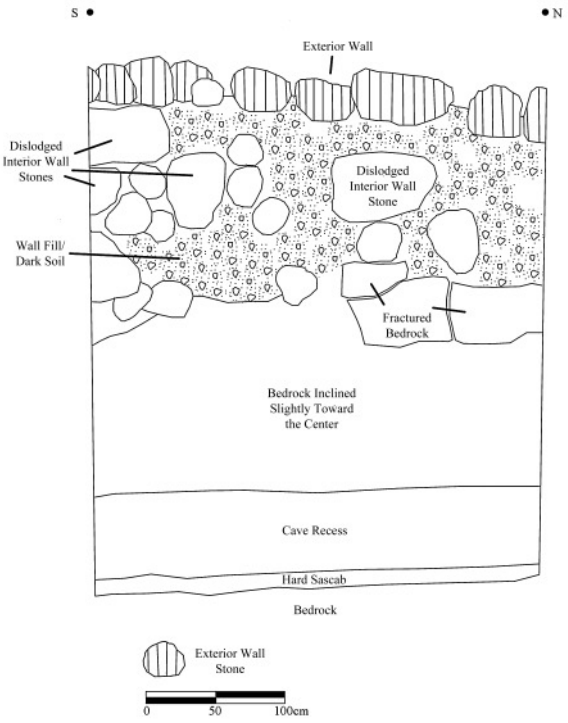


Figure 6-57: Profile drawing of the Western interior wall of Annular Structure 6.

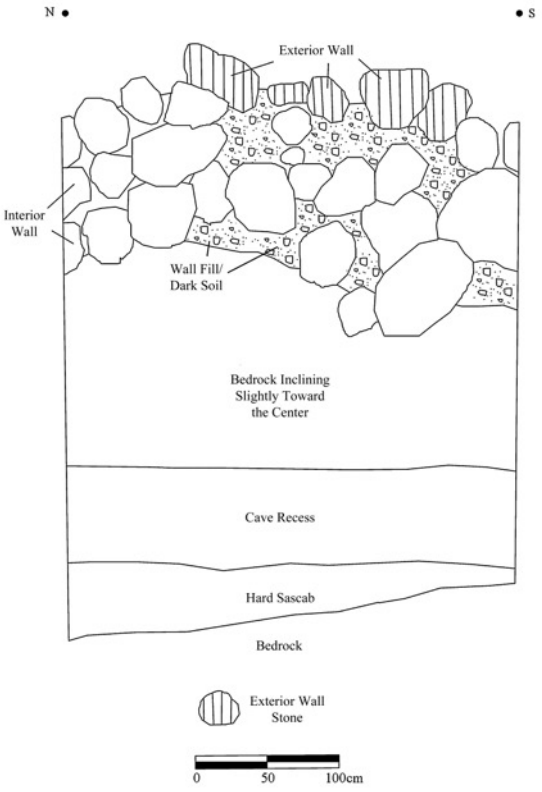


Figure 6-58: Profile drawing of the Eastern interior wall of Annular Structure 6.



Figure 6-59: Photograph of Pozo 6 excavation into the central depression of Annular Structure 6 looking North.



Figure 6-60: Photograph of Pozo 6 excavation into the central depression of Annular Structure 6 looking Southeast.

Annular Structure 7 (GPS 1967)

Location: Annular Structure 7 is located approximately 2 km to the west of *Escalera al Cielo* in the heart of the outer zone of the study area (Figure 6-1). Topographically, it is located on the edge of a low limestone mound rising only 0.75 m above the surrounding surface and is surrounded by very flat land that extends in all directions. The nearest Prehispanic architectural features are another small annular structure located approximately 60 m to the east and a small *pasel* foundation located 110 m to the northeast. The topography and quality of the soil in this area suggest that the land was agriculturally productive in the past; the only apparent reason for locating the annular structure at this specific position may be the existence of the small outcrop.

Construction Form: Annular Structure 7 was the smallest of the ring structures excavated during the 2014 and 2015 summer field seasons. The interior of the structure measured only 1.3 m North-South by 1.2 m East-West (Figure 6-61). The walls of the structure consisted of a single ring of medium/large boulders. The preservation of two medium-size boulders atop two other boulders on the north side of the ring suggests that there was originally a second vertical row of stones atop the ring (Figure 6-62). Similar to the larger annular structures built on bedrock slopes, the wall of this small annular that is located at the base of the outcrop appears to have been constructed of more material than the wall higher up on the outcrop. In this case it is the south wall, and the large quantity of wall debris that has fallen outside the structure suggests that it may have originally possessed an adjoining row of retention stones to combat the slight slope of the outcrop. Aside from this retention wall, there did not appear to have been a double wall similar to Annular Structures 1, 2, and 6.

Excavation: Excavations within the central depression of the structure, which was not very deep at the start of the investigation, quickly arrived at the surface level of bedrock. The surface ring of boulders was placed directly atop the bedrock of the limestone outcrop and the central pit was excavated through this thin layer of bedrock to reach the *sascab* layer below. The bedrock walls of the interior were very friable and exhibited a dark gray color suggesting that they had been burned. The fill of the central depression started out as dark brown soil close to the surface but almost immediately became mixed with small pieces of *sascab* and/or stucco and soon became lighter. Less than 0.75 m below the top of the ring, excavations encountered a layer of soft, powdery *sascab*/stucco. Immediately below this layer was found a thin layer of orange-brown soil and *sascab*/stucco, most likely representing the remnants of multiple burning episodes. Beneath this layer, I discovered a thick layer of harder *sascab*/stucco (0.75 m deep) that lay atop the lower level of the bedrock. Excavations therefore demonstrated that the *sascab*/stucco layer below this limestone outcrop was relatively close to the surface. The *sascab* layer was so close to the surface, in fact, that *sascab* also appeared in excavations of the unit immediately outside the southeastern side of the ring, mixed with the surface bedrock layer. It is possible that the *sascab* encountered near the surface within the central depression represented reconstituted calcium carbonate. If this were the case, then the material found to be mixed in with the surface bedrock of the exterior unit might well have also been reconstituted calcium carbonate that had seeped through the perimeter of the structure after the lime production process. The other possibility is that the original excavation of the *sascab* from this outcrop extended over a wider area than was ultimately enclosed by the construction of this small, annular kiln.

Excavations discovered only a small quantity of stones from within the fill of the central depression that most likely represented the collapse of the uppermost interior walls into the

structure. Surprisingly, only two pieces of pottery were discovered during the entirety of the excavations within and around the outside of Annular Structure 7, both of which came from a unit outside the structure's ring. All of the other annular structures yet excavated contained much ceramic debris in the wall collapses, making the scarcity of ceramics in Annular Structure 7 unique. This lack of ceramics made it more difficult to ascertain the temporal context of this structure's construction and use, as the only piece of charcoal recovered from within the structure appeared to come from a disturbed context. Overall, Annular Structure 7 appeared to be a miniature version of the other ring structures excavated earlier in the 2014 field season (Figures 6-63 - 6-66).

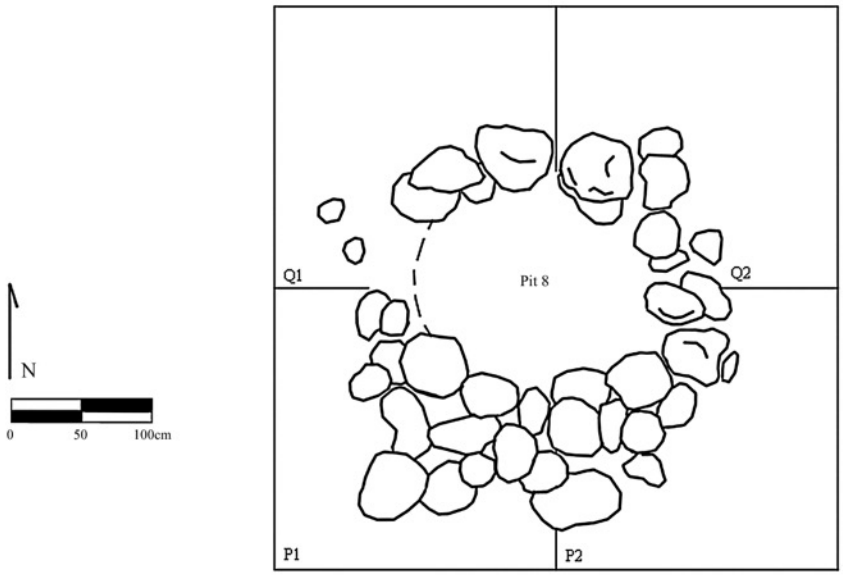


Figure 6-61: Aerial view drawing of Annular Structure 7.



Figure 6-62: Photograph of the Northern interior wall of Annular Structure 7 showing the extant two vertical rows of boulders ringing the central depression.

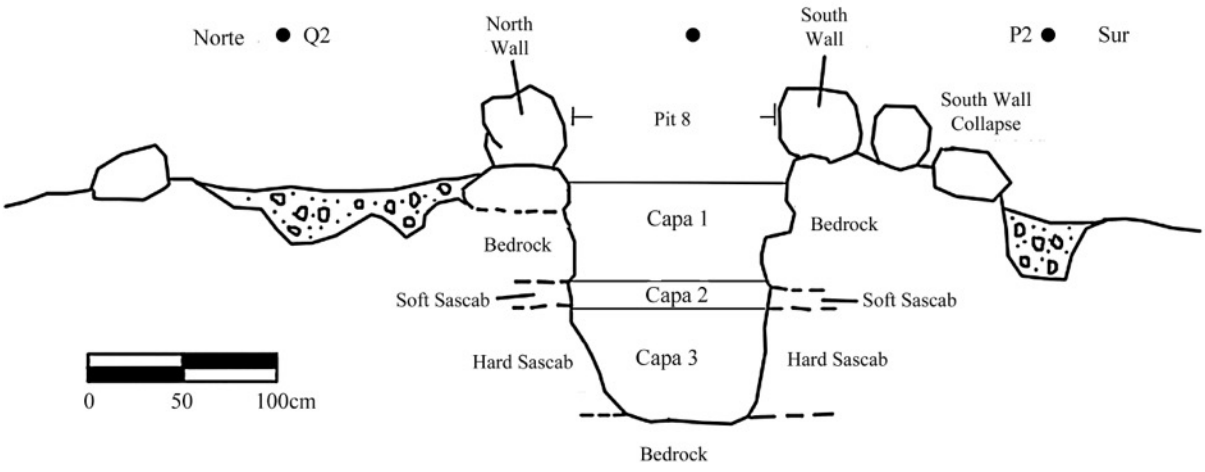


Figure 6-63: North-South profile cut drawing of Annular Structure 7 looking East.

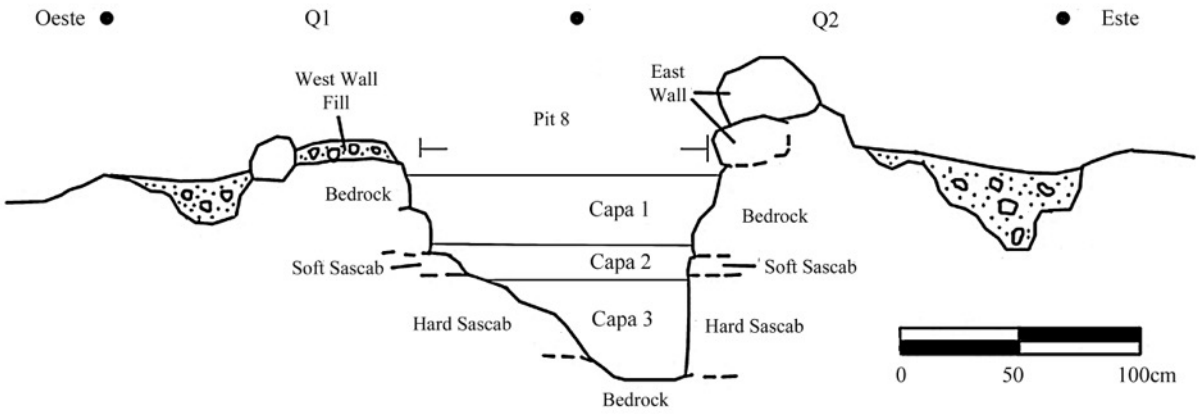


Figure 6-64: West-East profile cut drawing of Annular Structure 7 looking North.

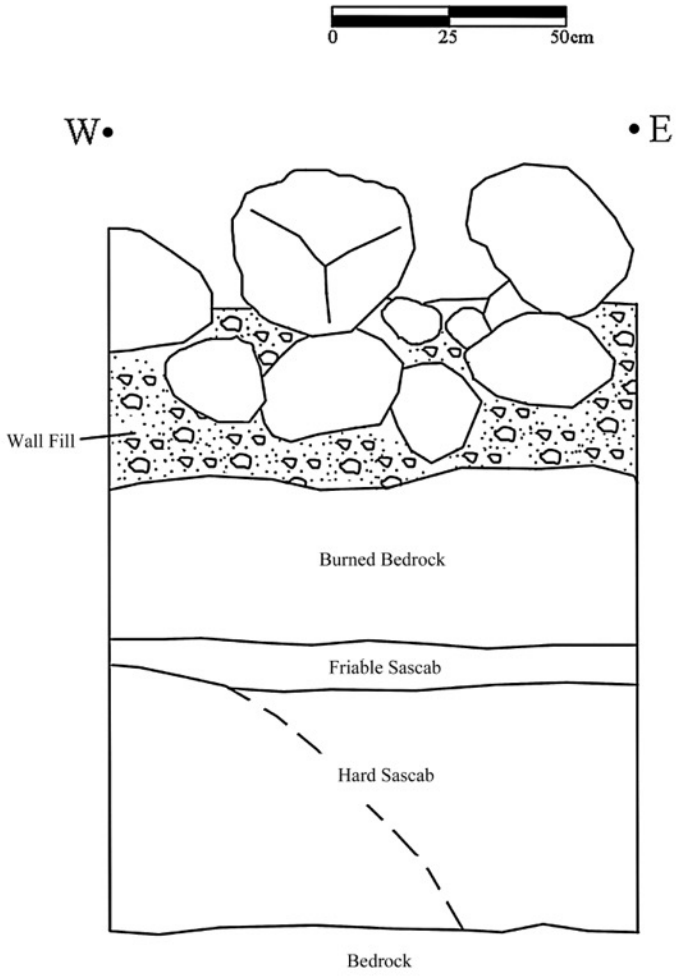


Figure 6-65: Profile drawing of the Northern interior wall of Annular Structure 7.

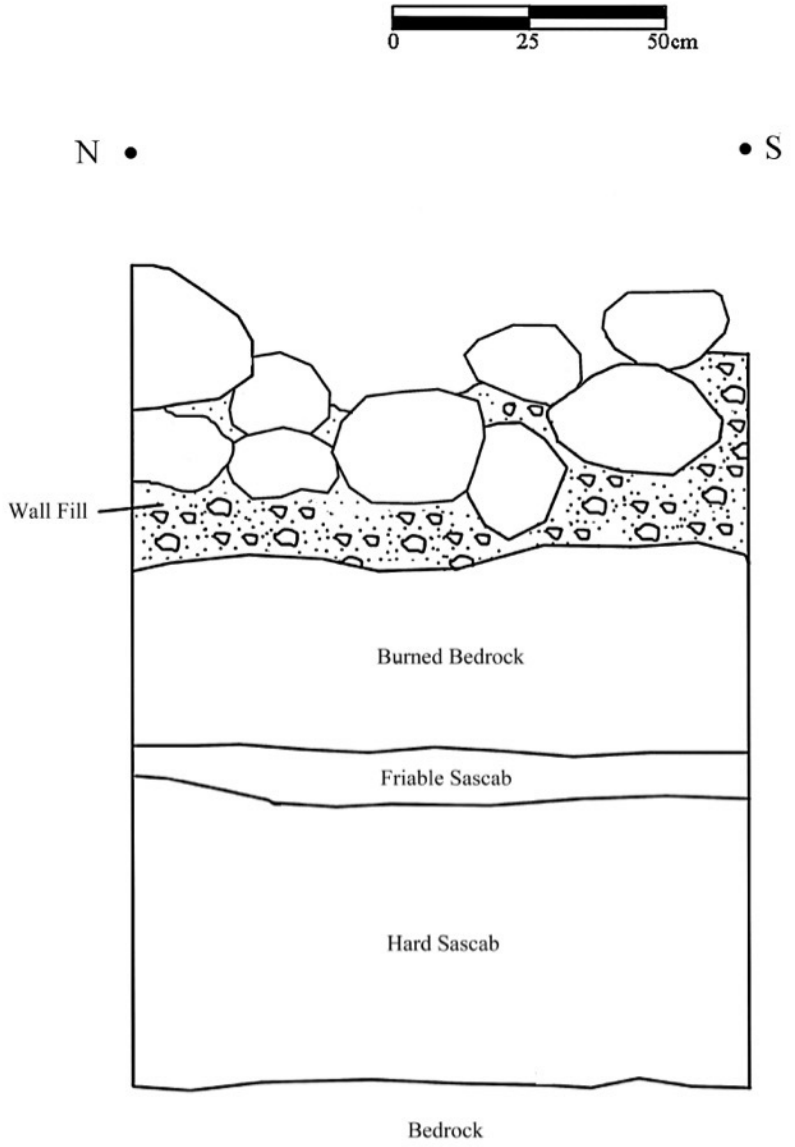


Figure 6-66: Profile drawing of the Eastern interior wall of Annular Structure 7.

Annular Structure 8 (GPS 2241)

Location: Annular Structure 8 is located at the southeastern base of a hill, approximately 200 m to the southwest of the Chulul palace complex of the Kiuic site center (Figure 6-1). It is located immediately to the east-northeast of Annular Structure 9 (their fill collapses overlap one

another), and Annular Structure 9 is surrounded on three sides by a collapsed *sascabera*/quarry system. The conjunction of these two annular structures and the extensive limestone extraction feature led me to hypothesize from the outset that this group may represent an Prehispanic lime processing complex. Annular Structure 8 is situated at the northeastern edge of a low limestone outcrop, through which it is connected to Annular Structure 9. The terrain levels out to the east and south of the annular structure where the soils are of a deeper, red variety known as *kancab*, which was and is particularly well suited for agriculture. Aside from Annular Structure 9 and the *sascabera*/quarry system there are no other archaeological features located nearby.

Construction Form: Annular Structure 8 was fairly well preserved, exhibiting a mounded form with a double-ring at the apex surrounding a depression in the center (Figure 6-67). Much of this superior double-ring of large boulders maintained their original circular formation, though some of the large ring stones of both the interior and exterior sides of the double-ring had fallen into the central depression. It appeared to have been similar in construction form to Annular Structures 1 and 2. The double-ring as it appeared on the surface of the mound was made of large stones varying in width from 1.5-1.75 m, and surrounding a central depression that measured approximately 2.5-2.75 m in diameter. This brought the total diameter of the ring to approximately 4-4.5 m (Figure 6-68). Taking into account the sloping fill collapse that surrounded the structure and gave it a mound-like shape, the maximum extent of the structure stretched to 10-12 m (Figure 6-69).



Figure 6-67: Photograph of Annular Structure 8 as it appeared prior to excavations.



Figure 6-68: Photograph of the Eastern interior wall of Annular Structure 8 showing the extant portion of the double-ring.

Excavations through a section of the Northeastern wall of the final phase of the structure found discovered a smaller double-wall made up of medium and large stones situated immediately on top of the bedrock (Figures 5-70 and 5-71). This smaller double-wall was part of an earlier (possibly the original) construction phase of Annular Structure 8. It was situated directly atop a natural arc in the bedrock below. When the natural bedrock arc veered further to the north, medium and large boulders were placed along the inside of the structure to continue a more circular pattern for the interior wall. An interesting feature of this original smaller wall was a natural fracture in the bedrock that cut a diagonal tunnel underneath the double-ring, potentially leaving an open passage between the central pit and the open-air outside the original structure (Figure 5-72). This situation was similar to the natural fissure in the bedrock of Annular Structure 5 that also provided a ventilation system to the center of the structure. It is possible that both the natural circular shape and the natural ventilation system factored into the decision to construct Annular Structure 8 in this location.

The small, original wall was made up of 2 concentric rings of at least 2 vertical rows of medium and large stones filled with smaller stones and soil. The wall measured 1.2-1.4 m in width and 0.7-0.9 m in height above the bedrock. It was eventually covered over by later stages of construction. It is unclear whether the later construction all took place in one construction episode or was built up over time as partially burned pieces of *chich* were discarded after firing episodes. Whether or not there were multiple later stages of construction, a final phase double-ring of large rough-cut boulders was placed atop the mound, brining the final height of the structure to at least 2-2.3 m above the bedrock. The later construction phase(s) of the structure used the interior side of the original double wall and consisted of an additional 2-3 more layers of medium-sized stones above it. A large amount of *chich* mixed with a few larger stones, as

well as ceramic sherds and soil were used to fill in the space behind the new interior side of the double-ring and completely cover the old ring. Surprisingly, there did not appear to be any larger stones below the exterior ring of the final apical ring. Instead, a sloping mound of *chich* and medium-sized stones were placed behind and below the new, higher interior wall and capped off by the exterior ring of large stones on top. The partially burned pieces of *chich* within the outer part of the structure were similar in appearance to the stones that were not completely calcined during my kiln firing experiment (Figure 6-73). It is possible that they represent leftovers from firing episodes inside the structure that were no longer candidates for calcining and were thus used to shore up the retention wall and provide extra insulation.

It is unclear how deep the central pit of the original structure was, but as demonstrated by the experimental portion of this investigation, each firing episode loosened up a layer of bedrock and/or *sascab* about 10-15 cm thick, which could have been easily removed and potentially used for the subsequent firing. In its final form, the central pit of the structure was lined on two sides by a fairly vertical cut in the bedrock, with the other two sides made up partially of bedrock and partially of medium and large stones apparently held in place by clay (Figures 6-74 and 6-75). The final shape of the pit was almost, but not exactly circular, and the final floor reached the level of the harder bedrock that underlay the *sascab* layer (Figures 6-76 and 6-77).

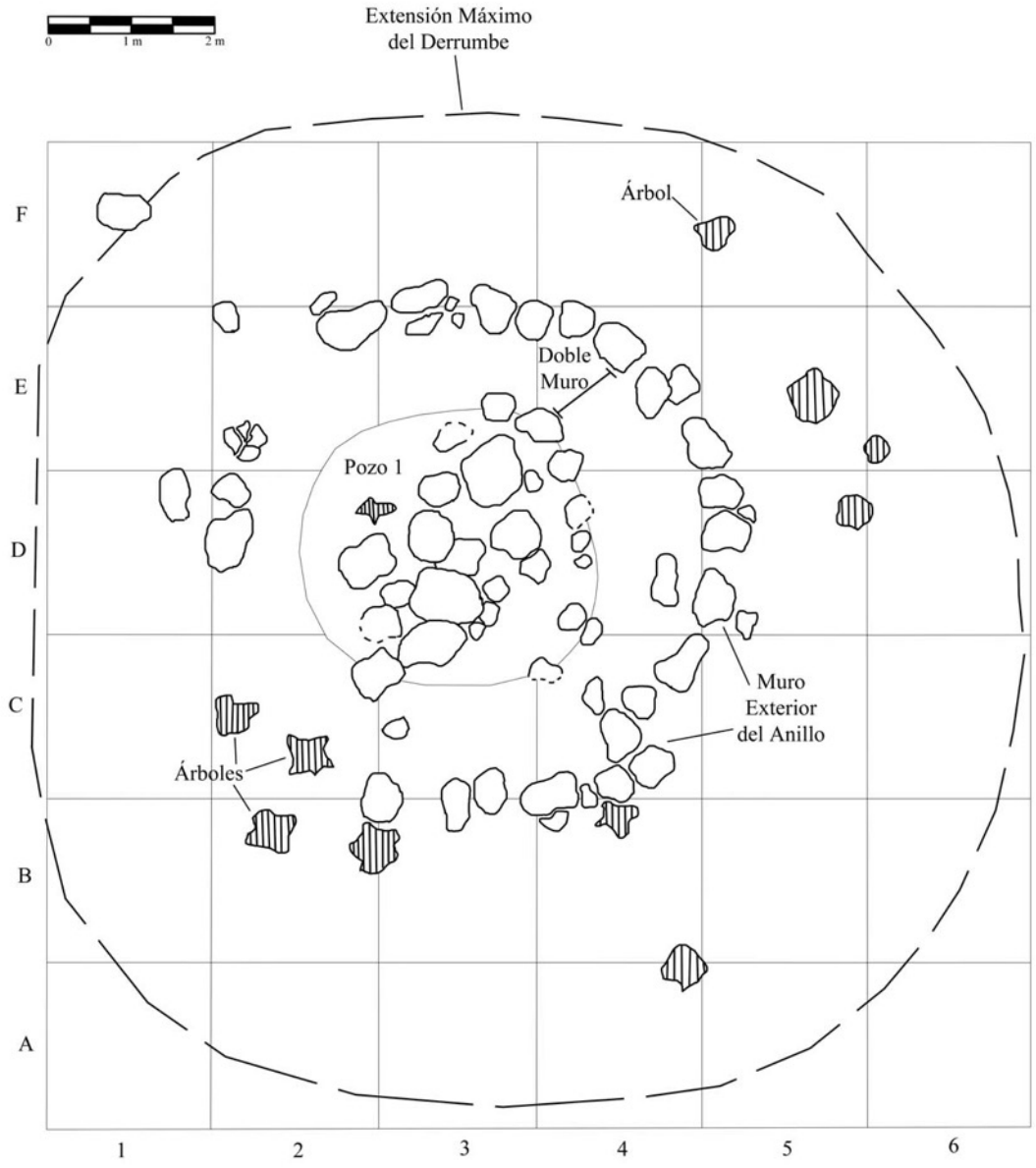


Figure 6-69: Aerial view drawing of Annular Structure 8.

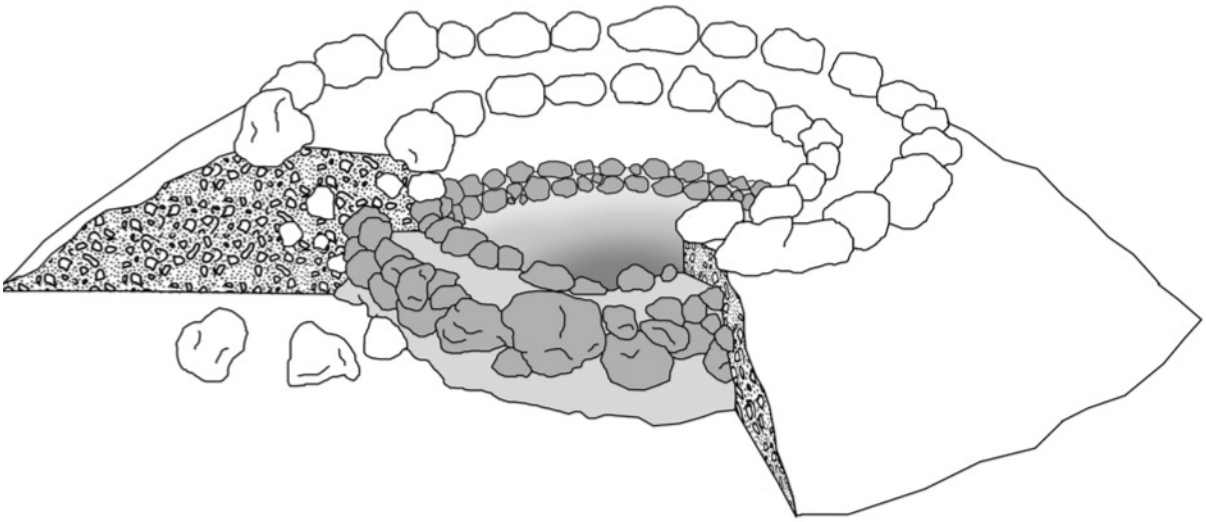


Figure 6-70: Schematic drawing of the construction phases of Annular Structure 8, showing the original phase small wall subsumed within the final, larger phase of construction.



Figure 6-71: Photograph of the smaller, original double-ring of Annular Structure 8 discovered beneath the larger double-ring and mound of the final construction phase.



Figure 6-72: Photograph of the natural fissure in the bedrock arc beneath the Northeastern section of the original small of Annular Structure looking Northeast from inside in structure.



Figure 6-73: Photograph comparison of the freshly burned *chich* that was leftover from the kiln experiment and the burned *chich* that scattered the surface of the mound surrounding Annular Structure 8.

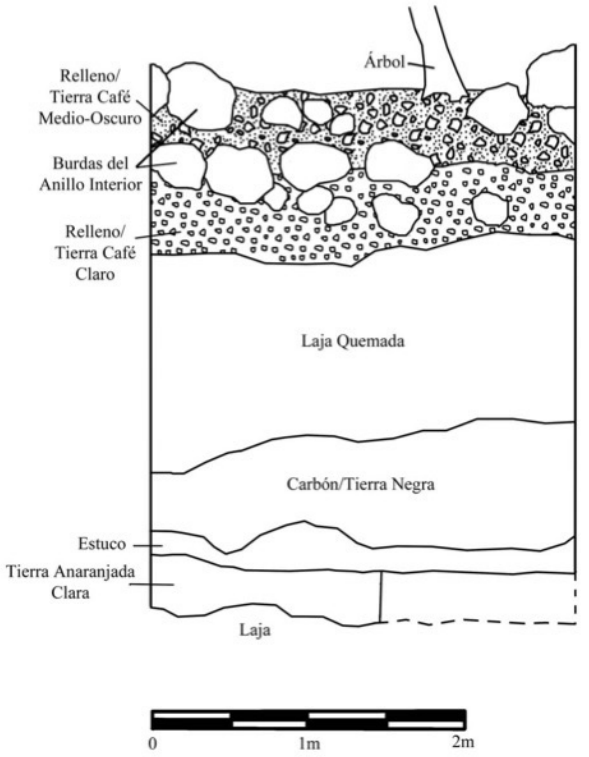


Figure 6-74: Profile drawing of the Eastern interior wall of Annular Structure 8.

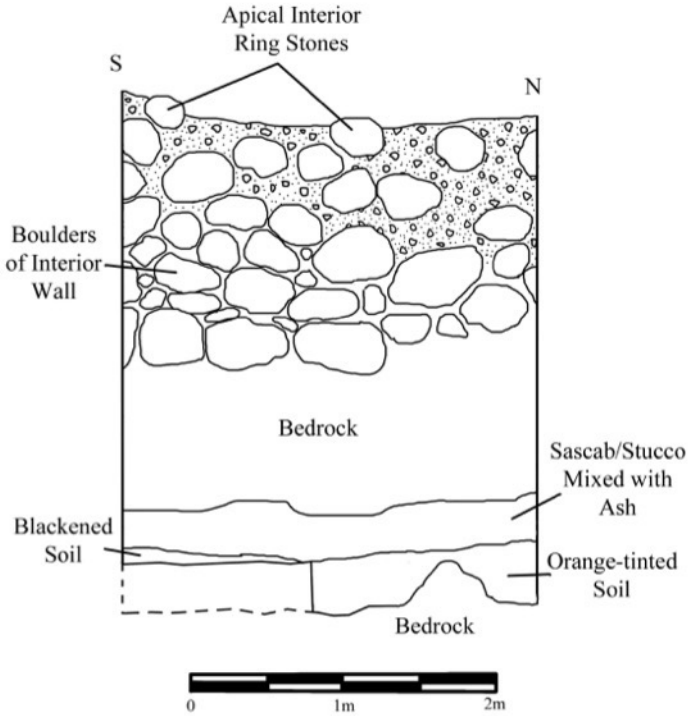


Figure 6-75: Profile drawing of the Western interior wall of Annular Structure 8.

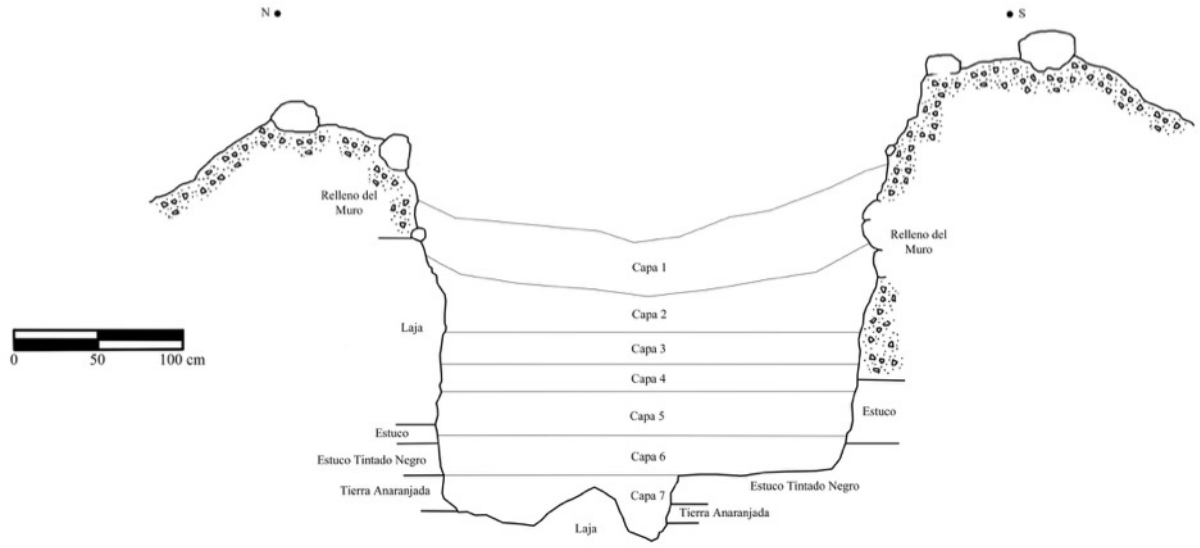


Figure 6-76: North-South profile cut drawing looking East of Annular Structure 8.

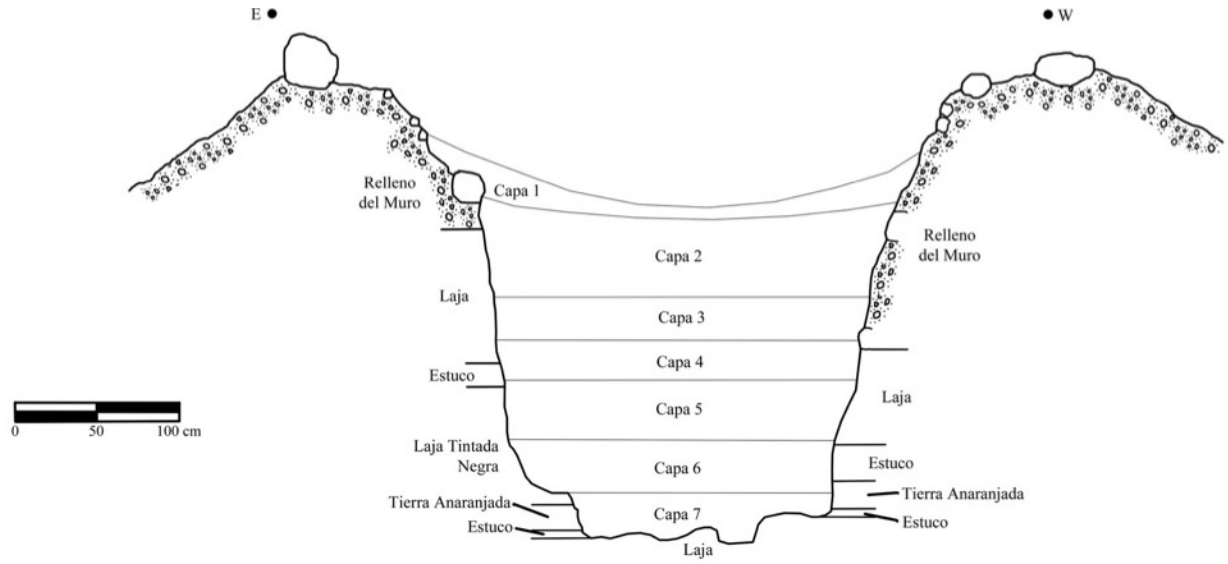


Figure 6-77: East-West profile cut drawing looking South of Annular Structure 8.

Excavation: Overall, twelve 2 x 2 m square units and one circular 2.5 x 2.75 m unit were excavated down to the bedrock in and around this structure (Figure 6-78). A unit was excavated through the central depression of the structure in order to determine the form of the interior walls

and the final depth of the pit. At a depth of 1.55 m below the top of the ring, a layer of cut bedrock was exposed on the eastern interior wall of the central depression. This cut bedrock wall mirrored similar examples that had been found in the previous excavations of annular structures and signified that the original excavators of the central pit had excavated down through the surface layer of bedrock. While the natural patterning in the surface bedrock had factored into the location and shape of the kiln, the original builders had also cut through the bedrock, perhaps aided by the loosening of the stone with each successive firing episode. The bedrock walls exhibited evidence of having been exposed to multiple burns through their slightly darkened appearance and friable texture. The eastern bedrock wall ended up measuring nearly 2 m in height, eventually meeting up with the layer of uneven floor of the depression made up of harder, undulating bedrock (Figure 6-79). The bedrock eastern wall curved around the southern end of the depression, but was unable to be followed completely in the western side of the structure due to the dangers of wall collapse.

Another line of evidence suggesting that materials were burned in the interior of the structure was discovered at a depth of almost 3 m below the surface of the ring in the form of blackened soil mixed with large chunks of charcoal (Figure 6-80). Large samples of carbon were recovered from this layer, and it is possible that this soil in fact represented a layer of disintegrated carbon. Sandwiching this layer of blackened materials were two layers of what appeared to be white stucco, which suggests that temperatures inside the structure were reaching high enough temperatures for long enough duration to calcine limestone. Samples of these layers were recovered for the purposes of oxygen and carbon isotope analyses to determine whether they represented naturally occurring *sascab* or reconstituted lime product. Below the lower level of stucco, a layer of light, orange-colored soil mixed with stucco bits was uncovered (Figure 6-

94). The orange tint to the material might also have reflected the burning of the bedrock floor from which it most likely eroded. The orange material lay directly above the final bedrock floor of the structure, which was at an average depth of 3.4 m below the surface of the final phase ring.

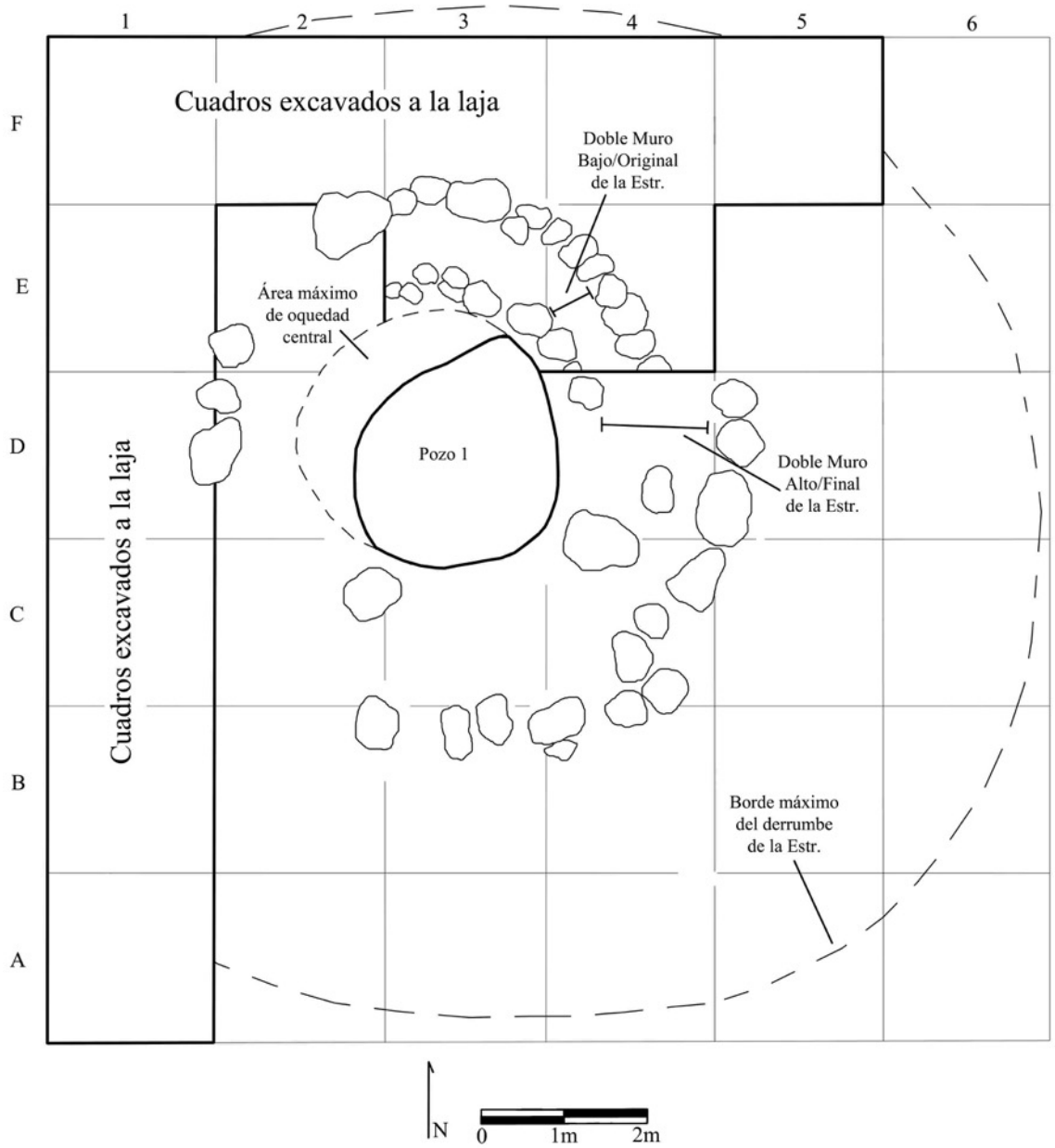


Figure 6-78: Aerial view drawing of Annular Structure 8 highlighting the excavated units.



Figure 6-79: Photograph of the bedrock beneath the excavated section of the original wall as well as the bedrock cut of interior eastern and northeastern sides of the central depression of Annular Structure 8.



Figure 6-80: Photograph of the layer of blackened soil and charcoal uncovered near the base of Annular Structure 8.



Figure 6-81: Photograph of layers of blackened soil, stucco/*sascab*, and orange-tinted soil near the base of Annular Structure 8.

The western and northern sides of the interior depression consisted of walls made of medium and large rough-cut stones that served to give the depression a rounder shape than the natural splintering of the bedrock afforded (Figure 6-82). Samples of clay recovered from within the cracks between the wall stones exhibit evidence of being partially cooked. A cross-section of a piece of this clay demonstrated how the side facing into the pit was completely cooked, the center was partially cooked, and the side that was wedged in between the wall stones was dry but not cooked (Figure 6-83). It is possible that the clay found along the walls represented a deliberate effort to insulate the kiln for firing.

In addition to the excavations in the central depression, two trenches were excavated along the western and northern edges of the structure, respectively (Figures 6-84 – 6-87). These were designed to determine the form of the exterior walls and uncovered evidence that the final phase(s) of the structure included massive amounts of small stone fill (chich) used to shore up the interior wall and provided a foundation upon which the superior ring of stones was placed. It is likely that the final pattern of the sloping fill wall is partially the result of collapse and therefore the maximum extent of the construction material recovered in the archaeological record was wider than the original structure extent. However, the infrequency of larger stones recovered from these exterior excavations indicated that the *chich* was part of the construction plan, purposefully used as insulation and wall support. As mentioned above, much of the *chich*, especially on the surface of the sloping exterior wall, exhibited evidence of having been burned and then discarded onto the slope, perhaps helping to build up the insulation over time.

Excavations in Square F5, just to the northeast of uncovered a small offering deliberately placed there most likely as part of the later phases of construction (Figures 6-88 and 6-89). It consisted of an overturned tripod bowl measuring 30 cm in rim diameter and was located 190 cm from the nearest point of the top of the exterior wall of the annular structure almost exactly due northeast from the ring of the structure. It was recovered at a depth of 160 cm below the top of the structure, in the south-central part of the unit. Four medium-sized stones were placed around it and a few more were placed on top to shield it from the rest of the small stone fill that surrounded it, but it was shattered into 7 larger pieces and a few smaller pieces. Almost all of the sherds were recovered, allowing for complete reconstruction of the vessel in the laboratory (Figures 6-90 and 6-91). Samples of soil were taken from immediately below the vessel to test for any organic remains through laboratory analysis. Based on the location of the offering at the

bottom of a whiter soil layer mixed with stucco, it appears that the plate was overturned at the bottom of the debris/fill from the northeastern exterior wall of annular structure 8, immediately atop sterile soil during the final phase(s) of construction.

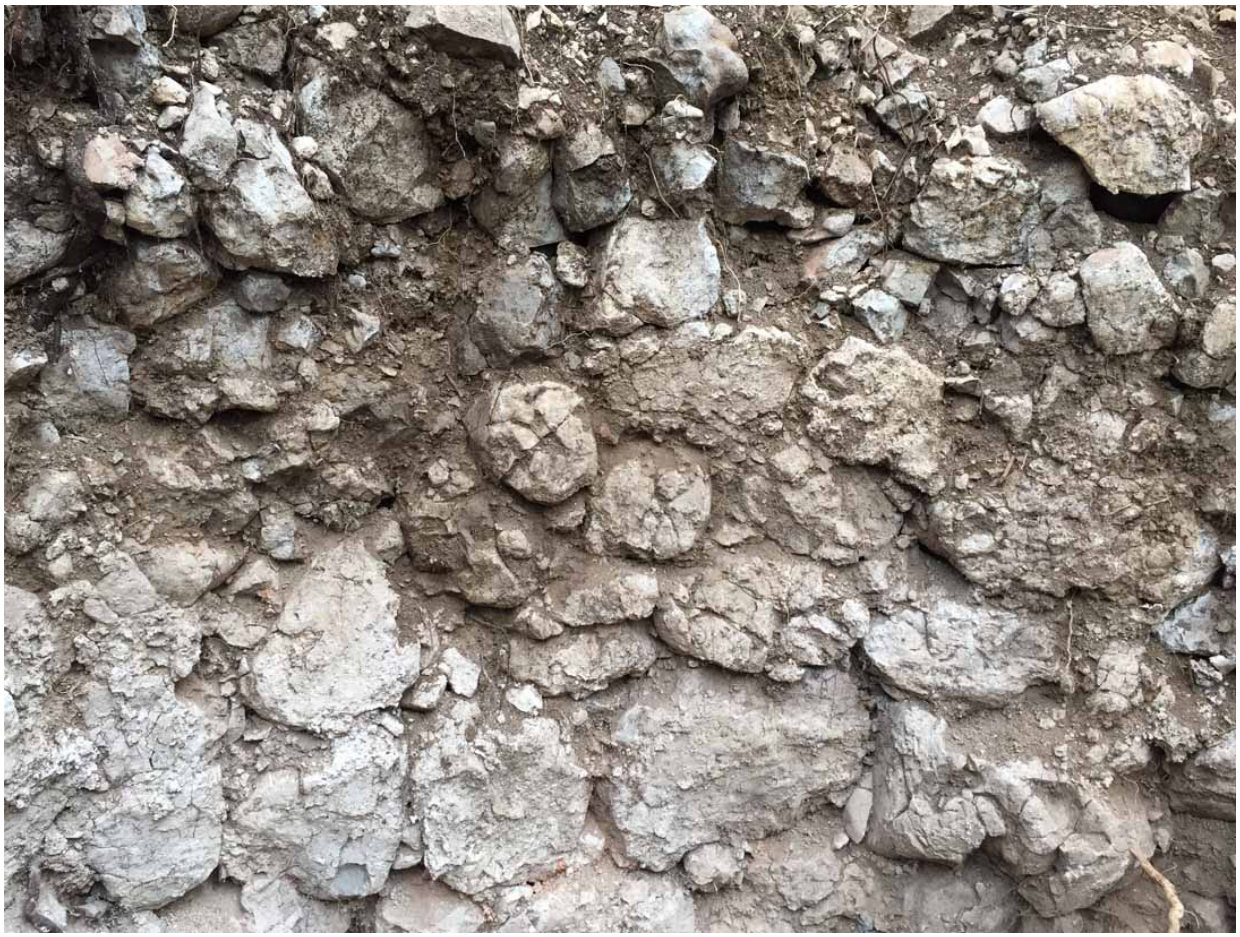


Figure 6-82: Photograph of the western interior wall of the central depression of Annular Structure 8 showing the medium- and large-sized stones used to round out the kiln.



Figure 6-83: Photograph of a piece of clay recovered from the cracks in the western interior wall of Annular Structure 8 showing various degrees of burning from most burned on the left to the least on the right.



Figure 6-84: Photograph of the northern half of the trench excavated along the western exterior of Annular Structure 8.



Figure 6-85: Photograph of the trench excavated along the northern exterior of Annular Structure 8 looking East.

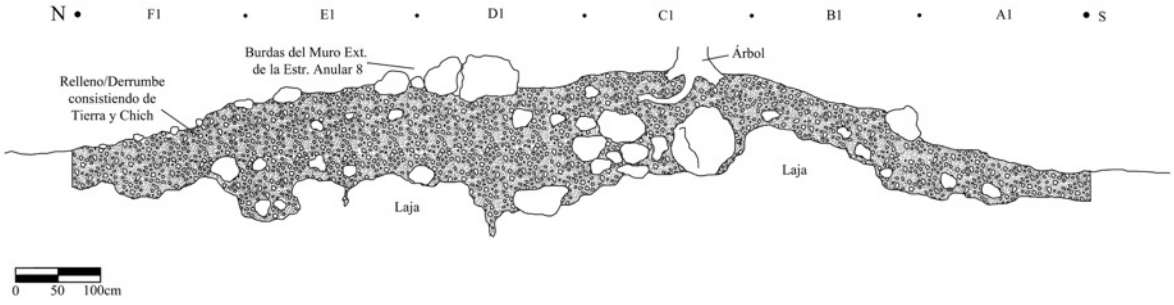


Figure 6-86: Profile cut drawing of the western exterior wall of Annular Structure 8.

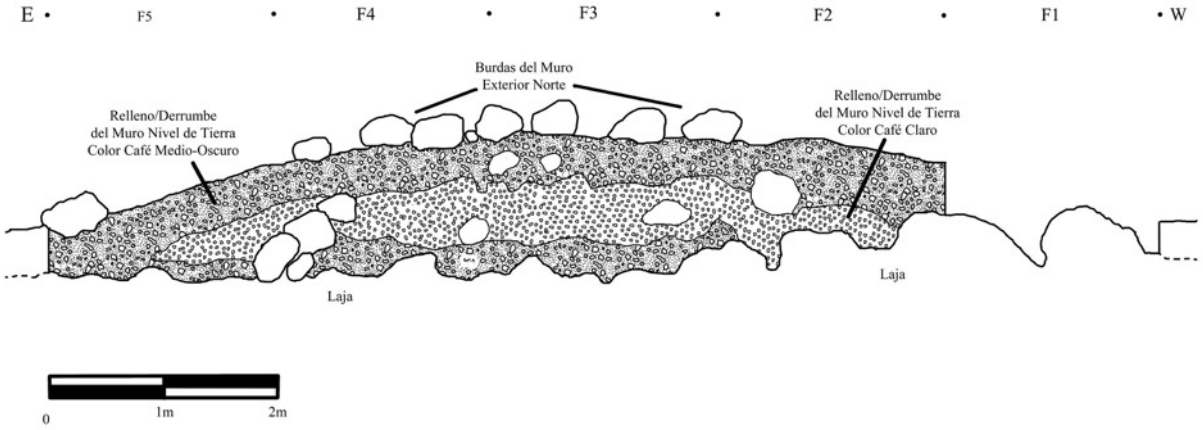


Figure 6-87: Profile cut drawing of the northern exterior wall of Annular Structure 8.



Figure 6-88: Photograph of the dish offering found buried to the northeast of Annular Structure 8.

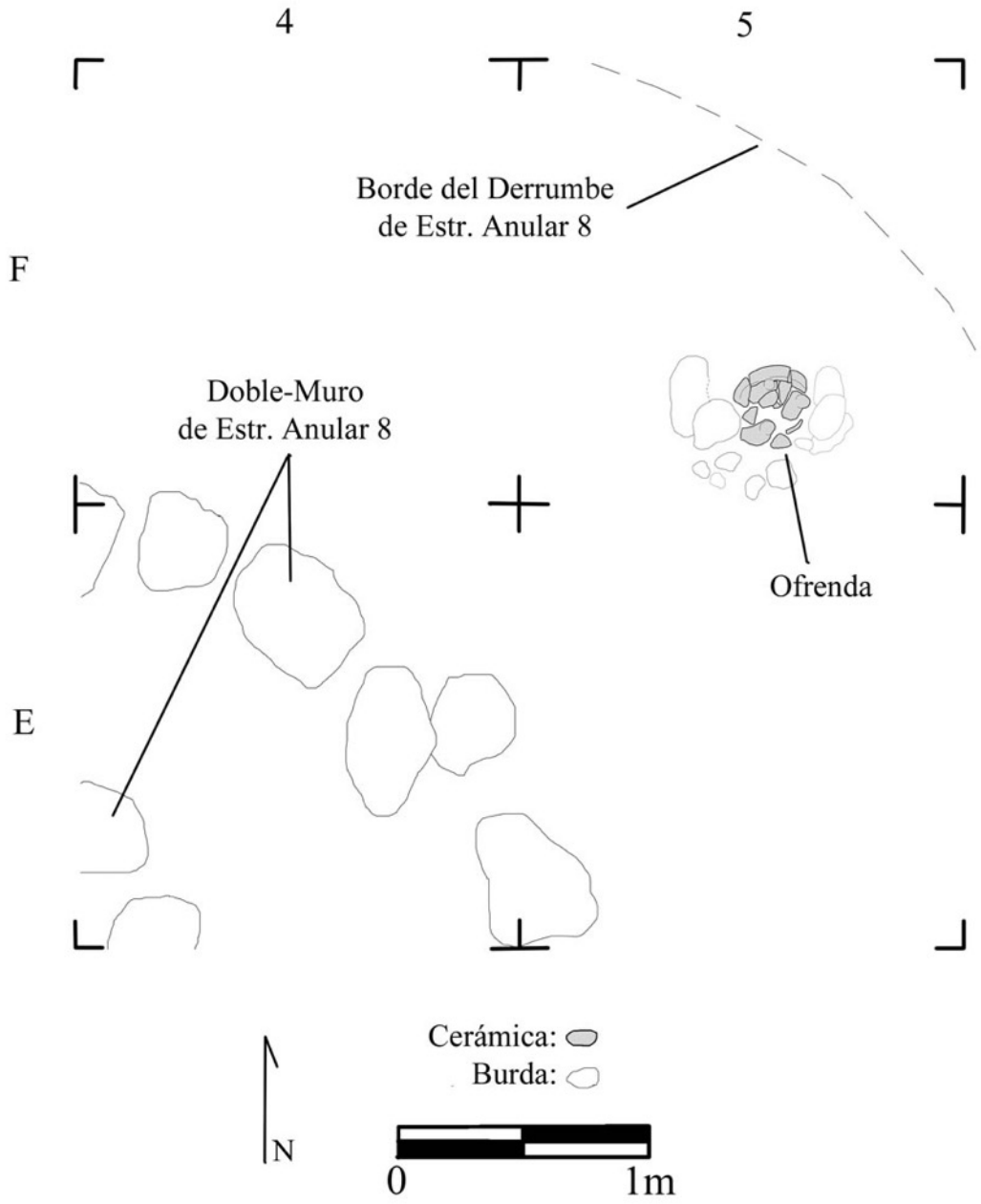


Figure 6-89: Aerial view drawing of the location of the offering found buried to the Northeast of Annular Structure 8.



Figure 6-90: Photograph of the reconstructed dish found to the Northeast of Annular Structure 8 – top view.



Figure 6-91: Photograph of the reconstructed dish found to the Northeast of Annular Structure 8 – view of bottom.

Annular Structure 9 (GPS 2242)

Location: Annular Structure 9 is located immediately to the west-southwest of Annular Structure 8 at the base of a low hill approximately 200 m to the southwest of the Chulul Palace group of the Kiuic site center. It is surrounded on three sides by a collapsed *sascabera*/quarry system (Figure 6-92). The conjunction of these two annular structures and the extensive limestone extraction system led me to hypothesize from the outset that this group may represent an Prehispanic lime processing complex. Annular Structure 9 is situated at the southwestern edge of a low limestone outcrop through which it is connected to Annular Structure 8. Aside from Annular Structure 8 and the *sascabera*/quarry system there are no other Prehispanic archaeological features located nearby. A more recent stone wall, probably dating to the Colonia-era Rancho Kiuic is located at the southern end of the collapsed *sascabera* system and is similar to walls constructed to prevent livestock from falling into caves or holes (Figure 6-93).

Construction Form: The builders of Annular Structure 9 used the limestone outcrop on which it is situated for much of its construction form. The northern, northwestern, and western walls, which abut part of a collapsed *sascabera* and surface quarry, were cut directly into the outcrop all the way up to the highest preserved level of the ring (Figure 6-94). This bedrock part of the ring is high enough that an additional row of boulders on top was unnecessary.

The apical part of the ring was completed by a double-wall of very large, rough boulders that abutted the bedrock on the northeastern side of the structure and swung around to connect once again on the southwestern side (Figure 6-95). Unlike Annular Structure 8, there did not appear to be a smaller, original phase of construction beneath the larger structure. The form of the double-walls was also slightly different in that there was a row of large boulders placed

below and slightly out from under the highest level of the double-ring. This lower row formed a sort of terrace, or large step, around the base of the double-wall, that supported and retained the upper levels of the walls against the slightly sloping terrain of the outcrop (Figure 6-96). In this way, Annular Structure 9 resembled Annular Structure 2, which also had at least one row of 'steps' or 'terraces' to support the higher levels against the slope of the outcrop into which it was built. A third terrace or step layer was located below and slightly out from under the second level in the southeastern, southern and southwestern parts of the structure where the slope is longest. This provided further retention against the natural inclination of the bedrock outcrop (Figure 6-97). The terrace/steps ringed the structure all the way to the bedrock bridge that connected the apical ring of the structure due west to level terrain of equal height across the collapsed *sascabera*/quarry system. The apical part of the ring, made up of a double-wall of very large boulders filled in with chich and medium-sized stones, sat directly atop the second level. The second level of the ring, which spanned all the way from the northeastern part of the structure southward and around to the western bridge was made of large and medium-sized boulders and measured between 1.7 and 2.2 m in width. The southern and southeastern slopes of the structure were covered with a scattering of burned *chich*.

A peculiar feature of Annular Structure 9 was its location immediately adjacent to and partially surrounded by the collapsed *sascabera* and quarry system. The partial collapse of the quarry system left a natural bridge that connected the western side of the structure to raised terrain approximately 3 m to the west. To the north and south of this bridge were depressions that sank at least 2 m below the height of the bridge. To the south, the depression resulted from the partial collapse of the *sascabera* system and to the north and northeast of the bridge was a surface quarry where limestone blocks had been quarried away. The bridge represented part of

the *sascabera* that did not collapse. The northwestern exterior wall of Annular Structure 9 consisted of very large boulders that shored up the wall against the incline into the depression of the quarry. In the southern part of this portion of the ring, closest to the bridge, some of the wall stones appeared to be pieces of collapsed roof stone from the *sascabera* (Figure 6-98). A few medium-sized stones crossed over the bedrock of the bridge to connect the northwestern part of the wall with the terraces/steps of the southern and southeastern part of the ring (Figure 6-99).

Excavation: A total of thirteen 2 x 2 m square units and a circular test pit were excavated into and around Annular Structure 9 (Figure 6-100). Six of these units were excavated along the northeastern, eastern, and southeastern exterior of the structure in order to uncover the construction form of the wall and discover any offerings that may have been placed in a similar position to the one found to the northeast of Annular Structure 8. No offerings were discovered and part of the reason for this was that the bedrock of the outcrop was extremely close to the surface along much of the northeastern exterior. The exterior excavations on the eastern side of the structure did reveal the terraced or stepped form of construction used to support the double-ring against the slope of the outcrop on its southeastern and southern sides. Unfortunately, the overlap between the fill collapse of structures 8 and 9 was too jumbled to make a distinction regarding which collapse may have superseded and thus postdated the other.

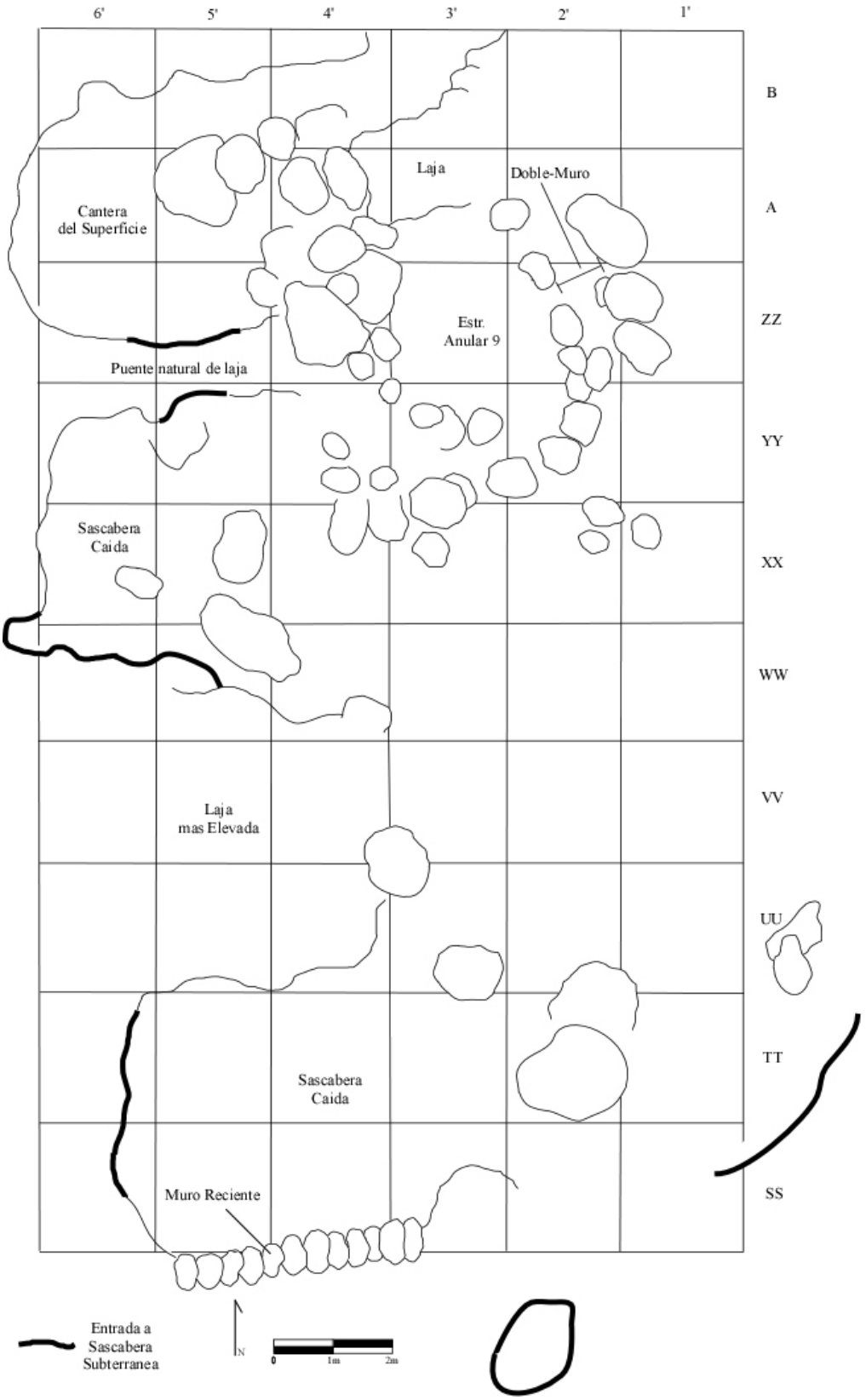


Figure 6-92: Aerial view drawing of Annular Structure 9 and the surrounding *sascabera*/quarry system.



Figure 6-93: Photograph of the historical-era wall at the southern end of the *sascabera*/quarry system.



Figure 6-94: Photograph of the northern and northwestern interior wall of Annular Structure 9 showing the bedrock and large boulders cut from the bedrock.

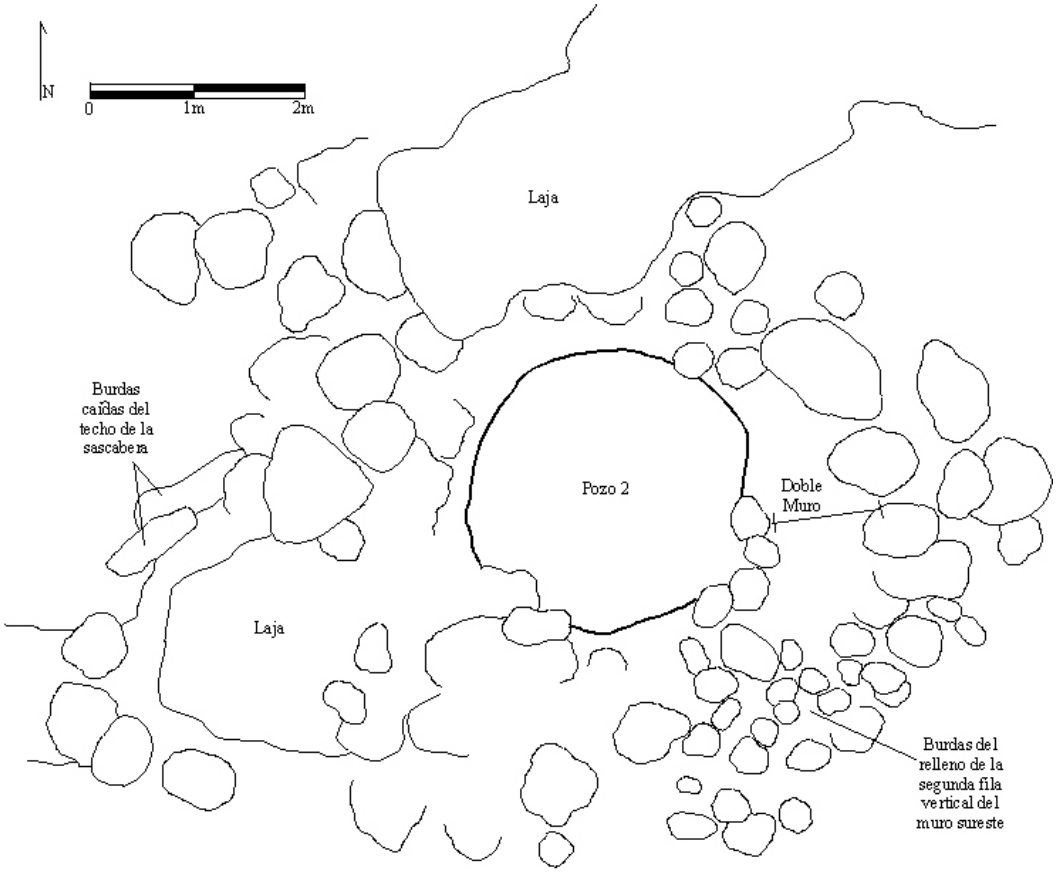


Figure 6-95: Aerial view drawing of Annular Structure 9 showing the double-wall that swings from the northeastern bedrock spur around clockwise to the bedrock bridge on the southwest.

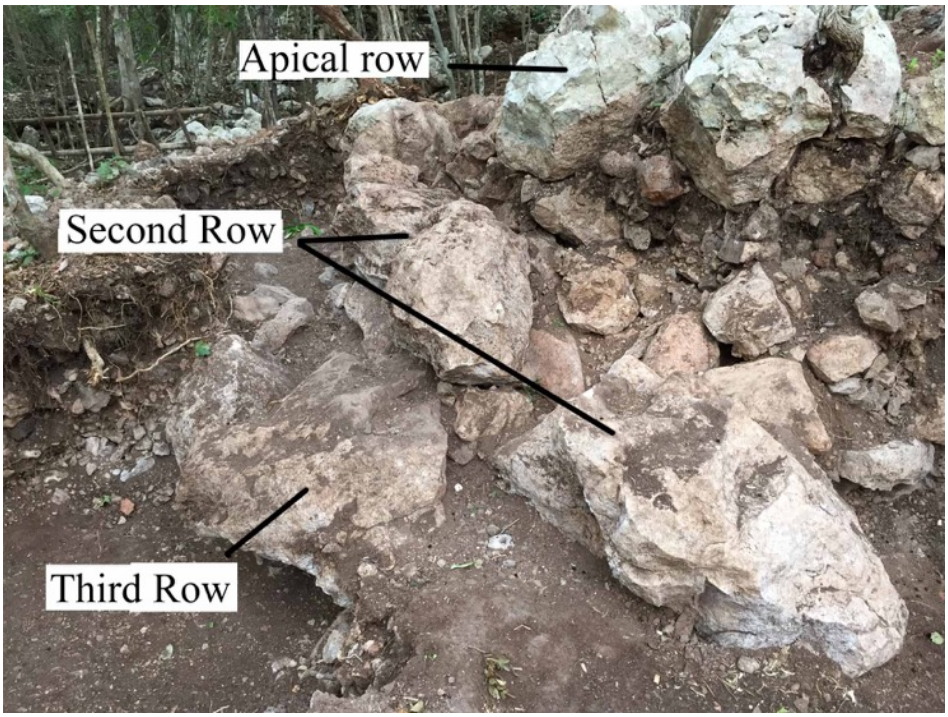


Figure 6-96: Photograph of the layers of the southeastern exterior wall of Annular Structure 9.

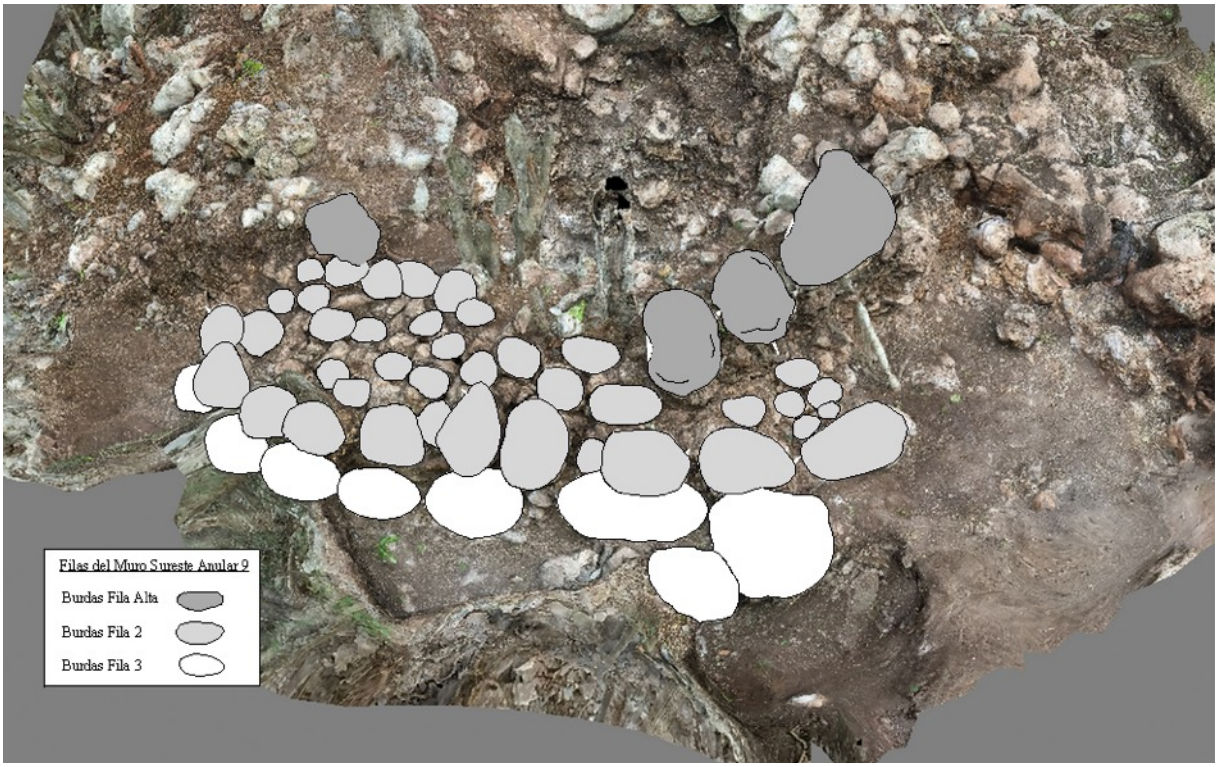


Figure 6-97: Drawing highlighting the different levels of the southeastern exterior wall of Annular Structure 9.



Figure 6-98: Photograph of the exterior of western wall of Annular Structure 9 showing the partially collapsed *sascabera* that borders the western edge of the structure.



Figure 6-99: The row of medium-sized boulders that continues the second level of the exterior wall of Annular Structure 9 over the western bedrock bridge.

The excavation of a test-pit (Pozo 2) into the central depression of Annular Structure 9 revealed a similar pattern to that uncovered in Annular Structure 8. The interior walls of Annular Structure 9 were not as well preserved and thus it was more difficult to discern the maximum extent of the central depression. It was apparent that the northern and northeastern walls consisted of bedrock from the surface outcrop down through the lowest levels, while the other interior walls appeared to possess vertical rows of boulders near the surface until bedrock was reached at lower levels (Figures 6-101 and 6-102). A level of blackened soil or dissolved charcoal was encountered at approximately 3.3 m below the apical ring, but unfortunately no solid pieces of charcoal were recovered from this layer. Similar to Annular Structure 9, this layer of blackened soil both underlay and overlay layers of *sascab* and/or reconstituted calcium carbonate. The lower level of stucco possessed a grayish tint, as if it had been mixed with ash

and/or charcoal. Below the layer of stucco, I uncovered a compact layer of soil mixed with *sascab*/stucco that had an orange tint, which was also similar to a layer found near the bottom of Annular Structure 8. Beneath this orange-tinted layer was the harder bedrock floor of the structure at an average depth of 3.75 m below the apical ring (Figure 6-103).

The excavation of three units on the northwestern and western side of the structure were designed to discover whether the current appearance of the wall represented a deliberate placement of large stones with cracks left between the rocks to aid with airflow into the structure, or whether the current form merely represented the remnants of the adjacent *sascabera*'s collapse (Figure 6-104). The excavations uncovered very large, flat stones that resembled the parts of the ceiling that caved in within other portions of the *sascabera* indicating that the western portion of the ring wall partially consisted of the northeastern edge of the *sascabera* system. However, the northwestern part of the arc also consisted of very large boulders arranged in two or three vertical rows rising up from the floor of the surface quarry that bordered the structure to the north and northwest. Thus, the partial collapse of the northwestern wall as well as the *sascabera* ceiling resulted in somewhat ambiguous evidence for the purposeful placement of an air vent into the central depression of the structure.

One 2 x 2 m unit was excavated within the extant subterranean portion *sascabera* system, directly inside the system's main entrance (Figure 6-105). This excavation uncovered a thick layer of *sascab* and *sascab* boulders that had fallen from the ceiling of the human-made quarry, as well as a few ceramics that had probably been transported in by post-depositional means. There were no other cultural features identified within the *sascabera*.

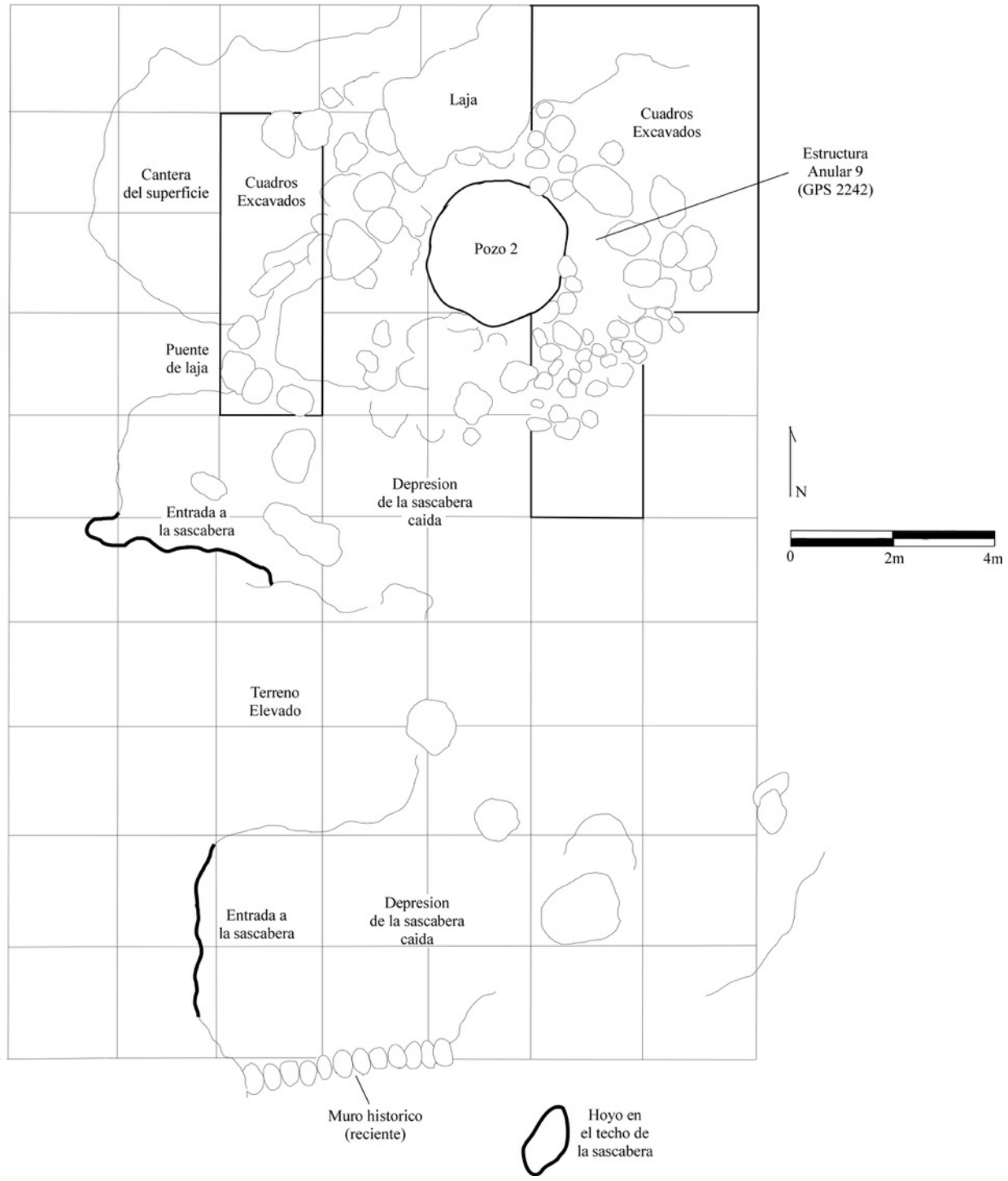


Figure 6-100: Aerial view drawing of Annular Structure 9 highlighting all of the excavated units.

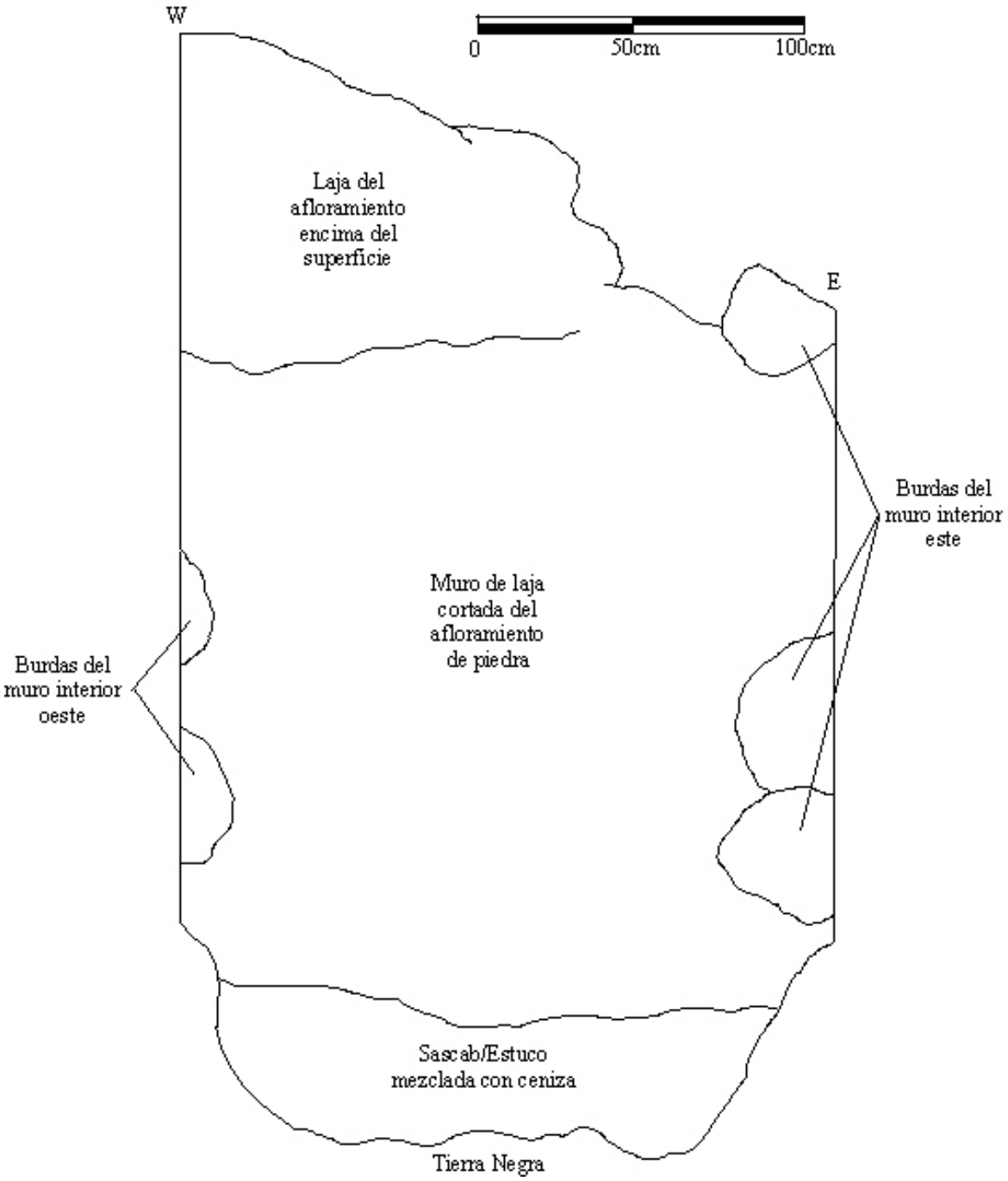


Figure 6-101: Profile drawing interior northern wall of Pozo 2 of Annular Structure 9.

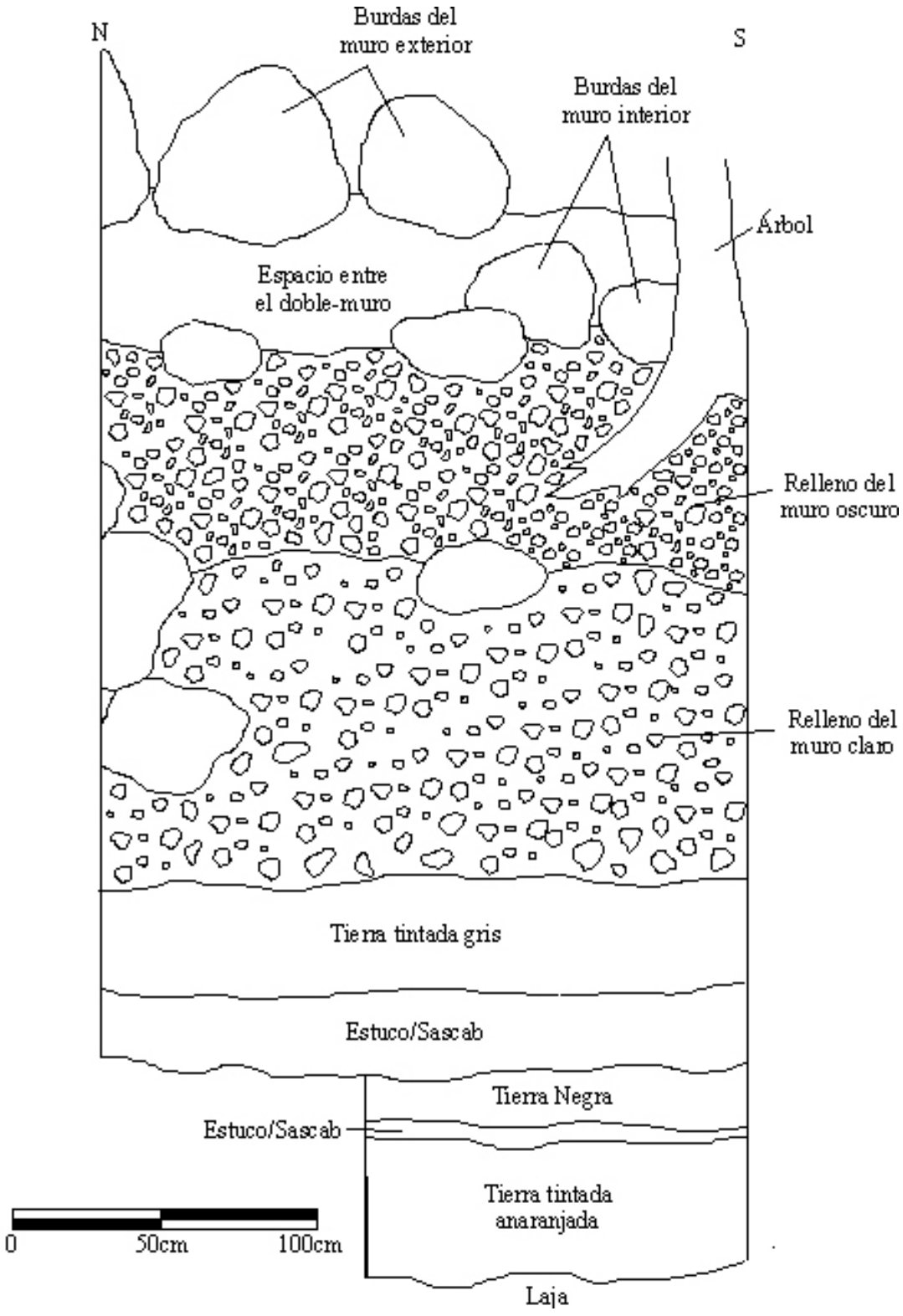


Figure 6-102: Profile drawing eastern interior wall of Pozo 2 of Annular Structure 9.



Figure 6-103: Photograph of the layers of blackened soil, stucco and orange-tinted soil at the base of the central depression of Annular Structure 9.



Figure 6-104: Photograph of the potentially purposeful ventilation hole left in the northwestern wall of Annular Structure 9, viewed from the exterior of the structure.



Figure 6-105: Photograph of the entrance to the extant subterranean portion of the *sascabera* system in which Unit TT6' was excavated.

*Annular Structure N1065 E0965 (Patio A)**

*This annular structure was excavated by Stephanie Simms as part of the 2008 field season excavations in the Yaxche Group of the Kiuic site center and a complete description of the excavations can be found in Gallareta Negrón et al. 2009: 4-37 to 4-40.

Location: This annular structure was located in the northern part of Patio A of the Yaxche Group of the Kiuic site center (Figure 6-2). It was the only annular structure located within any of the public architectural groups of the site center.

Construction Form: The peculiar location of this annular structure was mirrored by a unique construction form. The ring of the structure rose only approximately 0.8 m above the surrounding patio floor, and the structure appeared to have been built directly atop the patio. There were no carved stones used in its construction, marking one of the few characteristics similar to the other excavated annular structures. The maximum extent of the exterior *chich* collapse had a diameter of between 9.1-9.4 m, which was on the larger side compared with the other structures (Figure 6-106).

Excavation: Excavations in the central depression of the structure found that it was built atop the previously constructed raised plaza of Patio A, as two patio floor layers and then patio fill were encountered within the pit. The pit was therefore not very deep and no evidence of burning was recovered, suggesting that it was never used as an oven. Unfortunately, no units were excavated through the walls of the structure and thus the full construction form of the structure is yet to be determined. Based on the crudeness of the stones used in construction, lack of discernible firing episodes, and the chronology of the ceramic samples recovered from the collapsed fill within the central depression, Simms posited that the structure was hastily built perhaps near the end of the site's occupation (Gallareta Negron et al. 2009:4-39).

Taking into account the descriptions provided by Simms and the data gleaned from my excavations of the other annular structures, the Patio A Annular Structure does not appear to be the same type of structure that I posit to be an annular lime kiln. It is possible that its resemblance is limited to its superficial appearance in the archaeological record as both its location atop a previously constructed plaza and lack of burning evidence suggest its use for other purposes besides lime production. Another possibility is that the structure was built very

late in the site's settlement history with the intent of being used to cook materials, but that the site was rapidly abandoned (Simms et al. 2012) before it could be used.



Figure 6-106: Photograph of Annular Structure Patio A looking southwest.

A Proposed Typology for Annular Structure Construction Forms

All of the 53 annular structures in the study area were identified as 'annular structures' based on their shared basic structural form: a ring of boulders surrounding a central depression. Moving beyond this general description, there is enough variation within the overall group to warrant dividing them into four sub-groups based on physical attributes that may reflect differences in the socioeconomic standing of the people that commissioned and/or used them.

The four categories include: 1) Double-ring structures (*n*=13); 2) Partial double-ring structures (*n*=4); 3) Single-ring structures (*n*=14); and 4) Partial single-ring structures (*n*=20) (Figure 6-107). There are two outliers in the study sample that do not fit within these categories and are labeled as 'other' in the typology. As the type names indicate, the categories are based on the number of horizontal rows in the structures' rings and whether or not the ring is completely made of loose boulders. While the partial double-ring structures have a larger average external diameter, there does not appear to be a strict correlation between type category and structure diameter (Figure 6-108). A fifth general type of annular structure has been identified at the site of Oxkintok by María Soledad Ortíz Ruíz and colleagues (Ortíz Ruíz 2014), which will also be discussed below.

The only factors that appear to correlate with the differences in construction types are the distance from the site center in the case of the double-ring types, and the gradient of the terrain on which the structures are built. Distance from the site center may be a correlate of socioeconomic status and access to labor and material resources. Double-ring and partial double-ring structures are more prevalent near the site center than the single-ring and partial single-ring structures (Figures 6-109 and 6-110, Table 6-1). Five of the seven annular structures located in the inner zone (72%) are either partial double-ring or double-ring structures. Furthermore, a higher percentage of all of the partial double-ring and double-ring structures in the study area are located in the inner zone (5/17 or 29%) compared with just 6% of single or partial single structures (2 of 34). The variation between the two groups of structure forms is significant, returning a Fisher's Exact test p-value of 0.035 (Appendix E). There is also a higher concentration of elite residential compounds near the site center. Terrain is a factor in the categorization of the structures in that those structures that are categorized as 'partial' double- or

single-rings are done so because their ring formation is completed by sloping natural bedrock (Table 6-2). These structures are almost invariably built into sloping terrain (22/24 = 92%), which is used as part of the annular structure itself. The majority of structures with rings completely composed of loose boulders are located on flat or nearly flat terrain (20/27=74%).

This typology is created mainly to be used as a reference for future studies about annular pit-kiln technology. The 53 structures surveyed in this study are categorized into four general types plus two outliers. Should the sample number grow and the structure forms diversify with successive studies, it may become prudent to expand the number of categories or rethink the usefulness of type categorization altogether (Culbert and Rands 2007). For the purposes of the current study, however, it is useful to distinguish the amount of resources devoted to the construction of each annular structure as well as their location within the landscape. What follows is a proposed typology of annular lime kiln construction forms based on those excavated and surveyed in and around Kiuic, and informed by data gathered by Soledad Ortíz Ruiz at Oxkintok (Ortíz Ruíz 2014). More information about spatial correlations and structure characteristics can be found in Appendix C.

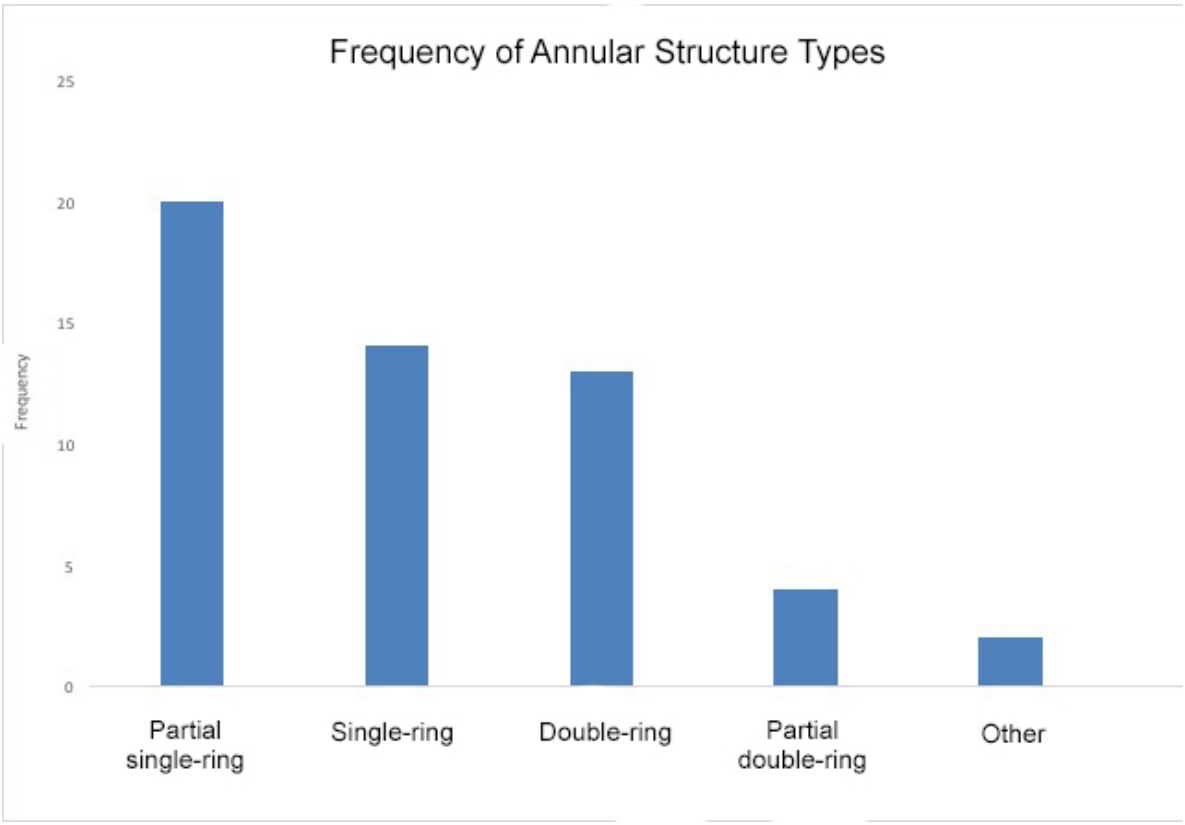


Figure 6-107: Histogram showing the frequency of the different annular structure types.

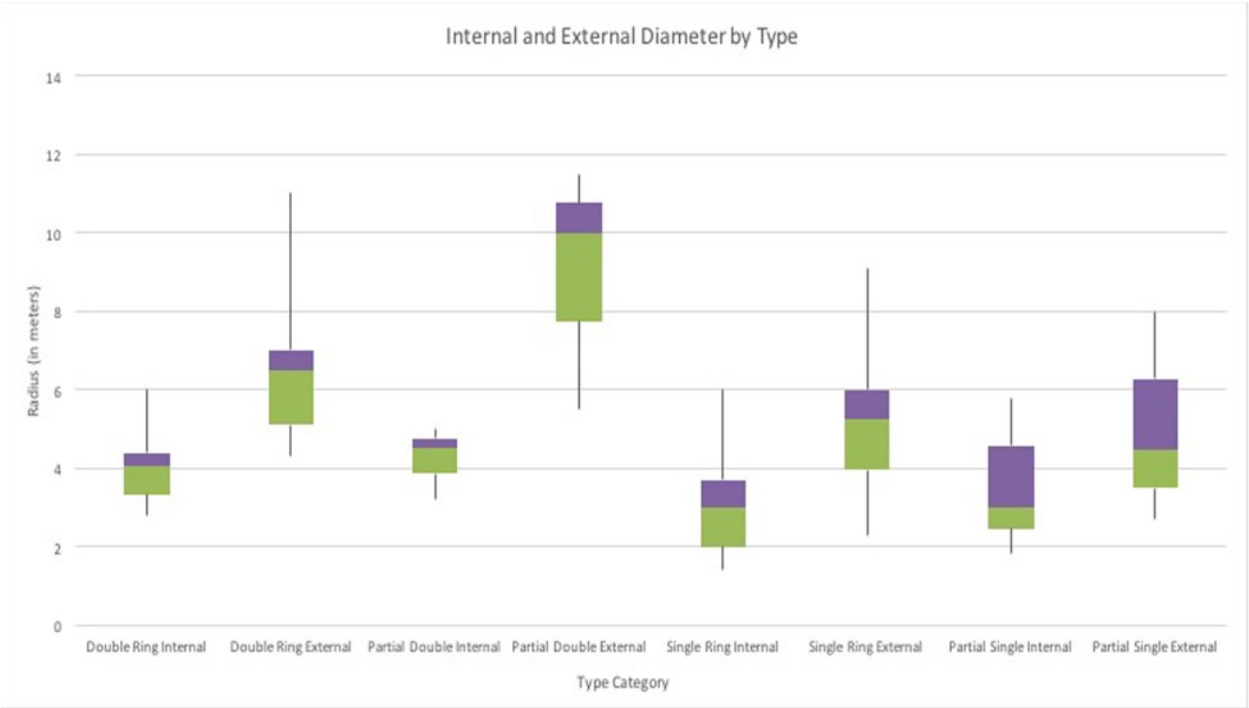


Figure 6-108: Box plot showing the distribution of internal and external diameter measurements for the different type categories of annular structures.

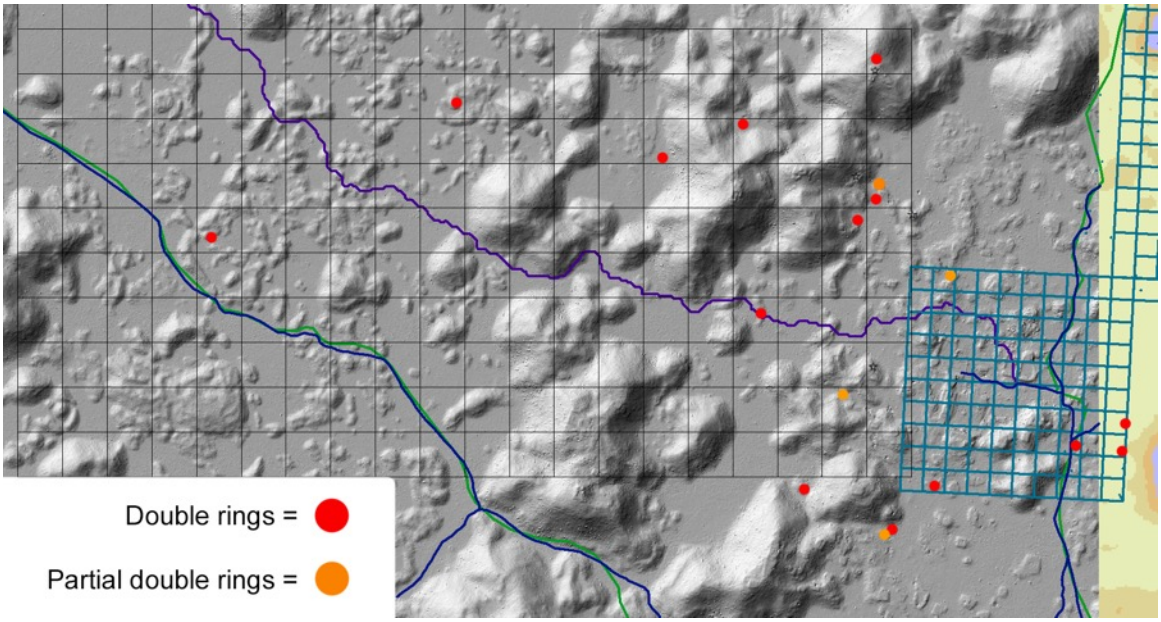


Figure 6-109: Map showing the locations of the double-ring and partial double-ring annular structure types (adapted from Gallareta Negrón et al. 2014).

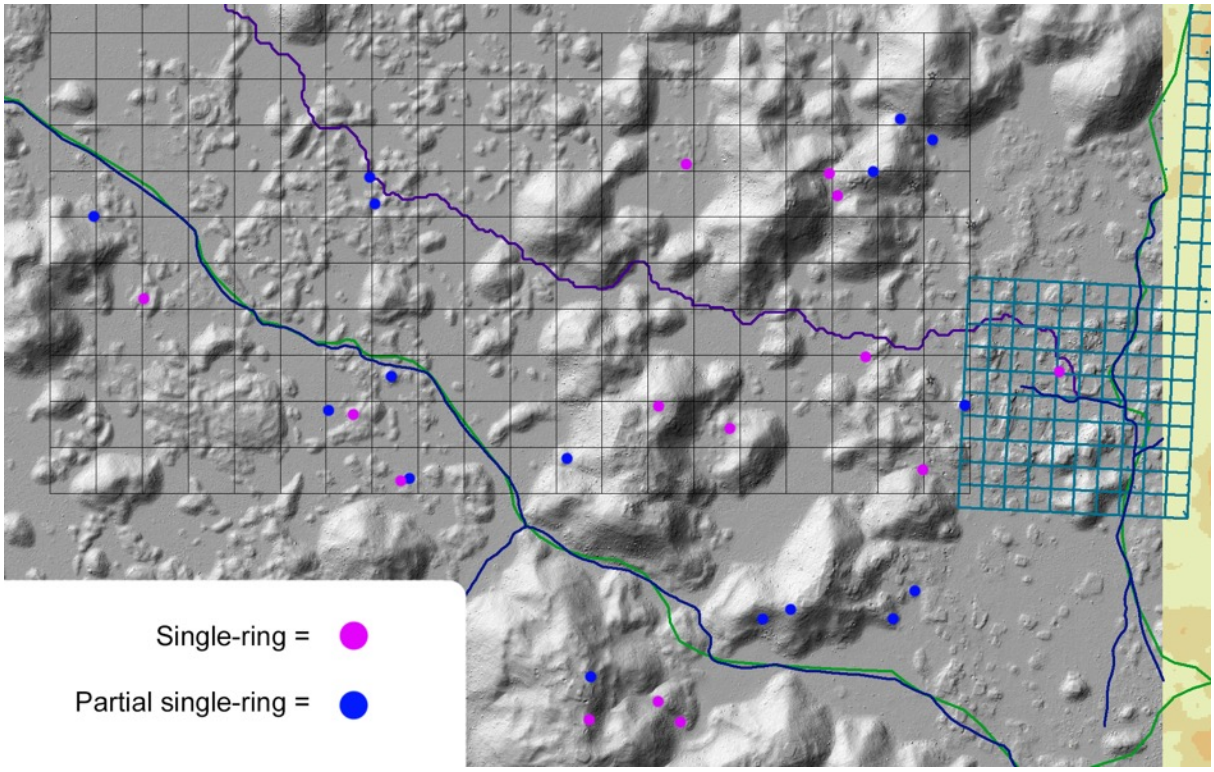


Figure 6-110: Map showing the locations of the single-ring and partial single-ring annular structure types (adapted from Gallareta Negrón et al. 2014).

Table 6-1: The distribution of the four different categories of annular structures across the outer, intermediate, and inner zones.

	Outer	**Intermediate**	**Inner**	**Total**
Double-Ring	2	7	4	13
Partial Double-Ring	0	3	1	4
Single-Ring	3	10	1	14
Partial Single-Ring	6	13	1	20
Other	0	2	0	2
Totals	11	35	7	53
All Doubles (partial or whole)	2	10	5	17
All Singles (partial or whole)	9	23	2	34
Other	0	2	0	2

Table 6-2: The distribution of the four different categories of annular structures across the outer, intermediate, and inner zones.

	Sloping Terrain	**Flat Terrain**	**Total**
Double-Ring	5	8	13
Partial Double-Ring	3	1	4
Single-Ring	2	12	14
Partial Single-Ring	19	1	20
Other	2	0	2
Total	31	22	53

Annular Structure Typology

Double-Ring Structures *(n=13)*

The double-ring type of annular structure is the most common construction form associated with elite residential complexes in and around the Kiuic site center. This may reflect the greater amount of material and labor resources and technological expertise necessary to construct efficient, nearly symmetrical double-ring annular structures. The standard double-ring

consists of two concentric walls of at least medium-sized boulders filled in with smaller stones and soil, surrounding a central depression (Figures 6-111 and 6-112). The boulder walls consist of anywhere from one to five vertical rows, the base of which is usually constructed directly atop the surface bedrock. There is no evidence for the use of mortar in the construction of the double walls. The double-ring resembles a short silo surrounding the central depression. While there are few examples of a perfectly preserved double-ring, the majority of these type of structures appears to be nearly circular. Examples of double-ring structures excavated have walls that range from 0.75 to 1.5 m wide.

Two of the double-ring annular structures excavated during the 2014 and 2015 field seasons yielded evidence of an original, smaller ring wall located within and beneath the final construction form (Annular Structures 1 and 8). It was unclear whether the smaller wall within Annular Structure 1 was also originally made up of double concentric rings, but the smaller wall within Annular Structure 8 clearly resembled a smaller version of the final double-walled ring. It is possible that other double-ring structures identified in the study area may also represent final construction phases enveloping earlier structures of varying forms. This can only be tested through further excavations.

Two of the double-ring structures identified in the study area exhibited slight variations that merit noting. One structure (GPS 1910) was somewhat transitional between the full double-ring type and the partial double-ring type. The top layer of the ring was completely made of loose boulders, but it was built into a gentle slope so the number of vertical rows of loose boulders was greater on the southeastern side of the structure than on the northwestern side. In order to maintain a balance against the slope of the hill, the northwestern (upslope) side of the structure had only one vertical row of boulders while the southeast side had at least two vertical

layers as well as an extra horizontal row of boulders abutting the exterior ring. This retention arc widened the southeast wall of the structure and provided stability against the downward slope of the hill. A few of the partial double-ring and partial single-ring structures also possessed similar retention walls on the downslope sides of the structures. The other slightly anomalous double-ring structure was particularly large and may have possessed a third ring of boulders outside of the standard double-ring (Annular Structure 6). This third ring on the surface is similar in basic form to the Oxkintok style structures discussed below.

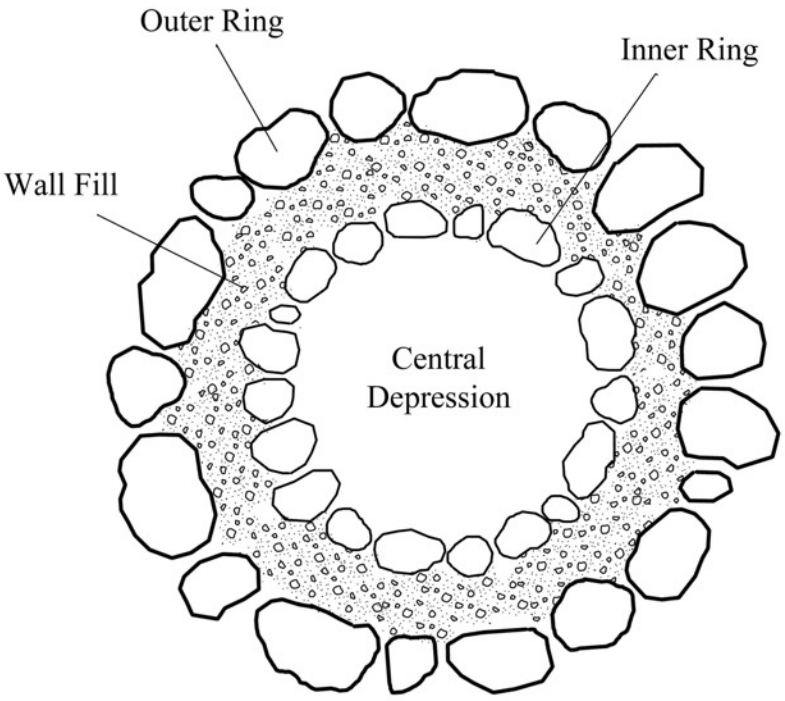


Figure 6-111: Aerial view schematic drawing of a standard double-ring annular structure.

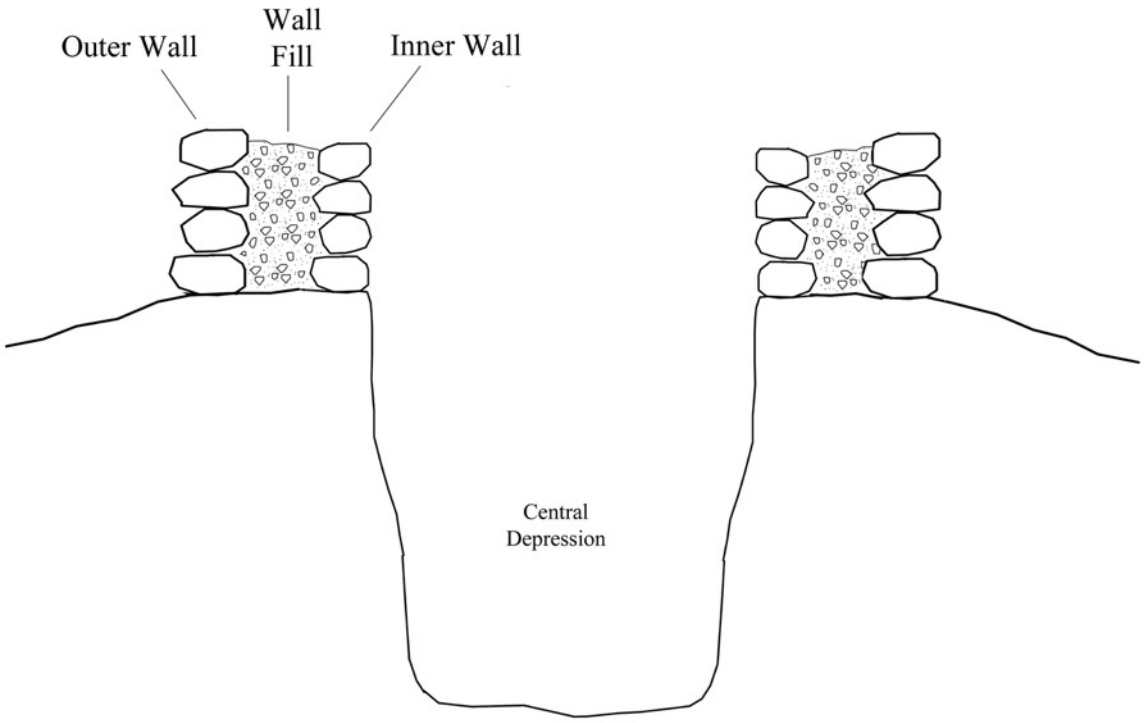


Figure 6-112: Profile cut schematic drawing of a standard double-ring annular structure.

Partial Double-Ring Structures *(n=4)*

The partial double-ring structures are very similar to the double-ring structures except for the fact that they are built into sloping terrain. Thus, the double-wall does not form a complete circle, but instead meets up with the slope of a hill or a limestone outcrop and takes advantage of the natural incline to complete the circle (Figure 6-113). Building into a sloping terrain means that at least one side of the interior wall of the structure consists largely of the bedrock of the hill or outcrop into which the structure is built. Thus, many annular structures consist of a surface ring consisting partially of loose boulders and partially of surface bedrock. While the central depressions of almost all of the annular structures identified appear to have been excavated through the surface layer of bedrock – meaning that bedrock was used in the interior walls of

most of the structures – only some structures actually use the surface bedrock as part of the apical ring of the structure. Only four partial double-ring structures were identified in the study area, all on the outskirts of the site center, but they were distinct enough in form from the full double-ring structures to warrant their own type.

One variation exhibited within the partial double-ring type is connected with topographical circumstances. Annular structures 2 and 9 possessed a stepped or terraced retention wall to combat sloping terrain into which the structure is built. This stepped/terraced retention wall is slightly different from the retention wall discussed in the previous section that directly abuts the exterior of the ring wall. The steps/terraces are constructed downslope from the ring of the structure to provide stability to the foundation as opposed to shoring up the wall itself. The examples excavated thus far include at least three terraces/steps made up of medium and large boulders located below and slightly out from under the superior rings of stones.

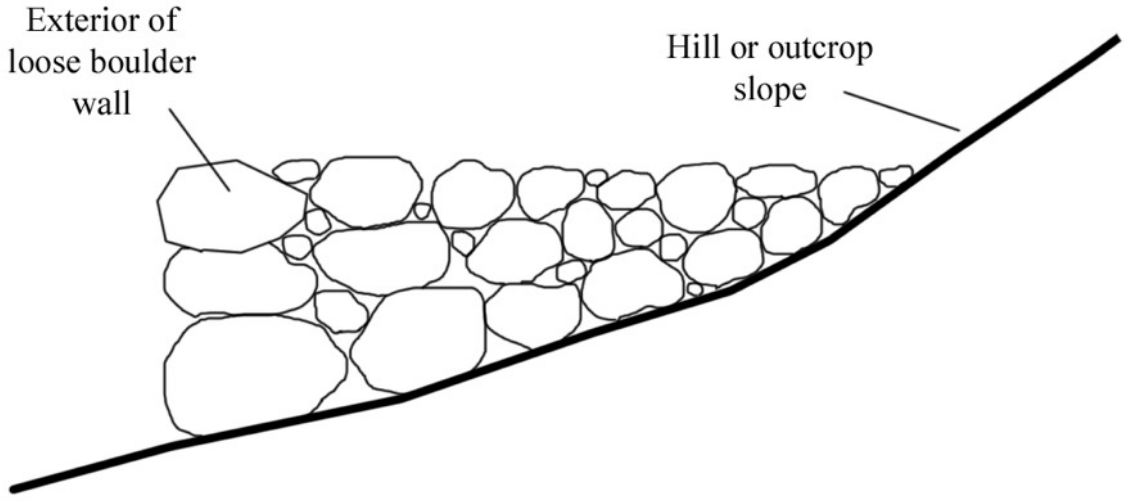


Figure 6-113: Exterior view of partial double- and single-ring structures showing how the ring is built into the slope of a hill or outcrop.

Single-Ring Structures *(n=20)*

The single-ring type of structure is the most prevalent of the four types identified in the study area and is almost usually located on level or nearly level terrain. As the name suggests, the superficial portion of this form of annular structure consists of a single ring of medium and/or large crude boulders surrounding the central depression (Figures 6-114 and 6-115). The superficial ring may consist of anywhere from one to several vertical rows of stones. The topography may be partly responsible for the use of this construction form, as level terrain would not require the use of extra retention walls to combat any type of incline. Annular Structure 4 was the sole example of this type of annular structure excavated during the 2014 and 2015 field seasons, though several others were encountered during the general survey of the study area. While Annular Structure 4 was similar to the other annular structures in terms of the depth of its central depression, it is unlikely that the superficial single ring offered a similar degree of heat retention and wind protection as those of the double-walled structures. Thus, it is possible that the main purpose of ringing the central depression with a single wall of medium and large stones was to demarcate the edges of the central depression and perhaps prevent people and/or animals from falling in.

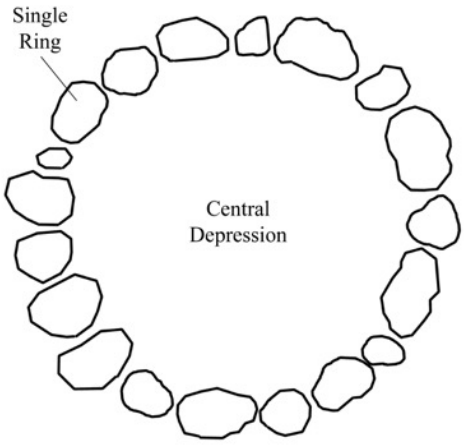


Figure 6-114: Aerial view schematic drawing of a standard single-ring annular structure.

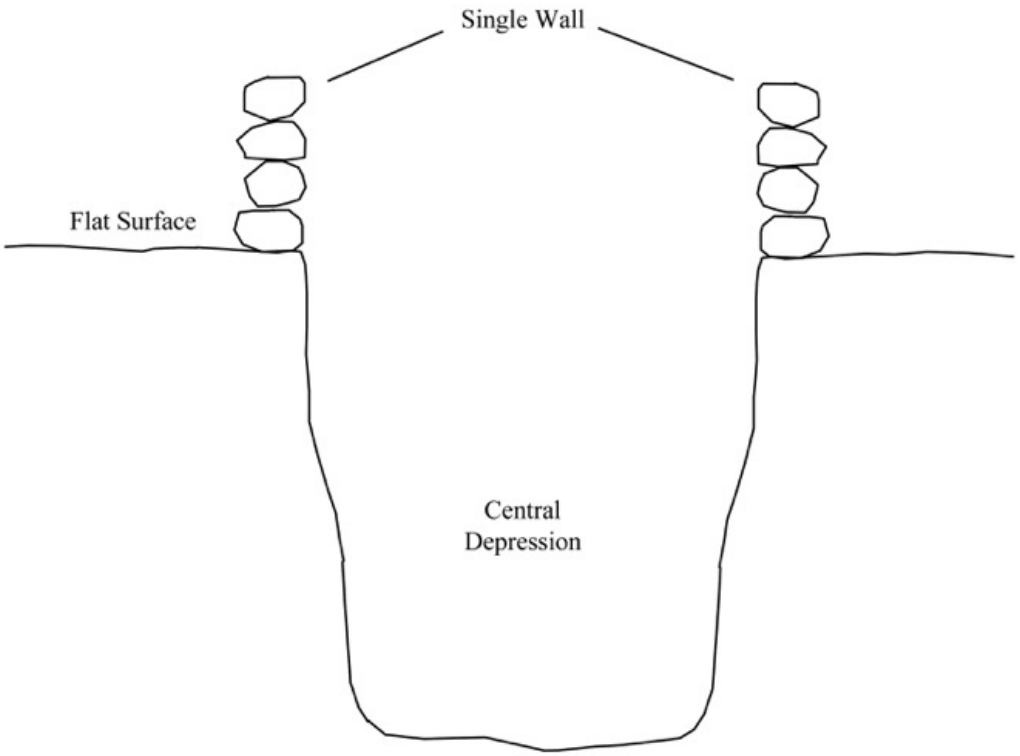


Figure 6-115: Profile cut drawing of a standard single-ring annular structure.

Partial Single-Ring Structures *(n=14)*

The partial single-ring structure type exhibits elements of both the single-ring structure type and the partial double-ring structure type: it consists of a single ring of boulders like the single-ring type, but is partially constructed of bedrock like the partial double-ring type. It consists of a single arc of loose boulders of anywhere from 1 to at least 3 vertical rows. The 'partial' in the type name refers to the fact that it is almost exclusively constructed on sloping terrain and uses the natural bedrock of the slope to complete the ring (Figure 6-116). While the central depressions of almost all of the annular structures identified appear to have been excavated through the surface layer of bedrock – meaning that bedrock was used in the interior

walls of most of the structures – only the partial double-ring and partial single-ring structures actually use the surface bedrock as part of the apical ring of the structure.

Due to the inherent structural instability of a single loose boulder wall on sloping terrain, these structures often (but not always) have a partial retention wall abutting the downslope side of the structure (Figures 6-117 and 6-118). This partial retention wall can be distinguished from a full double-ring wall in that the retention wall does not follow the single-ring wall all the way to where it meets with the bedrock of the upslope side. Additionally, there is no space between the retention wall and the ring wall similar to that of the double-ring wall that contains construction fill.

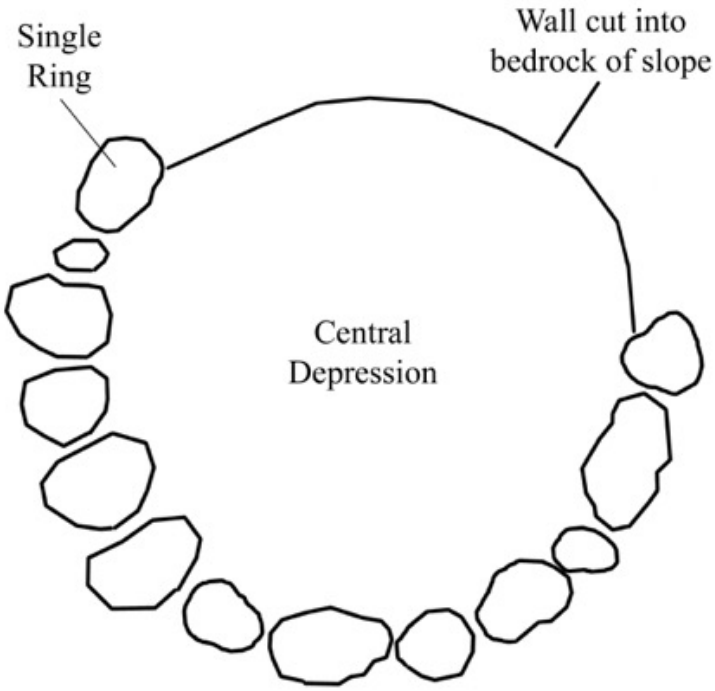


Figure 6-116: Partial single-ring structure aerial view.

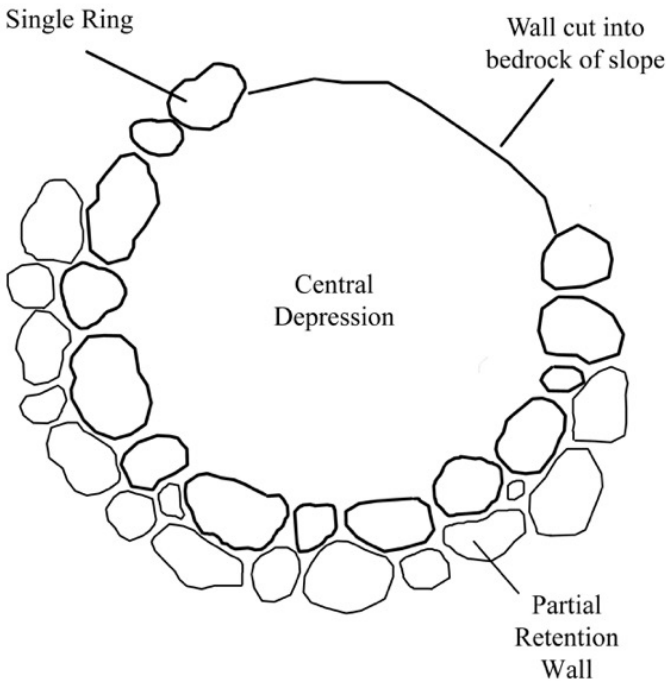


Figure 6-117: Aerial view schematic drawing of a standard partial single-ring annular structure with a partial retention wall.

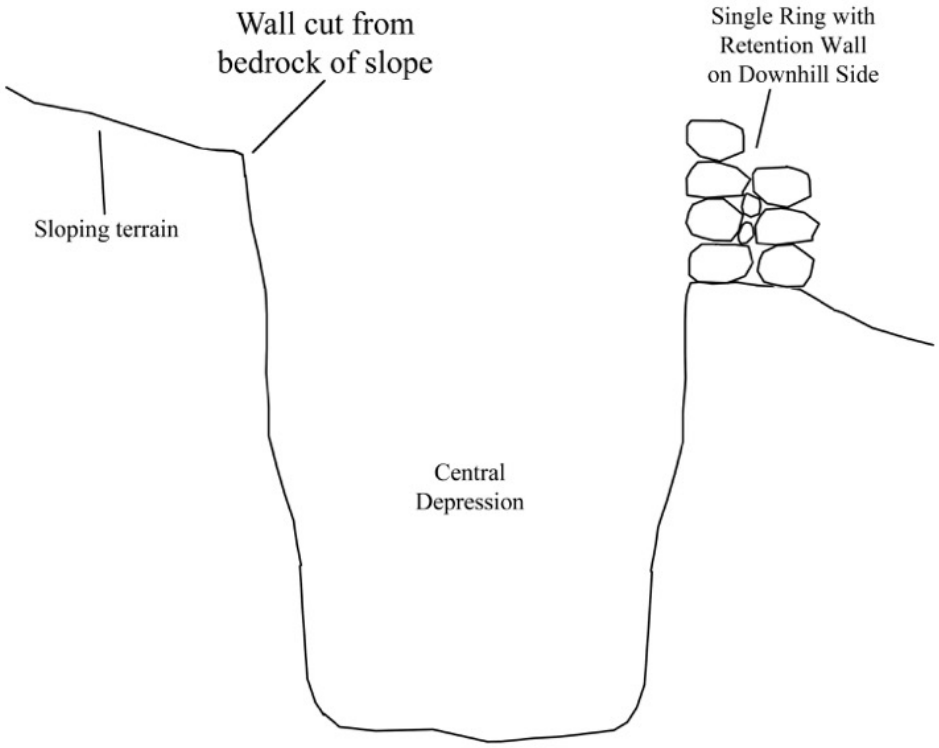


Figure 6-118: Profile cut schematic drawing of a standard single-ring annular structure with a partial retention wall.

Oxkintok Type (*not present at Kiuic*)

A fifth general form of annular structure was identified by María Soledad Ortíz Ruíz during the Federal Highway 180 Mérida-Campeche Salvage Project on the outskirts of the Prehispanic site of Oxkintok (Ortíz Ruíz 2014). This form is also made up of two concentric rings of boulders surrounding a central depression. What distinguishes the Oxkintok annular structures from those at Kiuic annular structures identified at Kiuic is the greater width of their concentric rings and the generally shallower depth of their central depressions. Several examples were excavated in which the extent of the superstructural walls was nearly as wide as the diameter of the central depression itself (Ortíz Ruíz 2014:41,44-48,51,55). Another distinction of the Oxkintok form is that it is almost exclusively constructed atop and into flat terrain, due to the natural topography of Oxkintok, which lies just outside the elevated Puuc region. Interestingly, Annular Structure 6 at Kiuic resembles the Oxkintok form of annular structure in its very wide double (or even triple) concentric surface rings and its construction on relatively flat terrain. The central depression, however, is much deeper than that of the average Oxkintok annular structure.

Chapter 7 – Experimental and Ethnographic Data

In this chapter I present the data collected during the experimental and ethnographic portions of the investigation. In the first section, I outline the significance of my lime kiln experiment in the context of previous lime production experiments and then I describe the process and results of the experiment. In the second section I present the ethnographic data concerning limestone processing gathered during interviews with local informants and by Dean Arnold during his ethnographic interviews at Ticul in the 1960s.

The Lime Pit-Kiln Experiments

The evidence recovered from the excavations of the nine annular structures strongly suggested that the majority of them were used to produce lime from limestone, in addition to several other possible other functions. The visible physical evidence for burning episodes within the central depressions of the structures and from the scatters of burned *chich* were further supported by stable isotope identification of reconstituted calcium carbonate within the structures. This in turn suggested that the inside of the annular structures reached a high enough temperature for long enough duration to calcine limestone into quicklime, which was then slaked to form lime and eventually hardened into reconstituted calcium carbonate. These datasets, as well as spatial and contextual evidence thus suggested that the annular structures were used as kilns to produce lime. However, in order to be certain of the logistical practicality of using these pit-kilns to produce lime powder from limestone, it was important to reconstruct one and experimentally produce lime powder. My first objective in constructing and firing an annular lime pit-kiln was to show that it could be done on a logistical level. The second objective was to

generate data concerning the multiple variables involved in pit-kiln construction and burning, including: hours of labor necessary for construction; hours of labor necessary to assemble raw materials; kiln temperature; burning episode duration; and wood fuel-to-burnt lime produced ratio. These data would directly address the benefits of the pit-kiln technology over the open-air pyre technique and perhaps provide clues regarding the circumstances of their invention and use.

Previous Experiments

Unfortunately, factory-produced lime is the most prevalent form of lime in use today throughout the Yucatán peninsula, which limits the ability to study non-mechanized methods of production (Russell and Dahlin 2007:407). Ethnohistoric accounts from the Maya area are also few and far between. Despite making several mentions of lime plaster and mortar, Diego de Landa did not include a specific description of the lime production process in his *Relación de las cosas de Yucatán* (Tozzer 1941). Ralph Roys also left out any account of lime production in his seminal work *The Indian Background of Colonial Yucatán* (1943). Bernardino de Sahagún mentioned the use of "ovens" or kilns in Central Mexican lime production (Sahagún 1989:570; Palma Linares 2009:229), but it is unclear whether this refers to a Prehispanic method or one introduced by the Spaniards. Working from three early Colonial period dictionaries – mainly the *Motul Dictionary* dating most likely to the early 17th century – Clark and Houston (1998) gathered information regarding the gendered divisions of craft production. They note that "With the exception of female spinners, weavers, thread-dyers, and seamstresses, all other crafts referred to by special title in the two early dictionaries are explicitly male (Clark and Houston 1998:37). This included lime production:

> "ah took chuk kab – 'he of the burnt charcoal earth' (This refers to the process by which lime is produced from fire-reduced limestone.)" (Clark and Houston 1998:44)

However, this description of lime makers as "he of the burnt charcoal earth" does not distinguish whether lime makers were necessarily using pit-kilns or open-air pyres to produce lime at this point in time. Despite the lack of explicit ethnohistoric research on the subject, the open-air pyre method has generally been accepted as the standard technique for producing lime in the Yucatán. While researchers may not explicitly reference the ambiguity surrounding the temporal origins of this method, they apparently accept its labeling as the standard method as sufficient cause to project its use back before the era of documentation (Morris et al. 1931:220; Schreiner 2002:11; Russell and Dahlin 2007).

There have been several archaeological experiments to produce lime powder using standard aboveground pyre methods, the vast majority of which have employed the open-air pyre technique documented during the Twentieth Century (Table 7-1). In 1931, Earl Morris and colleagues published a manuscript of their investigations of the Temple of the Warriors complex at Chichén Itzá. Included in this volume was an account of how the local workers produced lime using an open-air pyre (Morris et al. 1931:220-225). The description of the process was prefaced with a bold statement regarding the authenticity of the method:

> "The Yucatecan method of producing lime at the present time is an ancestral heritage that has come down through the centuries with practically no change, except the substitution of steel for stone tools." (Morris et al. 1931:220)

The process described involved the construction of a circular pyre made of freshly cut green wood with overall dimensions of approximately 5.5 meters in diameter and 2 meters in height.

The pyre was built around a straight post measuring approximately 2.75 m high and 13-20 cm in diameter that was removed prior to firing and the resulting empty shaft acted as a chimney. Fist-size and smaller pieces of limestone were carefully selected and placed in a mound on top of the pyre that ranged from 75 cm thick near the center to 50 cm at the edges (Figure 7-1).

Table 7-1: Raw material and lime product quantity data for prior lime production experiments in the Maya area.

Experiment	Production Method	Quantity of Wood Fuel	Quantity of Raw Limestone	Quantity of Burnt Lime Produced	Ratio Wood Fuel Used to Burnt Lime Produced
Morris et al. 1931	Aboveground circular pyre	~43.1 cu m	NA	11.33 cu m	3.8:1 (by volume)*
Xolocotzi 1995	Aboveground circular pyre	NA	NA	NA	4.4:1 (by weight)
Schreiner 2002	Various	NA	NA	NA	3.8:1 - 8.2:1 (by weight)
May and Gallareta 2003	Aboveground circular pyre	~10.24 cu m	~1.42 cu m	~1.63 cu m	6.3:1 (by volume)
Russell and Dahlin 2007	Aboveground rectangular pyre	4.95 cu m	0.57 cu m	~0.58 cu m	8.5:1 (by volume)
Seligson (Experiment 1)**	Annular pit-kiln	3.87 cu m	~ 3 cu m	0.76 cu m	5.1:1 (by volume)
Seligson (Experiment 2)	Annular pit-kiln	2.85 cu m	~ 0.7 cu m	0.722 cu m	3.94:1 (by volume)

* Rough, ideal estimate. Accuracy questioned by Schreiner (2002:84).
** Experiment was negatively affected by a prolonged period of rainfall.

Morris and colleagues (1931) noted that a large pyre takes an average of 24-30 hours to burn up completely. In attempting to estimate the amount of pyres that would have been necessary to produce the lime for the construction of the Temple of the Warriors, Morris et al.

calculated that a 5.5 m-diameter pyre was made up of approximately 11.9 cords of wood, and produced an average of 11.33 cubic meters of lime (Morris et al. 1931:225). This however, included Morris and colleagues' undoubtedly erroneous claim that the quicklime expanded to five or six times its original size when fully converted to slaked lime (Morris et al. 1931:223). If we infer that Morris and colleagues were using the commonly accepted understanding of a cord being 4 ft by 4 ft by 8 ft, or 128 cubic feet (3.62 cubic meters), then the average 5.5 m-diameter pyre would be made up of 43.078 cubic meters of wood. Thus the ratio of wood fuel to lime produced using the type of open-air pyre described by Morris and colleagues at Chichén Itzá would be approximately 3.8:1. However, questions about the accuracy of Morris et al.'s calculations (Schreiner 2002; Wernecke 2008) would require the caveat that 3.8:1 is at best a very radical estimation of the ratio of wood fuel to finished lime. Morris and colleagues' figure was actually reported as an expected outcome, not a measured one. Schreiner (2002:84) suggests that Morris et al. may have overstated their slaked lime volume by as much as thirty-five percent, which would lead to a revised ratio of 5.86:1. Morris et al. noted the potentially hazardous effects of wind on aboveground firing episodes. This suggests that one of the benefits of using semi-enclosed annular pit-kilns would be to protect against wind-related interference in lime production.

Thomas Schreiner (2002) reported on the experimental construction and firing of twelve lime production pyres that were "…regional variants of the basic Mesoamerican lime burning technique" (Schreiner 2002:61). Schreiner's goal was to compare the fuel efficiency of different non-mechanized construction methods and contrast them with the demonstrably more efficient Spanish Colonial variety of lime kiln. He found that the standard aboveground pyres produced lime with a fuel-to-product ratio ranging from 3.8:1 all the way to 8.2:1, with an average

production efficiency by weight of approximately 5.0:1 (wood fuel to lime powder). The Spanish Colonial type of kiln, built on the Roman model had a much higher fuel efficiency ratio of 1.1:1 (Schreiner 2002:62). Schreiner also reported on an experimental study by Hernandez Xolocotzi in the early 1980s, in which the fuel efficiency ratio after adjustment for an original arithmetic error came to approximately 4.4:1 (Schreiner 2002:63). Unfortunately, Schreiner's fuel efficiency ratios from his experiments were based on weight in kilograms and thus cannot be directly compared with those from other studies that measure ratios by volume in cubic meters. Conversion attempts between weight and volume estimates would be inherently speculative due to even slight variations in fuel density.



Figure 7-1: Lime pyre recorded and photographed by Earl Morris and colleagues at Chichén Itza (Morris et al. 1931:222).

In 2006, Bradley Russell and Bruce Dahlin constructed a square-shaped pyre with the help of local informants on the outskirts of the northern Yucatecan site of Mayapán (Bradley and Russell 2007). Among their several goals were to document the amount of labor and materials required to produce lime using the open-air pyre method, and then to gain insight into what the archaeological signature of an open-air pyre might look like. They noted that specific types of wood were desired for this cooking process, namely those that were hard and dense with a high water content that would also cook all the way through and leave only ash behind. While their informants told them that a typical pyre would be approximately 4 m long by 4 m wide by 1.5 m tall, they built a smaller one, measuring only 2 m long by 1.65 m wide by 1.5 m tall for a total of 4.95 cubic meters of wood fuel. The fist-size and smaller bits of limestone that were placed on top of the pyre formed a mound that measured 40 cm tall in the center, about 18-20 cm tall at the edges and left a 20 cm ledge around the top of the pyre (Figure 7-2).

They produced approximately 0.5 cubic meters of quicklime from 0.57 cubic meters of limestone, as some of the pieces of limestone did not completely calcine during the cooking process. They estimated that the quicklime expanded only about 15% in volume during the slaking process (Russell and Dahlin 2007:418), which would have produced a grand total of 0.575 cubic meters of slaked lime. This resulted in a fuel to finished product ratio of approximately 8.5:1 in terms of volume. They also noted that without waiting for dew and rain to slake the quicklime approximately 200 liters of water were necessary to slake the quicklime immediately. Russell and Dahlin extrapolated the figures from their small pyre to the average 4 m by 4 m by 1.5 m size proposed by their informants and deduced that a 24 cubic meter pyre would produce approximately 2 cubic meters of finished lime (Russell and Dahlin 2007:417), for a final volumetric ratio of approximately 12:1 wood fuel to burnt lime.

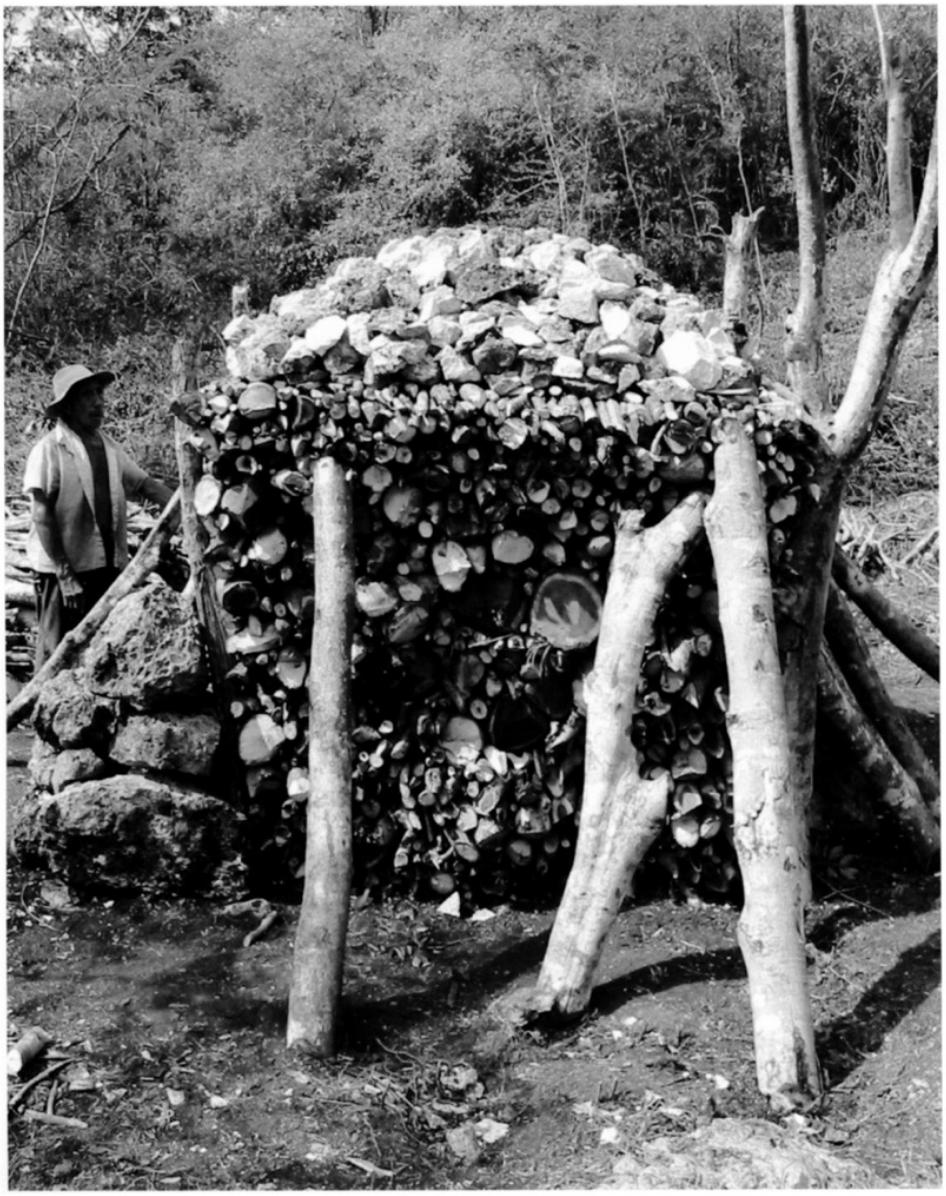


Figure 7-2: The open-air lime pyre constructed by Russell and Dahlin (2007:411).

During the 2002 summer field season at the Puuc site of Labná, Tomás Gallareta Negrón and Rossana May Ciau directed the construction of a circular lime pyre in an effort to test the aboveground pyre method of production and to produce non-chemical lime to use in consolidation and restoration efforts at the site (Figure 7-3) (May Ciau and Gallareta Negrón 2003). A mason from the town of Oxkutzcab oversaw the construction of a circular open-air pyre, which ended up measuring approximately 1.4/1.5 m tall with a diameter of about 3 meters.

Using 1.45 m as the average height of the pyre would result in a total volume of approximately 10.24 cubic meters of wood fuel used in the production episode. On top of the circular pyre, they placed a mound of small pieces of limestone, which measured 0.7 m in height at the apex. Having left an approximate 0.3 m ledge around the edge of the limestone mound, the total volume of limestone used would be approximately 1.42 cubic meters. Unfortunately, they did not record the exact amount for the final quantity of lime produced from the experiment. Using Russell and Dahlin's 15% quicklime to slaked lime expansion as a model, and assuming that all of the limestone calcined during the firing process, their pyre likely produced approximately 1.63 cubic meters of lime powder. The final ratio of wood fuel to finished lime would then be 10.24 cubic meters of wood to 1.63 cubic meters of lime, or 6.3:1, which falls within the range provided by Schreiner (2002).

A point of reference from outside the Maya area is provided by Kenneth Pike's (1980) ethnographic account of the firing of a Mixtec updraft lime kiln outside the town of San Miguel del Grande, Oaxaca. This type of kiln was reported to be as much as 40% more fuel-efficient than the open-air Maya pyres discussed above (Wernecke 2008:204). The fact that the Mixtec method involved using dry wood instead of wet wood and still managed to be more fuel-efficient than the open-pyre method (Wernecke 2008:204) raises the possibility that the Prehispanic Maya did not necessarily harbor the same penchant for green wood as contemporary Maya lime producers.



Figure 7-3: Radial open-air pyre constructed at Labná by May Ciau and Gallareta Negrón (2003:6-16).

The First Kiuic Pit-Kiln Experiment

In February 2015, I oversaw the construction and firing of an annular lime kiln modeled on the Prehispanic annular structures that I had excavated over the previous field season. First, with the help of a local consultant, I chose a location for the kiln approximately 350 m to the East of the Kaxil Kiuic Research and Learning Center base, butting up against the ring of hills at the southern end of the Kiuic Valley. Following the tendency of the Prehispanic Maya to construct these annular kilns on the incline of limestone outcrops or low hills, we chose a location on the eastern slope of a low limestone outcrop. The center of the kiln would be near the

base of the outcrop and thus half of the circular pit would be excavated into the side of the outcrop in order to use the limestone bedrock for the eastern side of the kiln's arc. This location carried the added advantage of being protected by two hills, one to the north and one to the south, which would lower the risk of wind interference during the firing process.

Between five and seven men worked daily to excavate the central pit of the annular kiln over the course of ten days. The difficulty of cutting through the hard limestone bedrock was only exceeded by the difficulty of cutting through the slightly softer *sascab* below, which had a tendency to crumble and break off bit by bit whereas the harder rock could be dislodged in larger portions. Switching off constantly, and using heavy iron bars called *barretas*, large iron hammers, and a heavy iron spike, it took a total of 179 hours of labor to complete the construction of the annular kiln. This included both the excavation into the side of the outcrop, cutting through at least 40 cm of the surface bedrock at the base of the outcrop and constructing a single-walled ring around the pit out of some of the larger pieces of hard bedrock that had been removed during the excavation. None of these tools were available to the Prehispanic Maya builders, who likely used harder grades of limestone and chert to cut through the limestone bedrock and *sascab.*

When finished the annular kiln possessed an elliptical shape, somewhat similar to Annular Structure 3 of the hill group *Box Peek' Pocpocxic* due to the way in which some of the outcrop bedrock had fractured during the excavation process. Thus, what was meant to originally be a 3 m diameter circle, was ultimately an ellipsis with a major axis of 3.4 m and a minor axis of 2.9 m. The base of the internal depression measured a little narrower at 3 m x 2.7 m. Just over 3/5 of the structure's ring consisted of the loose stones created during the excavation process and just under 2/5 of the ring was made up of the limestone bedrock and underlying *sascab* of the

outcrop. An opening that measured 60 m across was left in the loose-stone wall in order to provide easier access for the placement of fuel within the kiln. The single-wall ring measured between 40 and 50 cm wide, and was approximately 75 cm high at its greatest extent, which was in the southeastern sector to either side of the opening left in the wall. The boulder walls shortened as they climbed the slight slope to meet the outcrop side of the ring. The total depth of the kiln (including both the above-surface loose-stone wall and the excavated central pit ranged between 1.25 and 1.40 m deep (Figure 7-4).



Figure 7-4: Photograph of the experimental annular kiln before the firing episode, looking South.

With the help of bio-reserve's caretaker Don Evelio Uc, and Don Gabriel Us, from the nearby town of Yaxhachen, we assembled the raw materials for the firing experiment. Twenty-eight hours of labor were required to gather the wood and assemble the logs within the kiln. As

with the abovementioned open-air pyre experiments, the informants insisted on the necessity of predominantly freshly cut green wood for the firing process. The high moisture content of green wood, as opposed to dry firewood, would allow for a slower burn at higher temperatures. Due to the kiln being located within the Helen Moyers Kaxil Kiuic Bio-Cultural Reserve, green wood could only be cut and gathered from the immediate vicinity of the kiln, where trees were in danger of presenting a fire hazard, and from where trees had begun to encroach on established trail routes and roads through the reserve. Adherence to the rules of the reserve increased the total human labor hours required for the fuel assembly and widened the catchment area beyond what would have been necessary had no prohibitions existed on harvesting the forest. The species of wood used for the firing of the kiln included: Box kaatsim (*Prosopis juliflora* or *Acacia guameri*), Chacáh (*Bursera simaruba*), Ja'abin (*Piscidia piscipula*), K'aan chunuup (*Thouinia paucidentata*), K'askaat (*Luehea speciosa*), Taak'in ché (*Caesalpinia yucatanensis*), Ts'iits'il ché (*Gymnopodium floribundum*), Ts'ulub may (*Colubrina greggii*), and Ts'ulub took' (*Bahuinia divaricate*). They were used in varying quantities depending mainly on availability, as all possessed high moisture content and burned well.

Don Gabriel directed the assembly of the wood fuel and raw limestone within the kiln. He was 75 years old at the time of the experiment and had participated in the production of lime using the standard open-pyre method in the past. He remarked that he had never seen nor heard of using an enclosed area, let alone a pit before, as all of the lime production events he had been party to had used the above-ground open pyre method. The method he described used a square pyre similar to the one constructed and fired by Russell and Dahlin. Despite his never having used a pit-kiln before, he adapted his knowledge of lime production to the scenario and constructed what for all intents and purposes was a low circular pyre within the annular kiln.

The first layer of wood was laid out in a radial pattern around a central point that was slightly closer to the entrance of the kiln than to the exact geometric center of the kiln. The logs used in the first layer included members of nearly all of the species that were eventually used and measured between 3-8 centimeters in diameter. The majority of the logs in this first layer lay at a depth of approximately 1.25 m below the top of the loose-stone wall due to the uneven surface of the kiln's floor. Only green wood was used in this first layer (Figure 7-5). The second layer was likewise constructed in a radial pattern but with sticks of a slightly smaller diameter and length. Another notable feature of this second layer was that the sticks used were predominantly dry, not green wood, as they would be used as kindling to get the fire burning at the outset.

The third layer, which began about 25 cm up from the bottom of the first layer, included green wood logs of a larger diameter (between 10-15 cm), as well as green wood chips that were chopped purposely to fill in the inevitable cracks between the logs of the first three layers of fuel. It was also in the third layer that Don Gabriel placed an offering in the center of the kiln, which he referred to as his 'secret ingredient' that would ensure a good burn. The offering consisted of about 3 tablespoons of salt, several dried chili peppers, and five dry, kernel-less corn cobs (Figure 7-6). The fourth layer, beginning about 35 cm up from the bottom of the first layer consisted of the widest-diameter logs cut from a chacáh (*Bursera simaruba*) that had partially fallen over the road into the Reserve, and the ts'iits'il ché (*Gymnopodium floribundum*) and ts'ulub took' (*Bahuinia divaricate*) that it had toppled in its fall. These green wood logs ranged from 20 to 30 cm in diameter and were arranged in a more haphazard design, crossing the radially arranged logs at odd angles in order to ensure a level and evenly spread tier (Figure 7-7). The fifth and final layer of wood fuel consisted once again of smaller green wood logs (from 2 to 8 cm in diameter) used to fill in the cracks between the larger logs and ensure a level bed on

which to place the limestone. The final height of the wood fuel within the kiln measured approximately 0.7 m, which, multiplied by the area of the base of the wooden pyre (2.8 m major axis by 2.5 m minor axis) brought the total volume of wood fuel used to approximately 3.87 cubic meters ((2.8 m x 2.5 m x 0.7 x pi)/4). Throughout the arranging of the fuel Don Gabriel was careful to leave a small tunnel open that led from the kiln entrance to the center of the kiln where he had placed his secret ingredient offering. This would help with the initial lighting of the fire in the center of the kiln. Before assembling the limestone atop the wood, Don Gabriel poured some kerosene down the center point of the kiln in order to provide an additional boost to the initial igniting process.

Atop the final layer of wood, Don Gabriel created a mound of limestone that had been broken down into fist-size pieces or smaller (Figure 7-8). He rejected using any *sascab* or stones with too much of an orange tint, as they were too soft and had too high an iron content, respectively. Again, I asked Don Gabriel to deviate from his normal lime production routine for the sake of the experiment in that I asked him to use much more limestone than he would normally place atop that amount of wood fuel. I explained that we were trying to discover the maximum amount of lime that could be produced from the given amount of fuel and that I did not expect all of it to calcine completely. The mound of limestone ended up rising to 0.6 m in the center, tapering to about 0.25 m at the edges and had a maximum basal diameter of 2.9 m and a minimum basal diameter of 2.5 m. Though it is difficult to calculate the exact volume of the mound, a conservative estimate would be approximately 3 cubic meters of limestone.

Using a piece of cloth soaked in kerosene and attached to a stick, we lit the center of the kiln through the open tunnel at 9:15 am on Friday, February 27. Unfortunately, although it was the dry season, it began to rain lightly almost immediately after the fire began to catch. It

continued to rain on and off for an hour and although the fire did not go out, the wetting of the surface stones undoubtedly negatively affected the results of the firing process. Small amounts of smoke began to seep out right at the outset of the experiment, as the drier firewood placed in the center of the wood pile caught fire. By 9:30 am, large billows of light white smoke began to pour out of the top of the kiln (Figure 7-9).

At 10:30 am, some of the limestone rocks at the center of the mound began to cave in slightly, forming a mini-volcano-like cone as the wood in the center continued to burn. Using a thermocouple, I was able to record that the kiln had reached a temperature of at least 830 degrees Celsius by this time. The thermocouple did not reach all the way to the exact center of the kiln, but came close. At this time, the smoke switched to a slightly darker and bluer color, and was no longer as billowy.



Figure 7-5: Photograph of the first layer of wood fuel placed inside the experimental lime kiln.



Figure 7-6: The placement of an offering of dried corn cobs, dried chili peppers and salt in the center of the fuel pile on top of the second layer of logs.



Figure 7-7: The larger logs that made up the fourth layer of wood fuel within the experimental kiln.



Figure 7-8: Photograph of the experimental kiln ready to fire with the pile of *chich* in place on top of the wood fuel.

By 11:00 am, the thermocouple recorded a temperature of 885 degrees Celsius, slightly above the temperature thought to be the minimum for calcining limestone (Schreiner 2002; Wernecke 2008). This temperature has been called into question, however, by such investigations as that of Meg Thibodeau who used Fourier Transform-Infrared Spectrometry to examine lime plasters from the sites of San Bartolo and Xultún in Guatemala and deduced that they were produced at temperatures lower than 800 degrees Celsius (Thibodeau 2013). At 11:08 am the thermocouple peaked at 937.4 degrees Celsius, then fell to 935 C and continued to fall slightly thereafter until it settled in the low 800s Celsius. It is unclear whether the temperature remained higher in other areas of the kiln, but the fact that much of the stones did end up calcining suggests that the temperature remained appropriately hot enough in the center of the kiln. At 11:30 am, the smoke took on a slightly greenish tint at times, which Don Evelio explained signaled that the actual stones were beginning to burn.

By 1:00 pm, the smoke had mostly stopped, though the fire was still roaring and had spread to almost the entire breadth of the kiln. The mound of stones continued to slowly collapse inward. By 2:00 pm there was hardly any smoke at all coming from the kiln, and although most of the stones on the surface of the mound had turned black and then grey, there was no evidence any quicklime being produced yet (Figure 7-10). Between 5:30 and 6:15 pm a light rain returned, which might have further negatively affected the calcining process, though it did not stop the fire from burning. The entire burning process took approximately 21 hours, with the fire still going lightly at 7:00 am the next morning. None of the surface stones appeared to have calcined, which was to be expected due to the low fuel-to-stone ratio and the multiple precipitation episodes, but there was evidence of quicklime beneath this outermost layer (Figure 7-11). In order to allow the quicklime to hydrate naturally into slaked lime, we left the kiln alone until the end of May.



Figure 7-9: Photograph of the experimental kiln during the firing process showing the blackening of the surface stones while the file still rages below.



Figure 7-10: Photograph of the experimental kiln on the day after the first firing episode, showing the blackened surface stones and the underlying layer of quicklime poking through at the center of the mound.

Returning to the experimental kiln at the end of May 2015, I found that the mound had slightly expanded as the layer of quicklime beneath the surface layer of blackened stones had absorbed moisture from multiple precipitation episodes. I peeled away the surface layer of stones to reveal the extent of the pile of slaked lime below (Figure 7-11). In total, we collected 40 19-liter buckets of lime powder from inside the kiln (760 liters of lime powder), and 49 buckets of non-calcined pieces of limestone. The high quantity of non-calcined limestone was most likely a result of both the superfluous amount of raw limestone placed atop the wood fuel and the multiple precipitation episodes that occurred during the experiment. The quantity of lime powder produced (760 liters) was equal to 0.76 cubic meters (Figure 7-12). This resulted in a final ratio

of wood fuel to lime produced of 5.09:1, which would place this firing episode just above the average fuel efficiency ratio discovered by Schreiner (2002). Thus, the results of this first experiment were rather inconclusive with regard to the question of why the local Prehispanic inhabitants of Kiuic may have used pit-kilns instead of open-air pyres for lime production. However, due to the possible negative effects of the rain and the disproportionate amount of raw limestone used in the experiment, I decided it would be prudent to conduct another lime production experiment using the lime kiln.



Figure 7-11: Photograph of the slaked lime beneath the surface layer of blackened, but not calcined, pieces of *chich*.



Figure 7-12: Photograph of the full 0.76 cubic meters of slaked lime recovered from the first firing of the experimental kiln.

The Second Kiuic Pit-Kiln Experiment

In June 2015 I conducted a second lime production experiment using the annular pit-kiln that I built for the first experiment. Before the second firing experiment, however, I made some changes to the kiln. The heat from the first firing episode had loosened the bedrock of the structure's floor to a depth of about 10-15 cm, which allowed us to excavate the central depression a little deeper. This heating, loosening and removal of more bedrock may account for the impressive depths to which many of the Prehispanic structures reached. Through continuous use, the floors of the central depressions of the annular structures would become more friable,

allowing the bedrock to be removed with greater ease either for use in subsequent firing episodes or to be discarded if it was not constituted of lime powder-grade stone. In addition to removing the loosened stone from the floor of the structure and excavating the central depression to a slightly deeper level, I took steps to make the experimental kiln more circular in shape. As mentioned above, the surface bedrock had cracked in such a way that the central depression exhibited more of a teardrop than a circular shape for the first firing. In order to ensure a more evenly distributed burning, I took a cue from the construction form of Annular Structure 8 and lined the western interior wall of the structure with boulders (Figures 7-13 and 7-14). This filled in the narrower section of the teardrop and rounded the interior of the structure into a more circular, if still slightly oval, shape. The new dimensions of the kiln were: 2.4 m N-S by 2.4 m E-W at the floor of the central depression; 2.6 m N-S by 2.7 m E-W at the top of the interior of the structure; 1.35 m from the floor to the top of the ring on the west side of the structure; 1.40 m from floor to top on the north side; 1.35 m from floor to top on the east side; and, 1.30 m from floor to top on the south side (Figures 7-15 and 7-16).



Figure 7-13: Photograph of the experimental kiln showing the new western interior wall of the structure made of boulders on the right side of the photograph.



Figure 7-14: A 3D rendering of the kiln prior to the second firing experiment.

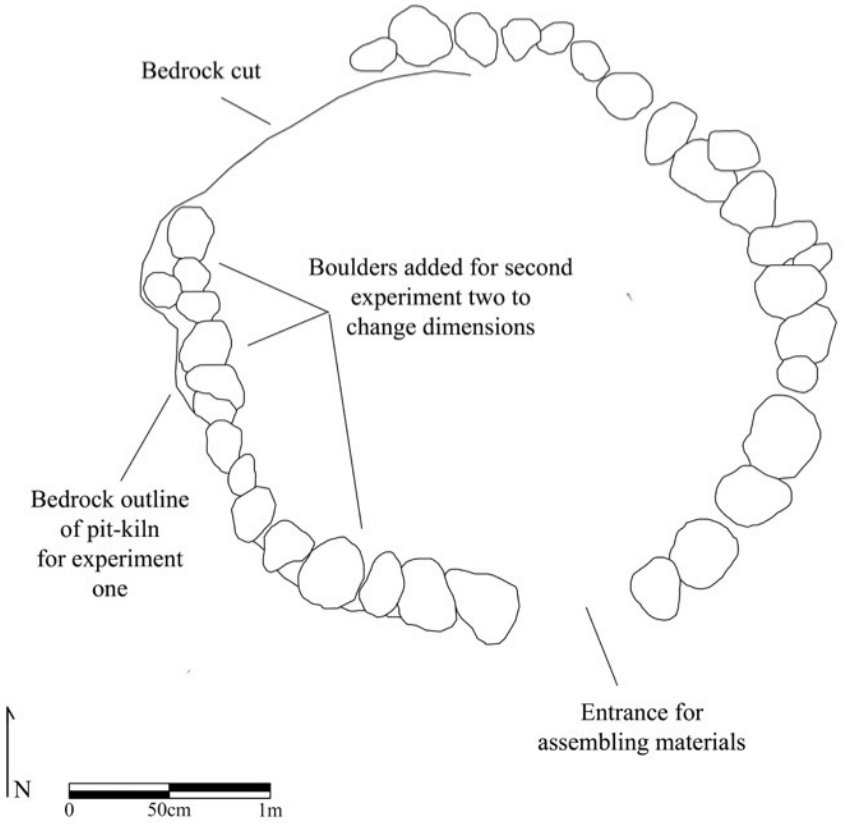


Figure 7-15: Aerial view sketch of the experimental pit-kiln prior to the second experiment.

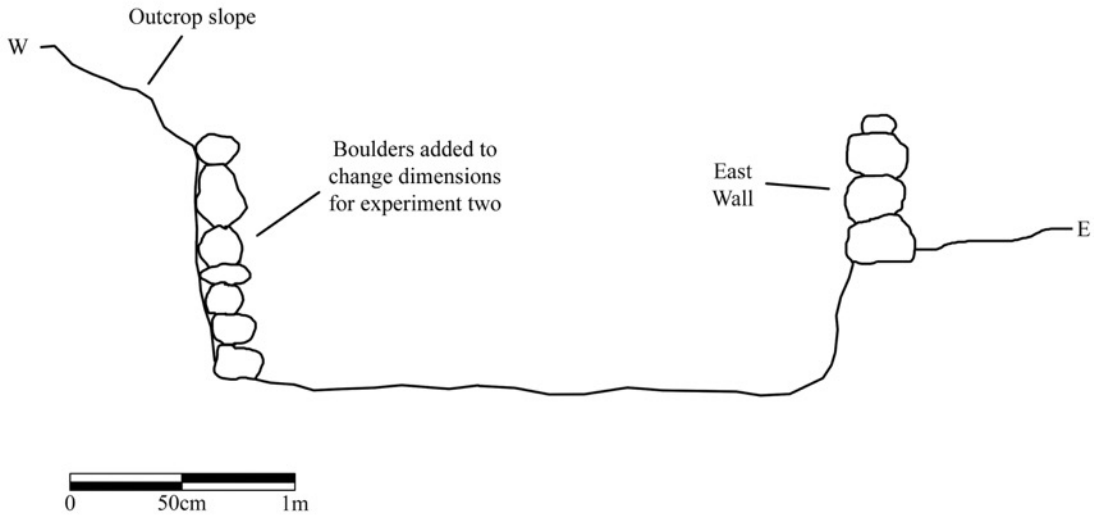


Figure 7-16: Cut view sketch of the experimental pit-kiln prior to the second experiment.

The second experiment proceeded along the same lines as the first experiment, with the exceptions of slightly different types of wood fuel used, and the use of a lower proportion of raw limestone *chich* to wooden fuel than was used in the first experiment. We followed the same general process for gathering the wood fuel as we did for the first experiment, only using trees that were encroaching on paths and roads within the Biocultural Reserve. Don Gabriel Us oversaw the assembly of the materials within the kiln, but this time I followed his judgment as to the ratio of wood to *chich* piled on top. Similar to the first experiment, Don Gabriel Us placed logs with medium diameters on the bottom, interspersed with some drier kindling and wood chips (Figure 7-17). He placed an offering of dried corncobs, dried Chile peppers, and salt in the center of the second layer. The third layer consisted of logs with larger diameters (Figure 7-18), and the fourth layer consisted of logs with medium-sized diameters as well as woodchips created to fill in any gaps in the lower levels (Figure 7-19). The fifth layer consisted of logs with medium and smaller diameters to create a level foundation on which to place the pieces of *chich*.

The small pieces of limestone were then arranged on top of the final layer of logs (Figure 7-20). The species of wood used in this second firing experiment included Box kaatsim (*Prosopis juliflora* or *Acacia guameri*), Chacáh (*Bursera simaruba*), and Ja'abin (*Piscidia piscipula*), which were all used in the first firing experiment. New species used in this second experiment included: Huayum (*Talisia olivaeformis*), Pichi ché (*Enterolobium cyclocarpum*), and Box salam (*Lysiloma latisiliqua*). All of the wood aside from the dry kindling was freshly cut and thus considered green wood with high moisture contents.



Figure 7-17: Photograph of the first layer of logs, kindling, and wood chips placed within the kiln for the second firing experiment.



Figure 7-18: Photograph of the third layer of wood fuel, consisting of large diameter logs.



Figure 7-19: Photograph of the fourth layer of wood fuel, consisting of medium-sized logs interspersed with wood chips.



Figure 7-20: Photograph of the *chich* placed atop the wood fuel ready to be fired.

Overall, less wood fuel and less raw limestone were used in this second firing experiment than in the first. This ensured that the materials would be enveloped completely within the kiln, with no *chich* poking up over the rim of the kiln even at the start of the experiment. The idea was to maximize the efficiency of the heat-retaining and wind-blocking attributes of the kiln and mirror more closely the characteristics of the Prehispanic annular structures. The final dimensions of the wood fuel pile assembled within the experimental kiln for the second firing experiment included a diameter of 2.2 m and a height of 0.75 m, which were used to calculate a total volume of 2.85 cubic meters of wood fuel (1.1^2 m x 0.75 m x pi).

The kiln was lit at 11am on June 24th, 2015 and the burning process followed the same patterns exhibited in the first firing experiment (Figure 7-21). I knew we were taking a risk by conducting this experiment during the rainy season, but luckily only a light drizzle fell for about

50 minutes in the early afternoon. The fire continued to burn through the night (Figure 7-22) and lasted until approximately 7am the following day, for a total burn of about 20 hours. The benefit of conducting this experiment during the rainy season was that I did not have to wait long for a precipitation event to naturally slake the quicklime that I had produced (Figure 7-23). It rained several times in the following days, allowing us to harvest the slaked lime from the kiln the following week. Some of the pieces of quicklime at the bottom of the heap still needed to be slaked manually (Figure 7-24). This time the vast majority of the *chich* had calcined and become lime powder. We removed a total of 38 19-liter buckets of lime from the kiln, which was equal to 722 liters or 0.722 cubic meters. Thus, the final ratio of wood fuel used to lime powder produced during this second experiment was approximately 3.947:1 (2.85 cu m/0.722 cu m).



Figure 7-21: Photograph of the kiln begins to produce smoke during the second firing experiment.



Figure 7-22: Photograph of the kiln burned through the night.



Figure 7-23: Photograph of the kiln the day after the second firing experiment showing the higher ratio of calcined stones to non-calcined stones than in the first experiment.



Figure 7-24: Photograph (Above) Pieces of quicklime recovered from the lower layers of the post-firing heap; (Below) The quicklime transforming into slaked lime after a sprinkle of water was added.

Results of the Kiln Experiments

The results of the two firing experiments provided considerable amounts of data that was significant for the investigation of Prehispanic lime production at Kiuic. Here I present and discuss the implications of these results.

1) Technical practicality: Purely on a practical level, the firing experiments demonstrated that the annular pit-kilns could be used to transform limestone into lime powder efficiently. While the experimental kiln was not as deep as the central depressions of the final stages of most of the annular structures encountered in the archaeological record, the experimental pit-kiln did provide a partially subterranean and completely encircled mechanism for burning limestone. Thus, one of the main objectives of the experiments, to test the functionality of annular pit-kilns for producing lime returned positive results that support the Prehispanic structures' use as lime kilns.

2) Fuel-Efficiency: The other main objective of the experimental firing episodes was to determine whether increased fuel efficiency may have been a factor influencing the development of annular pit-kiln technology. While unexpected rainfall and an inefficient proportioning of raw materials skewed the results of the first kiln experiment, the results of the second kiln experiment demonstrated that annular pit-kilns could be used to produce lime powder with an efficient fuel-to-product ratio. Unfortunately, as mentioned above, Schreiner's (2002) comparison of different pyre techniques measured fuel efficiency in terms of weight ratios (kg). An attempt to convert the weight ratios to volume ratios without knowing the exact densities of the different types of woods used would result in dubious comparisons with my own volume ratios. He found ratios of wood fuel to lime produced ranging from 3.8:1 to 8.2:1, with an average of 5.0:1 in terms of weight. One finding pertinent to my study was that the radial pyres tended to be more fuel-

efficient than square or rectangular ones. This makes sense from a physics standpoint as circular kilns lit from the center would burn outward more evenly and thus lead to more practical fuel consumption. The annular shape of the Prehispanic pit-kilns at Kiuic encouraged a radial arrangement of fuel within the central depressions, which would in turn have led to more efficient production episodes.

Russell and Dahlin's (2007) experimental open-air pyre produced a volumetric fuel efficiency ratio of approximately 8.5:1, and May and Gallareta's (2003) experimental burning was estimated to have produced a volumetric ratio of approximately 6.3:1 fuel-to-product. My second kiln experiment using the annular pit-kiln at Kiuic produced a volumetric ratio of 3.94:1 wood fuel used to lime powder produced, which was significantly more efficient than these two open-pyre production episodes. Being that it is hard to compare the volumetric ratios with Schreiner's weight ratios and I am left with a very small sample comparison, I can at least say that the pit-kiln technology is potentially more fuel-efficient than aboveground open-air pyres. Thus, while the experiments do not provide a clear basis for declaring fuel-efficiency to be the main reason for the development and use of annular pit-kilns, they do provide nominal support for this hypothesis. The 3.94:1 ratio, which might also have been negatively affected by a brief period of rain, thus provides a conservative baseline for the architectural energetics calculations discussed in later chapters.

3) Construction and Assembly: The construction and firing of the experimental kiln provided important data regarding the labor investments involved in the lime production enterprise. The initial construction of the annular structure, including the excavation of the central depression and erection of the partial single-walled ring required a total of 179 hours of labor using modern metal tools. The 2.7m-diameter size of the experimental kiln fell near the

middle of the range of diameter sizes for the annular structures (n=53) encountered in the archaeological record (mean=3.2±1.2m). Assuming that the construction process took longer using the non-metal tools available in Prehispanic times, 179 hours can be considered the minimum amount of labor hours necessary to construct an annular structure with a central depression measuring approximately 2.7 m in diameter.

While exact comparisons and projections of these modern figures back into Prehispanic times are inadvisable, the construction process did provide other important insights regarding the building and use of these pit-kilns. The difficulty encountered in chipping away the surface bedrock to create the central depression indicated the potential importance of the firing episodes themselves in allowing the builders to excavate to such low levels in the central depression. As mentioned above, the first experimental firing episode loosened 10-15 cm of the floor bedrock of the structure, allowing it to be removed with greater ease prior to the second firing. Lime producers likely removed any loosened or friable bedrock from the floor of these structures prior to firing episodes to ensure structural stability and irregular burns. They also likely used the loosened stone fragments in subsequent firing episodes. It is even possible that in their earliest construction phases, annular structures were not significantly subterranean, but were instead similar to aboveground open-air pyres placed in alcoves where limestone had already been quarried away from the side of outcrops. In this scenario, repeated firings in one location eventually led to the excavation of a deeper and deeper central depression until they reached the depths like those encountered in the archaeological record.

A total of 28 human labor hours were necessary for the collection and assembly of the raw materials required for the first burn, and approximately 26 hours were required for the second burn. These data, however, were skewed by the need to gather the wood fuel from

specific locations fairly distant from the experimental kiln and thus cannot realistically serve as analogues for the general amount of labor hours that were required to prepare a kiln for firing in Prehispanic times. However, the fact that several pit-kilns were located away from the sloping terrain that likely harbored the remaining stands of trees in the Terminal Classic Period suggests that transportation of wood fuel over large distances may have been occasionally necessary. Labor for these transportation activities was likely organized at the household or small corporate level. The use of metal tools (including a chainsaw) to fell trees and a truck to transport the larger logs served as additional barriers to estimating Prehispanic labor investments. As with the construction process, the gathering and assembly of the raw materials provided insights into the lime production process. The large labor investment required for gathering the raw materials, especially in the absence of beasts of burden or wheeled implements during the Prehispanic period, suggests that Prehispanic lime producers took steps to limit transportation efforts. This observation strengthens the theory that one of the reasons for locating the annular structures near or abutting limestone outcrops was to limit the transportation efforts required to assemble the materials for lime production. Likewise, the location of the majority of the annular structures in the intermediate hilly zone might have been part of this effort to limit transportation investments. During the Late and Terminal Classic Period, when the annular structures are hypothesized to have been in use, much of the flat land within the Kiuic Valley and in the hinterlands to the west would likely have been denuded of trees and put to agricultural uses. Thus, the majority of the available timber would most likely have been located on the hilly, non-agricultural slopes of the hills and their associated limestone outcrops.

4) The Firing Process: The firing process itself also provided some significant observational insights. The maximum temperature measured during the first firing experiment

was 937.4° Celsius, though the average temperature for the first half of the burning episode was in the low-800s. Past studies have indicated that the necessary temperature to calcine limestone is at least 800° C (Schreiner 2002; Wernecke 2005), though some researchers have suggested 880°C as a minimum (Ashurt and Ashurt 1988). Only recently was a study conducted that found that limestone could be calcined at temperatures lower than 800° C (Thibodeau 2013). The fact that temperature inside the experimental annular pit-kiln reached over 900° and consistently stayed above 800° provides further evidence of the functionality and efficiency of these kilns. The durations of the experimental burns, lasting for approximately 21 and 20 hours respectively, further provided evidence of the practicality of the annular pit-kilns.

Another lime production factor raised by the experimental firing processes was the issue of smoke pollution created by the burning of the wood fuel and the limestone. For approximately the first four hours of each of the burns, the pit-kiln produced large amounts of white and gray smoke. The first burn took place on a cloudy, foggy day and the mist did not allow the smoke to disperse into the sky. Instead it permeated the surrounding forest. Even though the second burn took place on a relatively dry, sunny day the smoke still permeated the surrounding forest to an extent of about 200 m in the downwind direction. This raised the issue of the possible negative effects of smoke pollution from the lime production process and whether there might have been methods for mitigating such negative effects in Prehispanic times. The desire to limit smoke pollution may have been in a factor in the decision to locate the majority of these annular pit-kilns outside of the inner site core in the intermediate hills. Foggy and misty days like the one experienced during the first burn are more common during the rainy season than the dry season, suggested that lime production may have predominantly occurred during the dry season to guard

against the exacerbating pollution effects of high humidity – not to mention the fact that rain adversely affects the firing process, as exemplified by the first experimental burn.

5) Slaking Issues: One factor arguing against lime production being limited to the dry season is the benefit of regular rainfall for the post-firing slaking process. While precipitation episodes are indeed common during the rainy season (much more so, at least, than during the dry season) they seldom occur daily. Thus, if lime production experts could plan their lime production activities for a 24-30-hour period in which they believed there would be a low chance of rainfall, they might have benefitted from a post-firing rainfall episode to help slake the quicklime. Rainfall would have been especially advantageous for slaking the quicklime produced in the very deep structures excavated during the 2014 and 2015 seasons. Transportation investments come into play for slaking considerations as well, and this is likely the main reason why some of the annular structures identified in the study area are located near to seasonal or human-made water sources like *haltúns* and *chultúns*. Assuming that lime producers would have preferred to use each kiln for multiple firing episodes in one year, especially during the population and construction boom of the Late and Terminal Classic Periods, they would have needed to slake the lime in a timely manner. For those pit-kilns not located near a stationary water source, water could have been transported in large ceramic vessels, or the quicklime would have been left alone to absorb water naturally. Thus, if the lime producers endeavored to both limit transportation efforts and create the lime for immediate use, production during the rainy season may have offered a way to address both problems. As I discuss in Chapter 9, however, there were likely a strong set of factors arguing for production being restricted to the dry season.

6) Burnt *Chich*: Another important insight gained from the experimental firings was the generation of a significant quantity of burnt or partially burnt, but not completely calcined *chich*.

Most of these pieces were located on the surface of the *chich* pile atop the wood fuel and due either to their distance from the fire or to their exposure to the rainfall episodes they were not transformed into quicklime. Some types of limestone do not calcine well based on their specific elemental makeup, and even when a person with a trained eye like Don Gabriel is doing the sorting, occasionally undesirable pieces of *chich* are used in the burn. The fact that they did not calcine proved their unsuitability for lime production and thus instead of using them in a subsequent experiment they were discarded nearby to the kiln. Thus, we were left with a large pile of burned *chich* to discard (Figure 7-25). The burned and partially burned pieces of *chich* resembled similar pieces of burned or partially burned stone identified in and around the majority of the archaeological annular structures. Prior to the kiln experiments, the pieces of burned *chich* found around the archaeological annular structures were taken to be general indications of burning events taking place in and around the structures. After the kiln experiments it became clear that these burned *chich* scatters most likely represented the detritus of lime production episodes. These were pieces that were to be transformed into quicklime but for any number of reasons did not completely calcine during the firing episode. Estimating the quantity of burned *chich* found around these archaeological features provide another line of evidence for calculating the use-lives of the Prehispanic kilns and the amount of firing episodes that might have taken place in each one annually.

7) Limitations and Future Directions: There were a few limitations during the two firing experiments and several factors and variables remain to be explored in future pit-kiln lime production experiments. First, the fact that rain was a factor in both kiln experiments was just the result of bad luck, and a future experiments will hopefully be able to take place without any interference from precipitation. Future experiments in dry weather will provide comparative data

and help to demonstrate whether the rainfall during the first two experiments really did have a negative effect on the outcome and if so to what degree.

Other variables that may be explored in future experiments concern the form and size of the experimental kiln. The type of kiln tested here was a single-walled annular structure of medium diameter size. For future experiments, I plan to build a double-ring wall and possibly expand the area within the central depression of the kiln to compare fuel-efficiency ratios, burn times, and heat retention. Additionally, each firing experiment will loosen up the bedrock floor of the structure, allowing for the central depression to be excavated deeper with each successive experiment. If kiln experiments continue at this location, we may one day reach depths comparable to those found in the archaeological annular structures, which would allow for more direct testing of the firing logistics of these Prehispanic pit-kilns.



Figure 7-25: Photograph (Left) Limestone discarded prior to the firing experiment due to being unsuitable for lime production; (Right) Partially burned but not calcined *chich* gathered from within the experimental kiln after the firing episodes.

The Ethnographic Data

Limestone was, and still is, by the far the most ubiquitous type of stone in the Yucatán Peninsula. Seeing as how it was the most durable material available for architectural purposes in the northern Yucatán, Prehispanic Maya architects, engineers, and lime producers most likely developed a detailed understanding of the different forms and grades of limestone. While it is impossible to extrapolate modern knowledge of limestone variation directly to the Prehispanic inhabitants of the Puuc, exploring the 'folk' names and usages for different types of limestone used by modern inhabitants of the region does provide the closest available analogue. Kelli Carmean and colleagues (2011) investigated Yucatec Maya terms for limestone in an attempt to uncover local knowledge of the distribution and use of different grades of limestone. Their project focused on construction forms; specifically, the names for the types of stones that were used to construct different parts of Prehispanic masonry structures. They noted that the limestone of the Puuc region is older than the limestone of the coastal regions of the Yucatán Peninsula and it has thus experienced greater compaction, which in turn has led to finer-grade construction materials (Carmean et al. 2011:147). They used the *Diccionario Maya Cordemex* (Barrera 1980) as their main source for Colonial-era and contemporary Yucatec Maya terms for different types of limestone. The terms that they found, which almost exclusively referred to architectural construction purposes, included:

"- Bak chi'ich' (small, gravel-sized stone)
- *bak pek* (small, fist-sized stone)
- *ch'eh* (fill stone)
- *k'oba* (water worn cobble – rock from a lake or river)
- *kowoh* (stone used in honey hive)
- *cháaltun* (stone slab)
- *tsaal yun* (uncarved stone)

- *tunil* (precious stone)
- *ah k'antixil ti'tun* (precious, golden colored stone)
- *u ya'axil tun* (precious, green colored stone – greenstone or jade)"

(Carmean et al. 2011:147)

Using these different terms for limestone, they investigated several Prehispanic architectural features at the Puuc site of Sayíl and correlated the usage of different types of limestone with the expression of socioeconomic differences.

Carmean and colleagues' vocabulary study was fairly limited with regard to the variations in the composition, texture, and color of the limestone grades. In an attempt to gain a better understanding of the degree of contemporary knowledge of limestone variation and of limestone processing, I interviewed several of my field assistants – most notably Don Gabriel Us, who was 75 years old at the time of our conversation. Unfortunately, it became apparent that even Don Gabriel's knowledge of types of limestone was fairly limited as he could only describe four general terms for limestone relating to lime production. They included:

- *saakel bach tuunich* (white birds egg rock) This type of limestone is particularly white in appearance and of a medium-hard composition, and it is the best type for making lime powder.

- *tok' tuunich* (hard rock) This general type of limestone is grayer in appearance, harder in composition, and is not suitable for making lime powder.

- *chak tuunich* (red rock) This type of limestone has a high iron content that gives it a reddish hue. It is generally unsuitable for making lime powder, and if used results in a lime powder that has a pinkish hue.

- *sah kab tuunich* (marl, or white earth rock) This is the softer, white limestone also known as *sascab* that is unsuitable for making lime powder.

These different grades/types of limestone occur in patches throughout the landscape, blending together to form the bedrock matrix. Using Don Gabriel's identification of these different types, I found that the majority of the quarries located near to annular structures in the study area contained high proportions of *saakel bach tuunich*, the type of limestone best-suited for making lime powder. Similarly, outcrops and *chich* piles located near annular structures also contained high proportions of *saakel bach tuunich*.

In speaking with Don Gabriel Us and other senior members of the local communities, I was told repeatedly that the previous generation (that has since passed away) was most likely the final generation that had possessed a more in-depth knowledge of Mayan terms for limestone, especially with regard to lime powder production. Fortunately, Dr. Dean Arnold of the Field Museum had recorded more detailed distinctions for types of limestone in the Yucatec Maya language in interviews he conducted with Don Alfredo Tzum in the nearby town of Ticul in 1965. Mr. Tzum was a potter by profession, and his in-depth knowledge of types of limestone and the uses to which they are generally put is thus largely in reference to their importance of pottery production. The most likely reasons for the recent disappearance of this sort of knowledge include the increasing pervasion of Spanish vocabulary into everyday conversational Yucatec and the abandonment of non-mechanized construction techniques in the face of easier access to modern construction technologies and materials. Dr. Arnold has yet to publish the limestone-related vocabulary data he gathered, but he gave me permission to include them here in my investigation (Arnold, personal communication 7/1/15). Here I present his data, which consist of 20 types of limestone, including the four reported to me by Don Gabriel Us (Table 7-2).

Although the majority of these terms for different types of limestone are couched in references to their importance for pottery production, they still provide important insights for my current study of lime production. The fact that the Yucatec language maintained so many distinctions for different types of limestone into the Twentieth Century indicates the extensiveness of the locals' knowledge of limestone grades and their disparate uses. This extensive knowledge reflects the important place that limestone and limestone products has had in the local culture for a long time. Although limestone was ubiquitous throughout the Northern Maya lowlands, if one considers the higher proportion of masonry architecture found in the Puuc Region and the generally finer composition of the more compacted limestone in the region, it is possible to imagine a uniquely comprehensive understanding by the Prehispanic inhabitants of the Puuc of their limestone environment.

Table 7-2: Local Ethnopetrology and Ethnogeology according to Ticul potter Alfredo Tzum (Arnold 1965, personal communication 7/1/15).

	Maya Name	**Use**	**Where Found (general)**
1.	*Sakel baach tuunich* (white birds egg rock)	Walls of houses	Pulled out of the ground
2.	*Tok' tuunich* (hard rock)	Kiln [walls]	High hill ridge
3.	*Chak tuunich* (red rock)	Walls of houses	Hill ridge
4.	*Sah kab tuunich* (marl)	Walls of houses	Pulled out of the ground
5.	*Boosh tuunich* (black rock)	Kiln [walls]	Hill ridge
6.	*K'an tuunich* (yellow rock)	Walls	Hill ridge
7.	*Hi' tuunich* (crystalline rock)	Temper for cooking pottery	Caves along the hill ridge
8.	*Boosh tok' tuunich* (black hard rock)	Kiln [walls]	High hill ridge
9.	*Chak tok' tuunich* (red hard rock)	Kiln [walls]	High hill ridge
10.	*Sak lu'um tuunich* [white earth rock]	Temper for non-cooking pottery (e.g. water carrying pot, water storage pot, food bowl)	Marl mines
11.	*Tuunich sak kab* [stone white earth]		Marl mines
12.	*K'at tuunich* (rocks in clay)	Not good for anything	Picked out of clay
13.	*K'an kab tuunich* (red earth rock)	Build a kiln	(no response)
14.	*Chak sah kab* (red white earth)	Walls of houses	In the earth
15.	*Nen us tuunich* ["salt/crystal/mirror" "gnat" rock]	Cooking pottery	Over very hard rock
16.	*Ts'ek'el tuunich* [hard bedrock]		Hill ridge
17.	*Hal tun tuunich* [stone from a seasonal pond]	Not used for making pottery	[Seasonal ponds]
18.	*Kab tuunich* [earth rock]	Grinding nixtamal	Small hills on the hill ridge
19.	*Tuunich ka'anab* [?]	To polish pottery	Seashore
20.	*Tuunichil aktun* (rocks in natural caves)	Wash basins	Natural caves in the hill ridge

Chapter 8: Results

To test the hypothesis that the annular structures were used as kilns to produce lime, I ran several archaeometric analyses on samples of limestone, *sascab*, and soil recovered from inside and around the structures. I ran Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) and stable carbon and oxygen isotope analyses to: 1) confirm the presence of burning episodes within the kilns; 2) determine whether the kilns reached temperatures high enough to calcine limestone; 3) identify what species of wood were used in the cooking process; and 4) identify elemental traces that would provide evidence for burning functions beyond lime production. I also recovered samples of charcoal from seven of the excavated structures, four of which were dated using AMS radiocarbon isotopic dating methods. In the first section of this chapter I present the results of the ICP-OES analyses, AMS radiocarbon dating, and the identification of the tree species represented by the charcoal samples. In the second section of the chapter I present the results of the ceramic analyses performed by the BRAP ceramicist Betsy Kohut. Then I combine the archaeometric and ceramic analyses data to support my hypothesis that the annular structures functioned as fuel-efficient lime kilns during the Late and Terminal Classic Periods. In the third section of the chapter I discuss the spatial and contextual data and how they indicate that the lime production industry was decentralized and organized at the household level. In the final section I summarize how the spatial and contextual data support the hypothesis that the annular structures functioned as lime kilns.

Archaeometric Results

Stable Carbon and Oxygen Isotope and ICP-OES Analyses

I collected numerous samples of a relatively soft, white limestone material from the lower levels of the central depressions of eight of the nine annular structures excavated that resembled *sascab*. *Sascab* is very similar in appearance and texture to burnt lime that has been hydrated, turned into a slurry (Figure 8-1), and then dried to reconstitute calcium carbonate (Figure 8-2). Therefore, it was important to run stable carbon and oxygen isotope analyses on these samples to determine whether the white material at the bottom of the ring structures was entirely naturally occurring *sascab* or reconstituted burnt lime. I ran these isotope analyses twice on each sample to double-check the results (Table 8-1). If the material at the bottom of some of the central depressions was reconstituted calcium carbonate, this would be a strong indicator that the Prehispanic inhabitants of Kiuic were using these structures to burn limestone into lime powder. I also ran ICP-OES tests on these *sascab*/plaster samples to determine whether there were elemental composition indicators that suggested what materials may have been burned in the pit-kilns in addition to lime and also to reinforce the *sascab*/plaster distinctions (Table 8-2).



Figure 8-1: Photograph of an example of contemporary lime plaster production showing the lime and water slurry as it is mixed with sand aggregates.



Figure 8-2: Photos of *sascab* (l) from Annular Structure 7 and reconstituted calcium carbonate or lime plaster (r) from Annular Structure 1 demonstrating their similarity in appearance.

Table 8-1: The $\delta^{13}C$ and $\delta^{18}O$ levels of the different *sascab*/plaster samples.

Sample #	Annular Structure	Depth below surface	$\delta^{13}C$ (1)	$\delta^{13}C$ (2)	$\delta^{18}O$ (1)	$\delta^{18}O$ (2)
1	AS1 (N0880E1255)	3.4 m	-22.08	-22.49	-15.06	-14.07
2	AS1 (N0880E1255)	Sascabera	-11.15	-11.08	-4.09	-4.11
3	AS1 (N0880E1255)	Sascabera	-11.19	-11.35	-4.22	-4.38
4	AS2 (N1240E0845)	3.45 m	-24.42	-26.54	-19.5	-16.2
5	AS2 (N1240E0845)	3.95 m	-10.45	-10.27	-4.46	-4.35
6	AS2 (N1240E0845)	4.2 m	-9.7	-9.84	-4.47	-4.42
7	AS3 (GPS2227)	1.75 m	-10.14	-10.01	-4.59	-4.83
8	AS3 (GPS2227)	2.8 m	-24.19	-25.72	-19.11	-22.3
14	AS3 (GPS2227)	3.99 m	-10.83	-9.74	-3.09	-3.75
9	AS4 (S2795E3330)	2.8 m	-26.61	-25.6	-20.33	-22.21
10	AS4 (S2795E3330)	3.06 m	-10.9	-10.3	-4.37	-3.08
11	AS5 (GPS2113)	Surface	-23.34	-24.91	-20.23	-22.1
12	AS6 (GPS1863)	3.7 m	-8.28	-10.02	-3.9	-3.92
13	AS7 (GPS1967)	1.75 m	-10.4	-10.64	-3.99	-4.49

Table 8-2: The ICP-OES results for the *sascab*/plaster samples – numbers represent PPM (micrograms per millimeter of solution).

Sample #	Structure	Al	Ba	Fe	K	Mg	Mn	Na	P	S	Sr	Zn
1	1	7.21	0.09	2.02	9.32	2.56	0.123	2.64	1.18	4.81	0.226	1.09
2	1	0.55	0.01	0.08	1.68	0.88	0.009	0.96	0.10	0.79	0.030	
3	1	1.01	0.03	0.06	0.86	1.30	0.003	0.87	0.04	0.86	0.062	0.51
4	2	0.92	0.02	0.17	0.69	1.30	0.034	1.60	0.51	0.34	0.210	0.66
5	2	0.67	0.03	0.16	0.43	4.01	0.006	1.49	0.13	0.49	0.144	0.42
6	2	0.58	0.04	0.20	0.41	4.87	0.013	1.17	0.06	0.78	0.261	
7	3	1.43	0.05	0.34	0.66	6.50	0.019	1.03	0.06	0.89	0.226	0.42
8	3	6.08	0.08	2.59	0.54	2.45	0.049	0.68	0.16	0.52	0.122	0.54
14	3	0.76	0.04	0.14	0.70	62.01	0.046	1.36	0.07	0.57	0.286	0.36
9	4	0.60	0.06	0.15	0.30	0.71	0.004	0.84	0.02	0.57	0.152	
10	4	1.78	0.05	0.59	0.64	1.58	0.363	0.69	0.04	0.82	0.051	
11	5	3.16	0.05	1.06	0.31	1.27	0.046	0.83	0.23	0.55	0.133	
12	6	0.49	0.08	0.06	0.27	4.20	0.025	0.79	0.03	0.92	0.188	
13	7	0.83	0.07	0.09	0.30	3.20	0.011	0.90	0.03	0.90	0.107	0.35

Annular Structure 1: *Samples 1, 2, and 3* were recovered from the excavations of Annular Structure 1. *Sample 1* comes from the lowest layer of the excavation within the central depression of the structure, where it was chipped off of a thick layer that appeared to be hard *sascab*. *Sample 2* and *Sample 3* come from layers 2 and 4, respectively, of a test pit within a nearby *sascabera*. These samples were recovered from the walls of the *sascabera* at depths of 30cm and 50cm, respectively, below the surface.

The stable oxygen and carbon isotope analyses indicate that *Sample 1* has isotopic levels consistent with reconstituted burnt lime, while *Sample 2* and *Sample 3* are more likely naturally occurring *sascab* (Table 8-1). These results are consistent with the hypothesis that Annular Structure 1 was used as a kiln to calcine limestone. The fact that *Sample 1*, recovered from the lower levels of the kiln, represents reconstituted lime indicates that temperatures in the kiln reached high enough temperatures (at least ~800 degrees C) for a long enough period of time to calcine the limestone, which was subsequently reconstituted. It is not surprising that *Sample 2* and *Sample 3* have values so similar to one another and that both represent naturally occurring *sascab* as they were recovered from the same cave-like *sascabera* that exhibits no evidence of burning episodes.

With regard to the ICP-OES analysis, *Sample 1* returned slightly higher levels of aluminum (7.21 micrograms per millimeter of solution – ppm), potassium (9.32 ppm), phosphorous (1.18 ppm), sulfur (4.81 ppm), and zinc (1.09 ppm) than the other samples tested. The higher level of phosphorous may reflect the presence of ash from a firing episode within the structure that mixed with the *sascab* layer. *Sample 1* also had a slightly higher level of iron (2.02 ppm) than the average, but it was not a significant amount overall. *Sample 2* and *Sample 3*,

which represent *sascab* from a slightly different source, had lower levels than *Sample 1* of all of the non-calcium elements tested.

Annular Structure 2: *Samples 4, 5, and 6* were recovered from the central depression of Annular Structure 2. *Sample 4* was recovered from a layer of hard *sascab* at a depth of 3.45 m below the surface of the ring. *Sample 5* was recovered from a test-pit excavated through this hard layer of *sascab* from a layer of reddish-black burnt *sascab* at a depth of 3.95 m below the surface of the ring. *Sample 6* was recovered from the layer of hard *sascab* underlying the burnt layer at a depth of 4.2 m below the surface of the ring.

The isotopic data indicate that *Sample 4* represents reconstituted lime, while *Sample 5* and *Sample 6* are most likely naturally occurring *sascab* (Table 8-1). These results suggest that the ring structure was used as a kiln to calcine limestone but that the kiln was originally only excavated to a depth of less than 3.95 m below the surface of the ring. The fact that *Sample 5* was recovered from a layer that exhibited visual evidence of burning but the sample itself appears to have been naturally occurring *sascab*, indicates that this level represents the lowest (and perhaps final) level of burning in the kiln. This in turn suggests that the approximately 50cm-thick layer of material between the points where *Sample 4* and *Sample 5* were excavated is made up of burnt lime that was likely left at the bottom of the kiln following the final calcining episode and left to reconstitute. Further studies of this layer would be required to make a more concrete argument but the leaving behind of a thick layer of unused burnt lime is another indicator suggesting the rapid abandonment of the Kiuic site center. Unfortunately, no datable carbon samples were recovered from the excavation of this pit-kiln.

The interpretation that the material between 3.45 and 3.95 m below the surface of the ring represents the lowest layer of burning in Annular Structure 2 is supported by the ICP-OES analysis of *Samples 4, 5*, and *6*. The multi-elemental analyses indicate that *Sample 4* (0.51 ppm) has a higher level of phosphorous than *Sample 5* (0.13 ppm) and *Sample 6* (0.06 ppm). The higher level of phosphorous most likely corresponds with the mixing of ashes in with *Sample 4*, which is another indicator that this layer experienced burning episodes while the lower layers did not. Another discrepancy between the uppermost sample and the two lower samples is the level of magnesium: *Sample 4* (1.30 ppm), *Sample 5* (4.01 ppm), *Sample 6* (4.87 ppm). The discrepancy in magnesium indicates the differences in the basic elemental structuring of the two materials from the two layers, reinforcing the notion that the upper layer represents a chemically transformed substance. It might also indicate that the limestone used to create the burnt lime came from a source outside of the rock outcrop in which Annular Structure 2 is located. A third possible reason for the higher magnesium levels in the lower layers is the fact that the lower layer materials are *sascab* and the upper layer material is not. *Sascab* has been shown to have higher magnesium levels than overlying limestone (or in this case burnt lime) due to the migration of magnesium atoms downward with rainwater (Villaseñor 2010: 25). The fact that *sascab* would not have been used for producing lime indicates that the layers with lower levels of magnesium that looked like *sascab* were actually reconstituted from a non-*sascab* limestone base. Thus, the higher level of magnesium found in *Sample 5* and *Sample 6* potentially provides another line of evidence suggesting that these samples represent natural *sascab* while *Sample 4* represents chemically altered burnt lime. While higher or lower levels of magnesium is not always a definite indicator of *sascab* vs. reconstituted calcium carbonate composition, it can be used to provide an additional indirect line of evidence when appropriate.

Annular Structure 3: *Samples 7, 8 and 14* were recovered from the interior of Annular Structure 3, located within the hilltop complex of *Box Peek' Pocpocxic* just to the southwest of the Kiuic site center. Annular Structure 3 was unique in that it appears to have been constructed atop and encompassing a previously existing *sascabera* or *chultún*. *Sample 7* was recovered from the interior wall of the annular structure at a depth of 1.78 m below surface of the ring, outside of the *sascabera*/*chultún* opening. *Sample 8* was recovered from within the *sascabera*/*chultún* opening at a depth of 2.8 m below the surface of the annular structure and 0.8 m below the entrance to the *sascabera*/*chultún*. *Sample 14* was recovered from the base of the *sascabera/chultún*.

The isotopic data indicate that *Sample 8* represents reconstituted lime, while *Sample 7* and *Sample 14* represent naturally occurring *sascab* (Table 8-1). Based on their proveniences, these isotopic results are not surprising. *Sample 7* comes from a layer that appears to be either friable limestone bedrock or hard *sascab* immediately above the opening to the *sascabera/chultún*. *Sample 14* was recovered from the base of the *sascabera/chultún* from a layer similar to the hard, naturally occurring *sascab* encountered at the base of the other annular structures.

Sample 7 and *Sample 14* were much more similar to one another than either was to *Sample 8* in terms of elemental composition. The ICP-OES analysis showed that *Sample 8* (0.16 PPM) exhibited slightly higher levels of phosphorus than *Sample 7* (0.06 ppm) and *Sample 14* (0.07 PPM), which indicates the possible mixing of or exposure to ash in the layer from which *Sample 8* was recovered. Also, in a similar situation to the samples recovered from Annular Structure 2, the samples recovered from Annular Structure 3 that appear to be natural *sascab* had much higher levels of magnesium (*Sample 7*: 6.5 ppm, *Sample 14*: 62.01 ppm) than the sample believed to be reconstituted lime (*Sample 8*: 2.45 ppm). *Sample 8* also possessed higher

aluminum and iron contents (6.08 ppm, 2.59 ppm) than *Sample 7* (1.43 ppm, 0.34 ppm) or *Sample 14* (0.76 ppm, 0.14 ppm).

Annular Structure 4: *Samples 9 and 10* were recovered from Annular Structure 4, located at the northern tip of the elite hilltop residential complex of *Escalera al Cielo*, located to the west of the Kiuic site center. *Sample 9* was recovered from a layer of softer, white material near the base of the structure's interior pit at a depth of 2.8 m below the structure's surface. *Sample 10* was recovered from the underlying layer of harder *sascab*, at a depth of approximately 3.06 m below the surface of the structure.

The isotopic data indicate that *Sample 9* represents reconstituted lime while *Sample 10* represents naturally occurring *sascab* (Table 8-1). These findings continue the pattern identified in the other annular structures, where a layer of reconstituted lime (either plaster or merely slaked, hydrated, and recarbonated burnt lime) overlays a layer of natural *sascab* at the base of the interior depressions of the structures. The multi-elemental analyses also indicate discrepancies in the chemical compositions of the two samples. *Sample 9* (0.71 ppm) has a lower magnesium level than *Sample 10* (1.58 ppm), in line with the former sample representing a chemically altered material and the latter sample most likely representing natural *sascab*.

Annular Structure 5: *Sample 11* was recovered from the base of the interior of Annular Structure 5, located near the western base of the *Escalera al Cielo* hill. The isotopic data indicate that the material recovered was reconstituted lime (Table 8-1). The ICP-OES data also supports this finding, as there is a relatively low level of magnesium (1.27 ppm) compared with samples of *sascab* taken from other annular structures. This finding is somewhat peculiar in that Annular

Structure 5 is the only annular structure excavated to date that does not have any clear visual evidence of having been used to calcine limestone. It is the only structure whose central depression does not cross through the surface layer of bedrock, and the base of the interior ring appears to be made of burnt bedrock. The fact that the isotopic data point to the sample scraped from this base being reconstituted lime provides evidence that this kiln may have been used to calcine limestone. The discrepancy between the kiln's appearance and isotopic results reflect a limited build-up of burnt lime on the basal surface of the interior depression. This suggests that the kiln might have been experienced only a limited number of cooking episodes leading to minimal build-up of burnt lime at the base of the central pit, or that the shallow depth of the central pit made it easier to recover all of the burnt lime after production episodes. The relatively high level of phosphorous (0.23 ppm) provides another line of evidence that the annular structure was used for burning or cooking episodes.

Annular Structures 6 and 7***:*** *Samples 12 and 13* were collected from Annular Structures 6 and 7, respectively. *Sample 12* was recovered from a layer of hard *sascab* at the base of Annular Structure 6's interior pit and the isotopic data indicate that the material was naturally occurring *sascab* (Table 8-1). *Sample 13* was recovered from a layer of hard *sascab* at the base of Annular Structure 7 and the isotopic data likewise indicate that the material encountered was indeed natural *sascab* (Table 8-1). Both samples have relatively high levels of magnesium (Sample 12: 4.20 ppm; Sample 13: 3.20 ppm), which further suggests that they represent *sascab* instead of burnt lime. Low levels of phosphorous in these samples (0.03 ppm for both) suggest that the layer they represent was beneath the lowest burning activities carried out in the central depression of the structure.

AMS Radiocarbon Data and Tree Species Identification

At least one charcoal sample was recovered from six of the nine annular structures excavated, and I selected seven of them to be sent for AMS radiocarbon dating at the University of Arizona AMS laboratory. Unfortunately, two of the samples returned dates from the modern period and one turned out to be a burnt mineral, but four of the charcoal samples were firmly dated to the Late/Terminal Classic Period (Table 8-3, Figures 8-3 – 8-7). These include samples from Annular Structure 1 (ca. 691 CE 675-775 cal AD at 2σ), Annular Structure 4 (658-765 cal AD at 2σ), Annular Structure 6 (766-892 cal AD at 2σ), and Annular Structure 8 (688-887 cal AD at 2σ). The measurements were background subtracted and isotope fractionation corrected. The calibrations were done using IntCal13 and OxCal4.2.4 software.

The chronological markers have important implications for the reasons behind the development of annular pit-kiln technology. They align with the early stages of the demographic and construction boom in the Eastern Puuc, for which we have evidence from an increase in residential construction activities. The expansion of local populations led to an increased demand for burnt lime for dietary and architectural purposes at the same time that more land was devoted to agricultural purposes to feed the growing populations. The decrease in available land for conducting aboveground controlled burns encouraged repeated lime production firings in specific locations. More importantly, an increase in agricultural land concurrently led to a decrease in forested land and thus the wood available for lime production fuel.

The dating of the annular structures to the Late/Terminal Classic Period transition (ca. 650-850 CE) supports the hypothesis that the invention of lime pit-kiln technology was related to an effort to conserve fuel resources. The fact that they were in use as early as ca. 650 CE indicates that lime producers exercised some forethought in attempting to preserve fuel resources

before the fuel availability situation became dire. However, it must be noted that the sample is small (only four structures out of fifty-three in the study area). The support of the ceramic data for a Late/Terminal Classic Period timeframe grows the sample size to nine of fifty-three, which is still small. Though the annular structures were selected randomly and represent different geographical and archaeological contexts, the small sample size raises the possibility that these annular structures represent a specific period of use by chance. It is possible that they just happen to be among the last annular structures built and used, and that the technology actually dates to earlier than the Late/Terminal Classic Period transition. This possibility is further raised by the depths from which the carbon samples were recovered. As the kiln experiments demonstrated, greater depth can be correlated with more episodes of use. The variation in the dates between the four structures also has implications for the development and use of annular pit-kiln technology throughout the Kiuic polity. All of these implications are explored further in Chapter 9.

In addition to using the recovered charcoal for dating the construction and use of the structures, some of the pieces were well enough preserved to allow for their biological identification. The majority of the identifiable pieces of charcoal were dicotyledon angiosperms (or hardwood species) (Morehart, personal communication 9/16/2015), similar to the ones chosen for use in the experimental burns. The charcoal species identifications occurred after both kiln experiments had taken place. One near-positive species identification was made in the form of *Piscidia piscipula* (or *ja'abin* in Yucatec) (Figure 8-8), and another piece also had characteristics of a *Lonchocarpus* species like the *balche'* tree (Figure 8-9) (Morehart, personal communication 9/16/2015). Both of these were used in the experimental burning and are known for being good burning woods throughout the northern Yucatán.

Table 8-3: Radiocarbon data for the seven charcoal samples.

Sample	Structure	Mass (mg)	d13C value	F(d13C)	+-F(d13C)	14C age BP	+-14C age	Cal AD dates at 2σ
1	AS1 (N0880E 1255)	2.91	-23.9	0.8549	0.0022	1,259	20	675-775 cal AD at 2σ
2	AS2 (N1240E 0845)	NA	NA	NA	NA	NA	NA	NA
3	AS4 (S2795E3 30)	2.55	-24.4	0.849	0.002	1,315	19	658-765 cal AD at 2σ
4	AS5 (GPS211 3)	2.09	-24.9	0.9871	0.0023	105	19	1689-1926 cal AD at 2σ
5	AS6 (GPS186 3)	2.48	-24.4	0.861	0.0028	1,202	26	722-892 cal AD at 2σ
6	AS7 (GPS196 7)	2.53	-24	0.983	0.0003	138	25	1671-1943 cal AD at 2σ
7	AS8 (GPS224 1)	1.61	-24.4	0.8586	0.0038	1,224	35	688-887 cal AD at 2σ

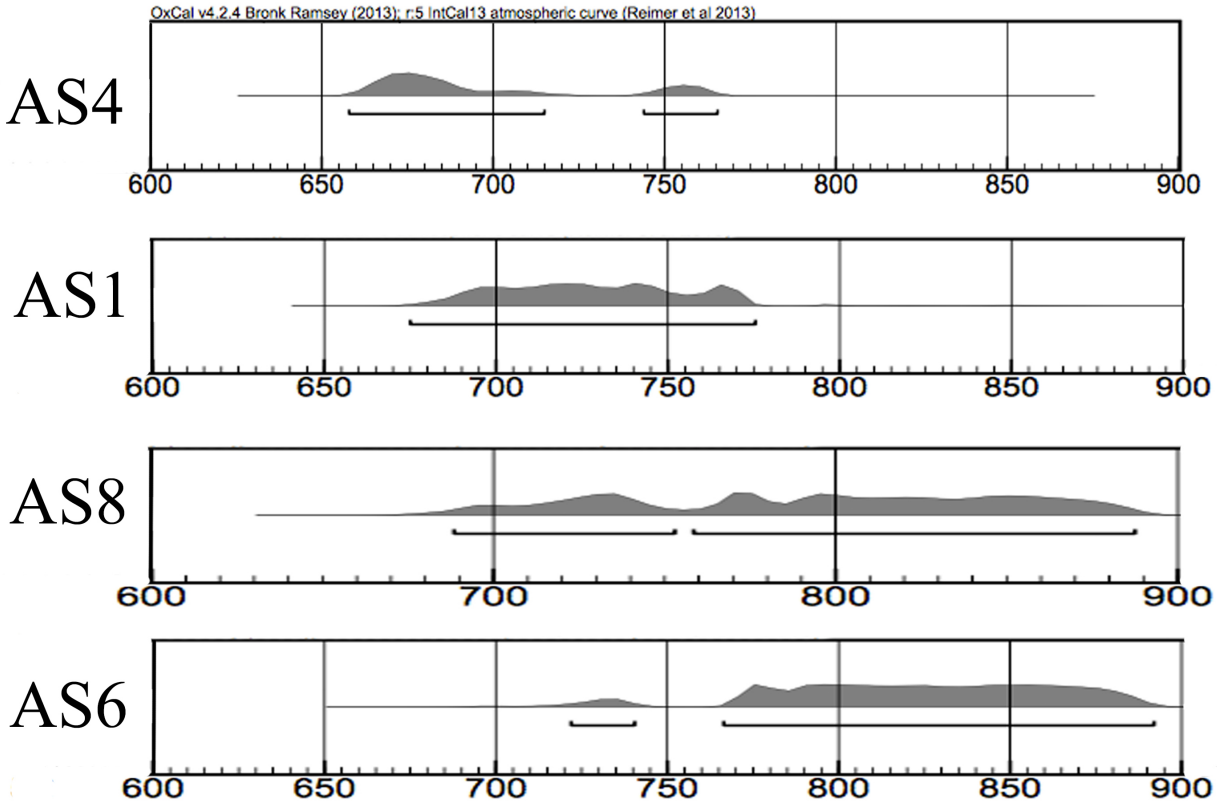


Figure 8-3: Comparison of the Prehispanic AMS radiocarbon dates calculated using OxCal IntCal13 atmospheric curve.

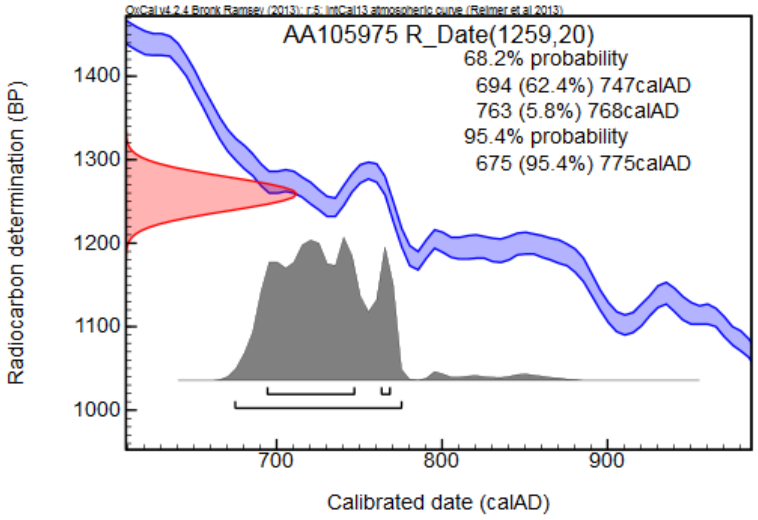


Figure 8-4: Calibration graph for the radiocarbon analysis of the charcoal sample from Annular Structure 1.

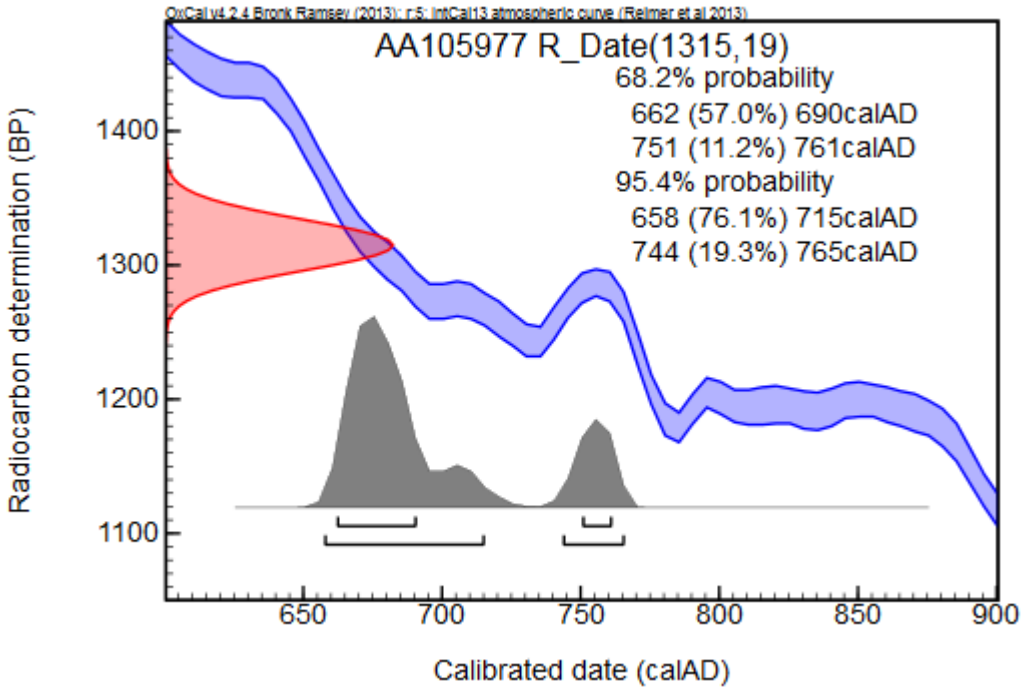


Figure 8-5: Calibration graph for the radiocarbon analysis of the charcoal sample from Annular Structure 4.

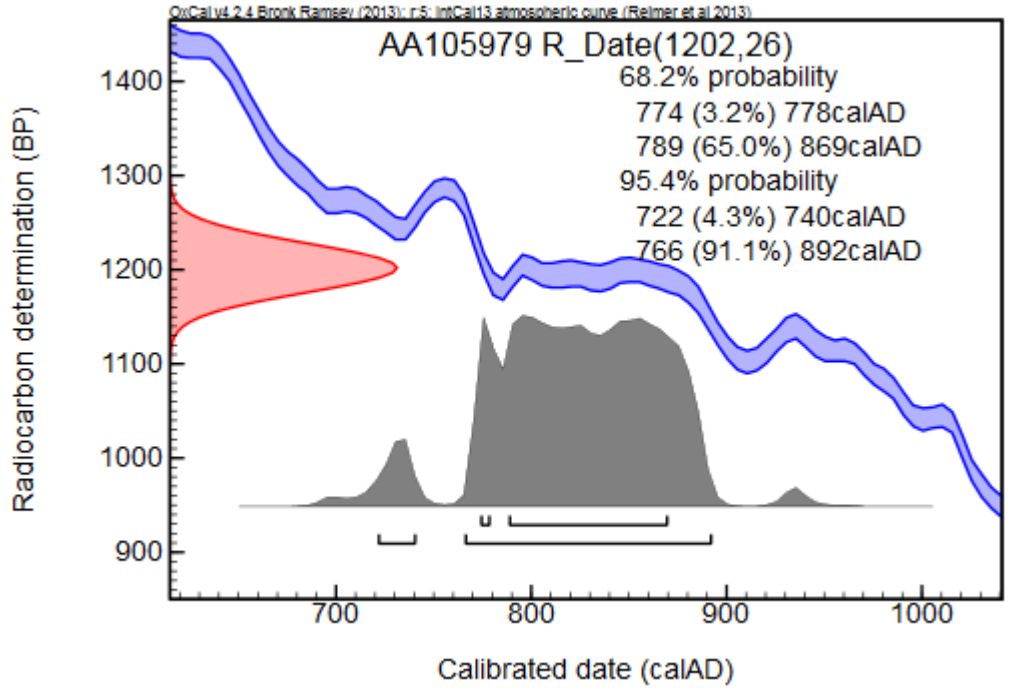


Figure 8-6: Calibration graph for the radiocarbon analysis of the charcoal sample from Annular Structure 6.

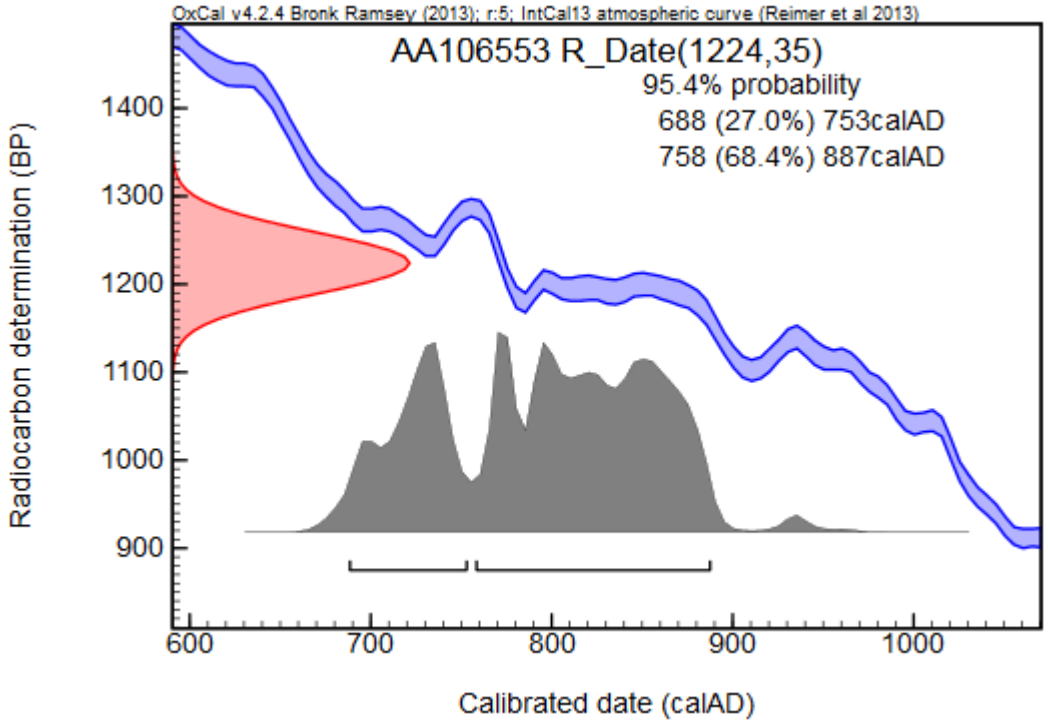


Figure 8-7: Calibration graph for the radiocarbon analysis of the charcoal sample from Annular Structure 8.

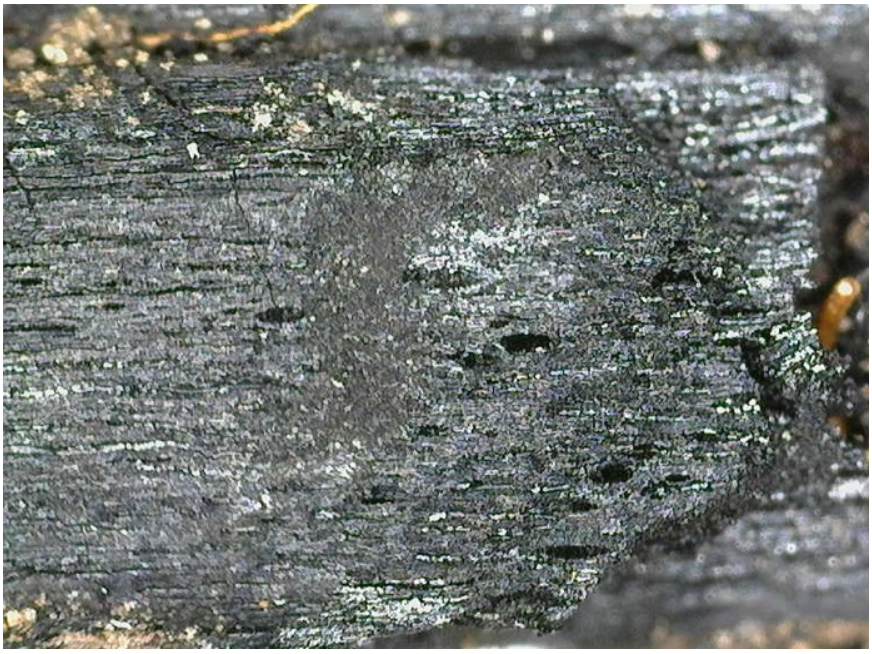


Figure 8-8: Microscopic image of the piece of charcoal identified as *Piscidia piscipula* (or *ja'abin* in Yucatec) (Morehart, personal communication 9/16/2015).



Figure 8-9: Microscopic image of the piece of charcoal identified as a *Lonchocarpus* species like the *balche'* tree (Morehart, personal communication 9/16/2005).

Ceramic Data

The BRAP project ceramicist Betsy Kohut performed the ceramic analyses of the sherds recovered from the excavations of the annular structures (Kohut 2015; Seligson et al. 2015). The majority of the sherds were part of the fill used in the walls of the annular structures. The identification of the sherds as belonging to certain ceramic complexes provided additional chronological information about the construction and use of the annular structures (Tables 8-4 – 8-7). The excavations demonstrated that the original phases of construction of the annular structures were on a smaller scale than the final phases encountered on the surface in the archaeological record. Not only were the original walls of many of the structures smaller and

lower than their final forms but it is also possible that in their earliest stages of use the annular structures consisted solely of a pit without a surrounding wall. Over time and through multiple burning episodes, the walls of the structures were expanded and built up with discarded *chich* and ceramic sherds mixed with earth. Thus, while the ceramic data provided a good indication of when the structures were in use, they may not reflect when the annular structures were originally constructed. The data presented here pertain to the ceramics recovered from the nine excavated annular structures.

Overall, 93% of the ceramics by weight recovered during the excavations of the annular structures dated to the Terminal Classic Period, with 3% dating to the Middle or Late Classic Period. Four percent of the ceramics were unidentifiable either due to erosion, wear or burning. Regardless of the original construction dates, the ceramic data clearly point to the use and expansion of the annular structures during the Late and Terminal Classic Periods, which complements the AMS radiocarbon data. The fact that 3% of the sherds by weight possibly dated to a slightly earlier period may just mean that there were still some vessels or sherds from earlier periods around the site that were used as construction fill. A few Postclassic Period sherds from the Zodz complex were also recovered from around annular structure 1, but the isolated nature of these finds suggests that the sherds were unconnected with the construction and use of the annular structure. Late and Terminal Classic construction and use dates indirectly support the hypothesis that the annular pit-kiln technology was developed to produce lime more efficiently during the demographic and construction boom of the Terminal Classic Period. Below I provide a brief summary of the ceramic data from each annular structure. A more complete dataset can be found in Appendix D.

Table 8-4: Ceramic chronology for Kiuic and the Eastern Puuc region (adapted from Kohut 2015).

Period	Complex	Date
Postclassic	Zodz	950-1300(?) CE
Terminal Classic	Ceh	800-950 CE
Mid-Late Classic	Yuc	600-800 CE
Early Classic	Chiic	300-600 CE
Late Preclassic	Och	300 BCE 300 CE
Late Middle Preclassic	Bah	600-300 BCE
Early Middle Preclassic	Ch'oh	800-600 BCE

Table 8-5: Sherd weight totals and percentages for the different ceramic complexes recovered from the nine excavated annular structures (adapted from Kohut 2015; Kohut personal communication 2/29/16).

Annular Structure	Chiic/Yuc (g)	Chiic/Yuc (%)	Ceh (g)	Ceh (%)	Zodz (g)	Zodz (%)	Unidentified (g)	Unidentified (%)	Total (g)
AS1 (N0880E1255)	2431	6%	37396	90%	154	0%	1761	4%	41742
AS2 (N1240E0845)	168	1%	16662	97%	0	0%	260	2%	17090
AS3 (GPS2227)	127	2%	7526	98%	0	0%	0	0%	7653
AS4 (S2795E3330)	1055	19%	4112	75%	0	0%	307	6%	5474
AS5 (GPS2113)	14	0%	5732	99%	0	0%	38	1%	5784
AS6 (GPS1863)	30	2%	1549	92%	0	0%	104	6%	1683
AS7 (GPS1967)	0	0%	18	75%	0	0%	6	25%	24
AS8 (GPS2241)	112	0%	26048	93%	0	0%	1831	7%	27991
AS9 (GPS2242)	13	0%	7242	97%	0	0%	183	2%	7438

Table 8-6: Table demonstrating the percentages of the sherd weight totals that date to each time period from the different annular structures (adapted from Kohut 2015; Kohut, personal communication 2/29/16).

	Early-Late Classic	**Terminal Classic**	**Postclassic**	**Unidentified**	**Total**
	300-800 CE	**800-950 CE**	**900-1350(?) CE**	**NA**	
AS1 (N0880E1255)	6%	90%	0%	4%	100%
AS2 (N1240E0845)	1%	97%	0%	2%	100%
AS3 (GPS2227)	2%	98%	0%	0%	100%
AS4 (S2795E3330)	19%	75%	0%	6%	100%
AS5 (GPS2113)	0%	99%	0%	1%	100%
AS6 (GPS1863)	2%	92%	0%	6%	100%
AS7 (GPS1967)	0%	75%	0%	25%	100%
AS8 (GPS2241)	0%	93%	0%	7%	100%
AS9 (GPS2242)	0%	97%	0%	2%	100%
Totals	3%	93%	0%	4%	100%

Table 8-7: Compilation of chronological data including both AMS radiocarbon data and ceramic data (adapted from Kohut 2015; Kohut, personal communication 2/29/16).

Annular Structure	Cal AD dates at 1σ	Cal AD dates at 2σ	Mid-Late Classic Period Yuc Complex or Earlier (<600-800 CE)	Terminal Classic Ceh Complex (800-950 CE)	Unidentified Ceramics
1	NA	675-775 cal AD	6%	90%	4%
2	NA	NA	1%	97%	2%
3	NA	NA	2%	98%	0%
4	744-765 cal AD	658-765 cal AD	19%	75%	6%
5	NA	NA	0%	99%	1%
6	722-740 cal AD	766-892 cal AD	2%	92%	6%
7	NA	NA	0%	75%	25%
8	688-753 cal AD	688-887 cal AD	0%	93%	7%
9	NA	NA	0%	97%	2%

Annular Structure 1: The ceramic data point to Annular Structure 1 being originally constructed by the Late Classic Period and continuing to be used and built up into the Terminal Classic Period. The ceramics recovered from the exterior of Annular Structure 1 mostly dated to the Terminal Classic Period *Ceh* ceramic complex (ca. 800-950 CE). The ceramic sherds recovered from the central depressions of the structures most likely represent the collapsed fill from the structure walls. In the case of Annular Structure 1, these sherds included examples from both the *Ceh* complex and the Mid-Late Classic Period *Yuc* complex (ca. 600-800 CE). The *Yuc* sherds included examples of Yucatan Gloss ware, Late Classic Red ware, and 2 unidentified Late Classic sherds with cream-to-orange slip. Late Classic *Yuc* complex sherds were also recovered from the lowest levels of two of the test-pits excavated immediately to the west of the annular structure on the same terrace.

Annular Structure 2: The ceramic sherds recovered from inside and around Annular Structure 2 were mostly associated with the Terminal Classic Period *Ceh* complex, however there were a few examples of *Yuc* complex ceramics recovered from within the structure. The ceramic data point to Annular Structure 2 possibly being originally constructed as early as the Late Classic Period, but being built-up the most during the Terminal Classic Period.

Annular Structure 3: The ceramic sherds recovered from inside and around Annular Structure 3 were mostly associated with the Terminal Classic Period *Ceh* complex. However, several sherds associated with the Late Classic Period *Yuc* complex were recovered from the lowest levels of the test-pit excavated into the *sascabera/chultún* underneath the annular structure. The presence of the *sascabera/chultún* complicates whether the annular structure dates to the Late Classic

Period or whether the Late Classic Period ceramics encountered were remnants of the *sascabera/chultún* being in use during that period. Regardless of when the annular structure was originally constructed, the ceramic data point to Annular Structure 3 being in use at least during the Terminal Classic Period if not earlier as well.

Annular Structure 4: The ceramic sherds recovered from inside and around Annular Structure 4 were mostly associated with the Terminal Classic Period *Ceh* complex, however there were a few examples of *Yuc* complex ceramics recovered from within the structure. The ceramic data point to Annular Structure 4 possibly being originally constructed as early as the Late Classic Period, but being built-up the most during the Terminal Classic Period. The Escalera al Cielo hilltop complex where Annular Structure 4 is located was previously believed to have been constructed and occupied only during the Terminal Classic Period. However, the combination of the ceramic data and the radiocarbon date of 658-765 cal AD at 2σ now raises the possibility that this compound may have been constructed slightly earlier during the Late Classic Period.

Annular Structure 5: The ceramic sherds recovered from inside and around Annular Structure 5 were mostly associated with the Terminal Classic Period *Ceh* complex. There was only one small sherd recovered that was associated with the Late Classic Period *Yuc* complex, suggesting that it was erroneous. The ceramic data thus point to Annular Structure 5 being constructed and used exclusively during the Terminal Classic Period.

Annular Structure 6: The ceramic sherds recovered from inside and around Annular Structure 5 were mostly associated with the Terminal Classic Period *Ceh* complex. There were only four

small sherds recovered from inside the structure that were associated with the Late Classic Period *Yuc* complex. The low number of anything but *Ceh* complex sherds points to Annular Structure 6 being constructed and used exclusively during the Terminal Classic Period.

Annular Structure 7: Curiously, only two ceramic sherds were recovered from the entirety of the excavation of the smallest Annular Structure. These were pieces of *Ceh* complex Yokat striated ceramics, the most ubiquitous type. Thus, the only available ceramic data point to Annular Structure 7 being constructed and used during the Terminal Classic Period.

Annular Structures 8 and 9: The ceramic sherds recovered from annular structures 8 and 9 almost exclusively dated to the Terminal Classic Ceh complex (93% and 97% respectively). Almost all of the ceramics that were not dated to the Terminal Classic Period were unidentified and thus could not be dated at all. These data put the construction and use of the two structures firmly in the Terminal Classic Period and combined with their proximity to one another this suggests that they may have been operated simultaneously.

Archaeometric and Physical Evidence for the Annular Structures as Lime Pit-Kilns

Evidence for Burning Episodes

The first line of evidence suggesting that the Prehispanic Maya used the annular structures for producing lime is the evidence for burning episodes within and around the structures. While general evidence for burning does not necessarily indicate whether it was limestone or other materials that were being burned in the structure, it is a prerequisite for identifying the structures as kilns or ovens of any kind. All nine annular structures excavated and

several of the others examined superficially exhibited several lines of evidence suggesting that they were used for burning materials at some point in the past.

With the exception of Annular Structure 5 (GPS 2113), the central depressions of all of the annular structures excavated crossed through the surface layer of bedrock. The bedrock portions of the interior walls of all of these structures (as well as the surface bedrock floor of Annular Structure 5) exhibited the blackened coloring and friable texture of bedrock that had been repeatedly exposed to firing episodes. Even in the case of Annular Structure 6 (GPS 1863), where the bedrock cut that delimited the central depression sank more than 2 m deep, the entirety of the bedrock walls was blackened, as was the bedrock floor of the structure. In some cases, even the surface ring of boulders exhibited a blackened appearance on the sides that faced the interior depression. Many of the larger boulders excavated from the central depressions of the structures were also blackened and likely represented collapsed portions of the upper interior walls.

Another, more direct line of evidence indicating that burning episodes had taken place within the central depressions of the structures, was the discovery and recovery of charcoal samples from the lowest layers of many of the structures. Carbon samples were recovered from: Annular Structure 1 (Capas 1, 2 and 4), Annular Structure 2 (Capas 5 and 6), Annular Structure 4 (Capa 5), Annular Structure 5 (Capa 2), Annular Structure 6 (Capa 5), and Annular Structure 8 (Capas 5 and 6). In each of these cases (with the exception of Annular Structure 5, in which the charcoal was discovered in the natural fissure in the surface bedrock floor of the central pit), the charcoal was discovered in levels of the central depression below the lowest level of post-use fill. In several cases, the layer from which the charcoal was recovered was less than 50 cm from the final floor of the structure, and in most cases the charcoal was recovered from a layer of

blackened soil and/or rocks that may represent the disintegrated remains of even more pieces of charcoal. The recovery of the charcoal from the lowest levels of the central depressions suggests that they were deposited during the original period of use of the structures and thus indicate that the structures were used for some type of burning activity. Of those samples that were successively radiocarbon-dated using Accelerator Mass Spectrometry (AMS) at the University of Arizona AMS Laboratory, four were dated to the Late and Terminal Classic Period: Annular Structure 1 (675-775 cal AD at 2σ), Annular Structure 4 (658-765 cal AD at 2σ), Annular Structure 6 (766-892 cal AD at 2σ), and Annular Structure 8 (688-887 cal AD at 2σ). Not only does the radiocarbon evidence indicate the usage of these structures as kilns during the Late and Terminal Classic Maya period, but they also coincide with a population and construction boom in the Kiuic area.

As mentioned above, the charcoal samples were often recovered from a layer of blackened or at least darkened soil that may have represented further pieces of charcoal that have since disintegrated. In addition to these blackened layers, other layers of soil and/or small rocks were encountered in the lower levels of many of the annular structures that indicated the existence of multiple burning episodes in the past. Layers of ash were encountered in the central depressions of Annular Structure 1 (Pozo 1 Capa 1), Annular Structure 2 (Pozo 2 Capa 5, Sondeo 8 Capa 1), Annular Structure 3 (Pozo 3 Capa 7), Annular Structure 7 (Pozo 8 Capa 3), Annular Structure 8 (Pozo 1 Capa 5), and Annular Structure 9 (Pozo 2 Capa 6). The discovery of reddish-orange layers of soil and/or clay indicate that at some point clay or clayey soils may have been used to insulate the interior walls of the central depression. These reddish/orange layers were encountered in Annular Structure 2 (Sondeo 8 Capa 1), Annular Structure 3 (Capa 6), and Annular Structure 7 (Capa 3). The most indicative example, however, was uncovered during the

excavation through the ring wall of Annular Structure 8, when a sample of partially burnt clay was recovered from between the cracks of the interior boulder wall of the upper levels of Annular Structure 8. These samples of clay indicate that they were fully cooked on the sides that faced the interior pit, partially cooked in the middle, and not very cooked on the side that had been wedged in between the boulders. Their appearance was similar to the partially burned clay balls identified as cooking implements at the elite hilltop complex of *Escalera al Cielo* located 1.5 km to the west of the Kiuic site center (Simms et al. 2012).

The shear depth of the majority of the annular structures alone indicates their repeated use for containing long-burning fires. The experimental burning of the lime kiln at Kiuic demonstrated that the 20-plus hour burn loosened up at least 15 cm of bedrock from the floor of the central pit of the structure. This limestone, which was the same *saakel bach tuunich* that dominated the outcrop into which the experimental kiln was built, was then easily removed and could potentially have been used for a subsequent burn. If this pattern had continued, with repeated long-term burns the depth of this experimental kiln would eventually reach to levels comparable to those encountered in the archaeological record.

A final line of evidence pointing to the use of the annular structures for burning activities is the identification of possible ventilation systems in two of the structures excavated. While it is not surprising that the partial collapse of most of the structures would preclude the discovery of any deliberate holes or tunnels left in the walls of some the structures, there were two exceptions. Annular Structure 5, which was unique in several respects, one of which is that it is the only annular structure excavated during the course of this study whose central depression did not cross through the surface layer of bedrock. A possible reason for this lack of depth may the deliberate use of a natural fissure in the surface bedrock to provide ventilation for keeping a fire

stoked within the central ring. The fissure passes from within the center of the structure underneath the northwestern section of the ring, using a natural bedrock 'bridge,' upon which the medium-sized boulders of the ring were placed. This kept a passage open through the side of the structure wall, presumably to stoke a fire within the ring. In fact, there are no other apparent factors influencing the construction of Annular Structure 5 in that location aside from this unique feature in the surface bedrock.

A similar construction form was uncovered through the intensive excavation of Annular Structure 8. Excavating through the northeastern wall of the structure, I uncovered a smaller double wall that presumably represented an older construction and use-phase of the structure. This original wall, in turn, was constructed atop a protruding mound in the surface bedrock that nearly mimicked the arc of the overlying ring. Snaking through the center of this bedrock mound was a narrow passage or fissure that appeared to be either completely natural, or slightly modified. Similarly to the fracture in the surface bedrock of Annular Structure 5, this fissure through the underlying bedrock wall potentially permitted the passage of air between the central pit and the exterior of the structure. Obviously, when the final phases of the structure were built and completely covered the original, smaller wall, this natural fissure would not have been useful. Ventilation shafts would not have been necessary, however, if the wood was assembled correctly and efficiently within the pits of the kilns. If they were arranged similar to the aboveground pyres, around a central vertical log that was removed to create a chimney, this would have provided enough airflow into the kiln and may even have formed a vortex that sucked air down into the pit.

Taken together, all of these lines of data provide convincing evidence that the Prehispanic Maya used the annular structures as kilns or ovens for cooking something. The question becomes: what were they cooking in these pit-kilns?

Burnt Chich

One indication of what the Prehispanic Maya were cooking in the central depressions of the annular structures is provided by the scattering of partially burnt small pieces of limestone called *chich*, in and around many of the structures. *Chich* is a term that refers exclusively to the size of the stones, which can be generally described as fist-sized or smaller, and does not distinguish color, shape, nor type of stone. The majority of the pieces of *chich* that are scattered around the structures, however, belong to the general category of limestone referred to in Yucatec Maya as *saakel bach* that is known to be the best type for making lime powder. In some cases, the partially burned pieces of *chich* can be found scattered in random patterns around the outside of the ring structure, as if discarded after they did not completely calcine during the cooking process. In other cases, it appears that the Prehispanic Maya used the partially-calcined/partially-burned pieces of *chich* as deliberate insulation and/or retention material to shore up the exterior walls of the structure. Examples such as Annular Structure 2, Annular Structure 8, and Annular Structure 9 possess an outer, sloping ring composed almost entirely of *chich*, both burnt and unburnt. Many of the pieces of *chich* that do not exhibit evidence of burning can be identified as the category of limestone known as *took' tuunich*, a general term for very hard, greyer bedrock that is not good for making lime powder. This indicates that stones collected for potential firing were discarded prior to the lime production process due to the recognition of their inappropriateness for producing lime. I go into more detail regarding Mayan

names for and knowledge of different types of limestone in Chapter 7, but for the purposes of deducing the materials cooked within the annular structures, it is important that the stones gathered and apparently burned within the kiln were of the type specifically used for making lime, while those that do not exhibit evidence of burning were of the category not generally used for making lime. Additionally, the partially burned pieces of *chich* are very similar to those pieces of *chich* that did not completely calcine during the lime kiln production experiment (also described in Chapter 7) that were subsequently discarded after the firing process. These lines of evidence suggest that small pieces of limestone were being cooked within the kiln, possibly to calcine them into lime powder.

Stucco/Reconstituted Calcium Carbonate

Another line of evidence suggesting that the Prehispanic Maya were using the annular structures as pit-kilns to cook limestone into quicklime was the discovery of layers of stucco in many of the structures excavated. In this case I am using the term stucco to refer to reconstituted calcium carbonate, not to a specific combination of lime and aggregate products used to the coat the exteriors of walls throughout the Maya area. The mostly horizontal layers of stucco found near the lowest levels of many of the excavated structures represent calcium carbonate that had been burned to the point where it transformed into calcium oxide (quicklime). It then absorbed water either through deliberate human-induced hydration episodes or naturally from water vapor in the air, forming calcium hydroxide (lime powder). Over time the calcium hydroxide absorbed carbon dioxide from the air and hardened once again into calcium carbonate, which was the stucco layers encountered in the structures.

The identification of these thin and/or amorphous layers of stucco in the kilns suggest that they were byproducts of the firing episodes. Again, the results of the experimental project described in the following chapter provided an analogue for the materials I encountered in the Prehispanic kilns. After producing the lime powder through intensive, high-temperature burning, I allowed the resulting quicklime to hydrate into lime powder and then it was removed from the pit. It was impossible to remove all of the lime powder, as even with our best efforts, a thin layer of lime powder remained in the pit. Over time, this layer hydrates further and then dries into a layer of stucco similar to the ones discovered near the lower levels of the Prehispanic annular structures. The fact that multiple layers of these stucco layers were identified in several pits, in some cases overlaying and underlying burnt layers of soil, rock and/or charcoal, suggests the remains of multiple lime production episodes within these pits.

At first, it was unclear whether the stucco products recovered from the pits represented actual reconstituted calcium carbonate, or the naturally occurring softer, powdery limestone known locally as *sahcab* or *sascab*. Oxygen and carbon isotope analyses indicated that the materials encountered in the pits had absorbed water and carbon dioxide from the surrounding environment when passing through the lime production cycle, a strong indication that they were in fact reconstituted calcium carbonate. These lines of evidence in turn suggest that the kilns reached high enough temperatures for a long enough duration to transform pieces of *chich*, like those encountered around the outside and in the wall fill of the structures, into quicklime. There are no other likely reasons for the presence of multiple thin, amorphous stucco layers near the lowest levels of these pits.

Additional Indirect Lines of Evidence

An additional line of evidence that suggests that the Prehispanic Maya used annular structures to cook limestone into lime is the type of the wood fuel recovered from within some of the kilns. Charcoal samples were able to be identified as hardwood species, specifically those belonging to the *Piscidia* and *Lonchocarpus* genera, which include the ja'abin and baalche' tree species that are commonly used for burning throughout the Yucatán today and were used in the experimental pit-kiln burns. These slow-burning woods were likely the preferred type for long-duration fires such as those necessary to produce lime.

Finally, while not definitive, the absence of any specific evidence for the burning of other materials within the kilns supports the notion that they were used to burn limestone. Granted, this final line of evidence is especially indirect and the absence of evidence cannot necessarily be taken as strict evidence for absence. Dean Arnold has found that despite steady output, modern potters in the town of Ticul that borders the Puuc Region leave no ceramic wasters in the vicinity of their kilns (Arnold, personal communication 7/4/2015). Thus, the absence of ceramic wasters recovered from the vicinity of any of the annular structures cannot necessarily preclude the cooking of ceramic vessels in the past. Similarly, multi-elemental analyses of the soil and stucco samples recovered from within the central depressions of many of the annular structures are inconclusive with regard to the presence of other materials that may have been cooked in the kilns.

Spatial and Contextual Results

The physical evidence clearly points to the use of these Prehispanic annular structures as lime pit-kilns. The identification of the structures as pit-kilns allows for a spatial analysis of lime

production in the Kiuic community. I analyzed the distribution of annular pit-kilns throughout the Kiuic community and the spatial and contextual relationships between the pit-kilns and other archaeological features. These data highlight two main points that have implications for the organization of the Prehispanic lime production industry: 1) The annular pit-kilns were mainly located in the hilly intermediate zone to mitigate pre- and post-production transportation efforts; and 2) Lime production was largely decentralized, with at least some production being organized at the household or small-scale corporate level. In this section I discuss how the data reflect these these two main points.

Limiting Transportation Efforts

The pit-kiln experiments demonstrate that lime production requires substantial amounts of labor for the collection and preparation of raw materials. The recovery and distribution of the heavy burnt lime that was produced in the annular pit-kilns also required much labor. Taking into account the effort involved in producing and distributing lime, I expected that the Prehispanic inhabitants of Kiuic would have taken steps to limit the transportation efforts involved in the lime production industry. The distribution of annular pit-kilns throughout the study area appears to support this proposition by correlating with three main factors: 1) The location of *saakel bach tuunich* outcrops; 2) Sloping and/or elevated terrain; and 3) Population density. Combining all three of these factors sheds light on how Prehispanic lime producers endeavored to limit the labor involved in gathering raw materials and distributing finished lime after production events.

Of the 53 clearly identified annular structures in the study area, 11 are located in the outer zone (21%) to the west of the ring of hills that surround the Kiuic valley (Figure 8-10), 35 are located in the hilly intermediate zone (66%) (Figure 8-11), and seven are located in the Kiuic

inner zone (13%) (Figure 8-12). Across all of the zones, the most consistent contextual correlations for the annular structures are that they are located near outcrops of *saakel bach tuunich* limestone (the type most desirable for making lime), and they are situated on elevated or sloping terrain (Table 8-8). Nine of eleven (82%) outer zone annular structures are located within 25m of a *saakel bach tuunich* outcrop, and all eleven are located within 50 m of *saakel bach tuunich* outcrop. Twenty-seven of thirty-five intermediate zone annular structures (77%) and six of seven inner zone annular structures (86%) are also located within 25 m of a *saakel bach tuunich* outcrop. My survey data indicated that while *saakel bach tuunich* bedrock and outcrops were widespread across the landscape, their distribution was not even. The high correlation of annular structures with prominent *saakel bach tuunich* outcrops suggests that annular structures were purposefully located close to this specific type of limestone, which also provides further evidence for the annular pit-kilns' connections to lime production.

The fact that eight out of eleven (73%) of the outer zone annular structures are located on elevated or sloping terrain reflects three probable factors: 1) The desire to be close to the outcrops and hill-slopes from where the raw wood and stone materials were harvested; 2) The desire to use the natural slope in the construction of the kiln; and 3) The desire to leave as much flat arable land as possible for agricultural production. A correlation between annular structures and sloping or elevated terrain is also seen in the intermediate and inner zones, likely for similar reasons. Thirty of thirty-five (86%) intermediate zone annular structures are located either on a hill or immediately at the base of the hill. The high correlation in the intermediate zone is partially due to the greater prevalence of sloping terrain in general, but this may be only one of multiple reasons for the higher concentration of annular structures in the zone as I discuss below.

The small sample size of the inner zone (n=7) limits its significance to this discussion, though 6 of 7 (86%) of inner zone annular structures are located on sloping or elevated terrain.

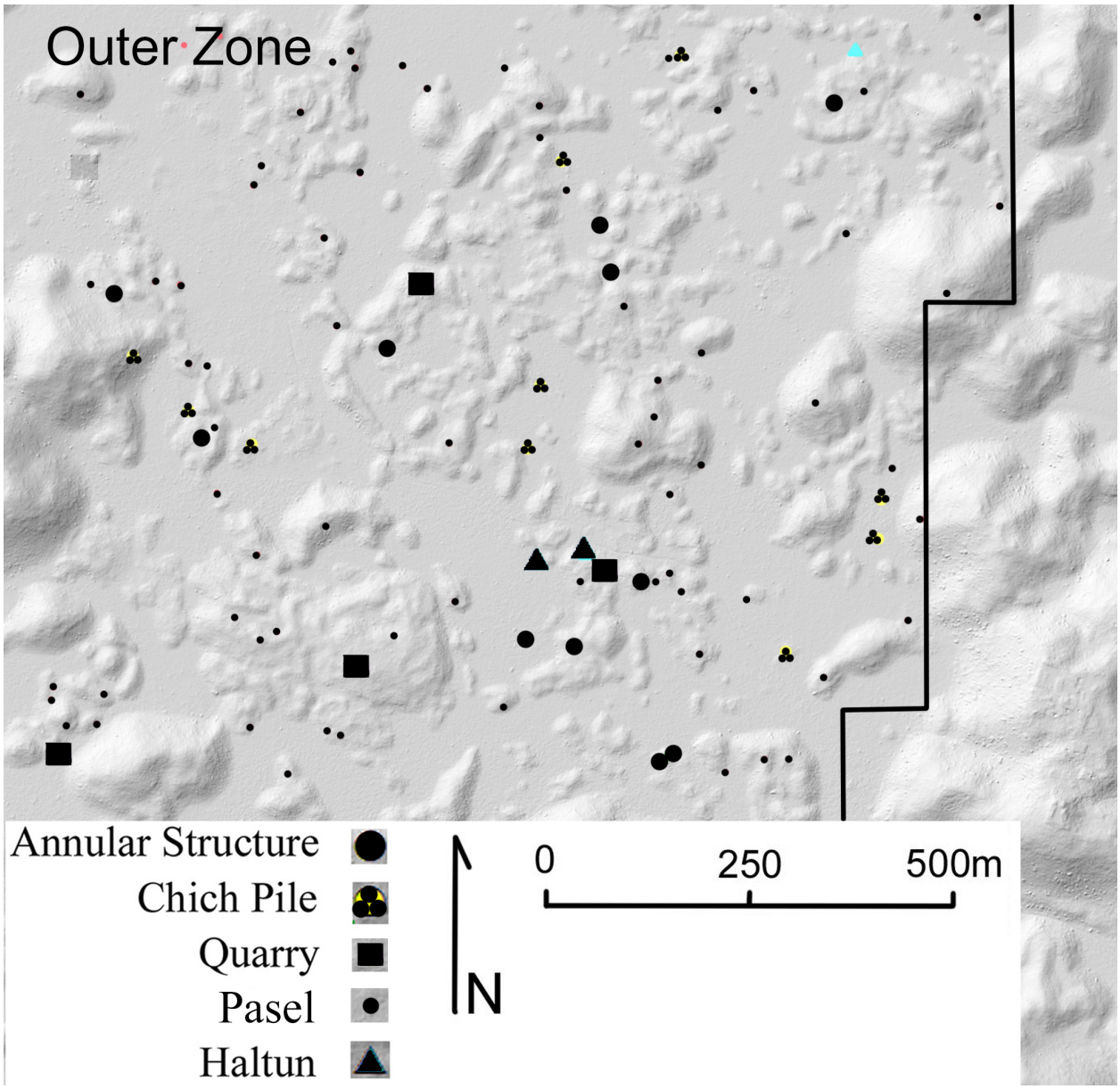


Figure 8-10: LiDAR map of the outer zone of the study area showing the locations of annular structures and other limestone industry features (adapted from Gallareta Negrón et al. 2014).

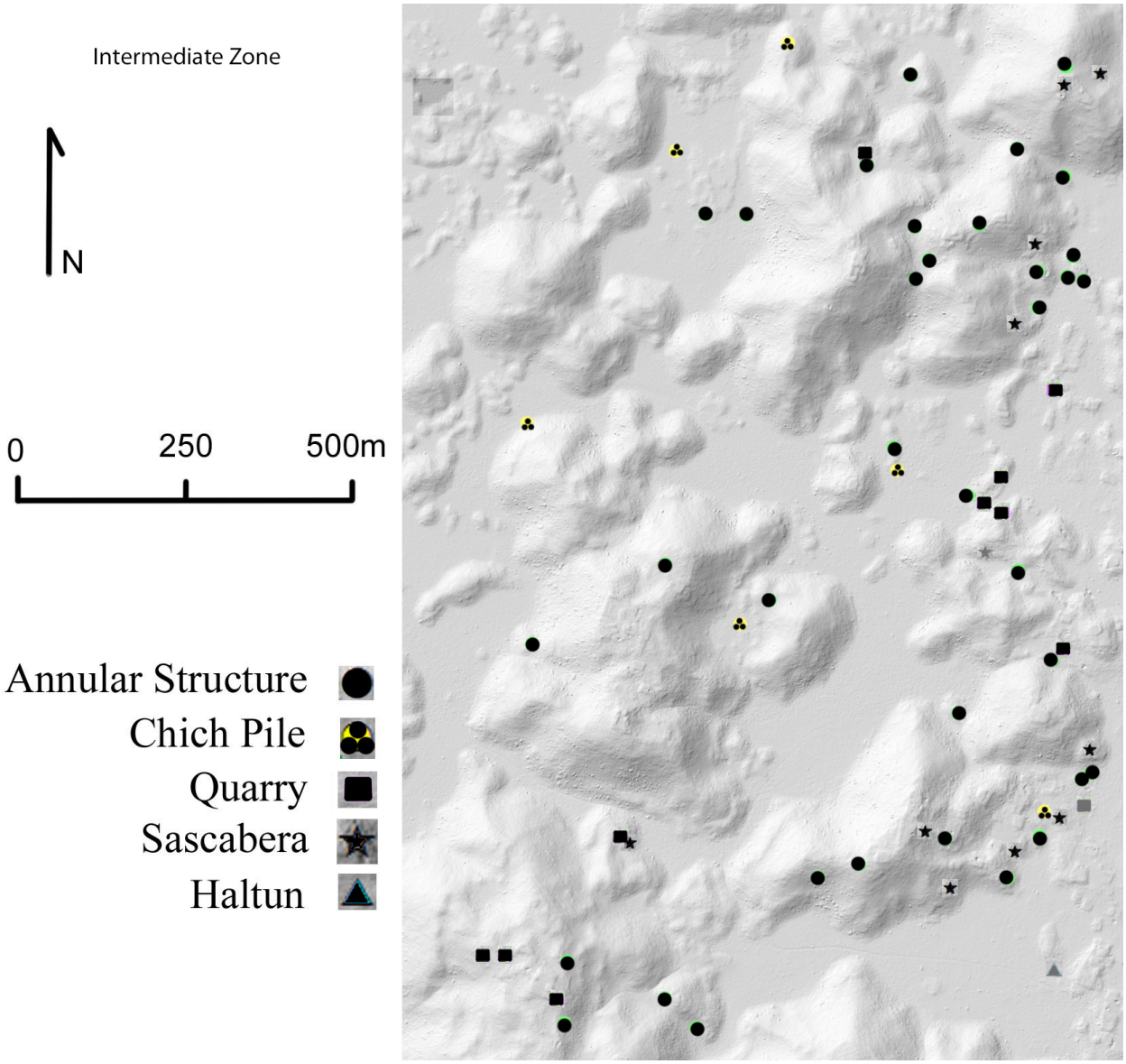


Figure 8-11: LiDAR map of the intermediate zone of the study area showing the locations of annular structures and other limestone industry features (adapted from Gallareta Negrón et al. 2014).

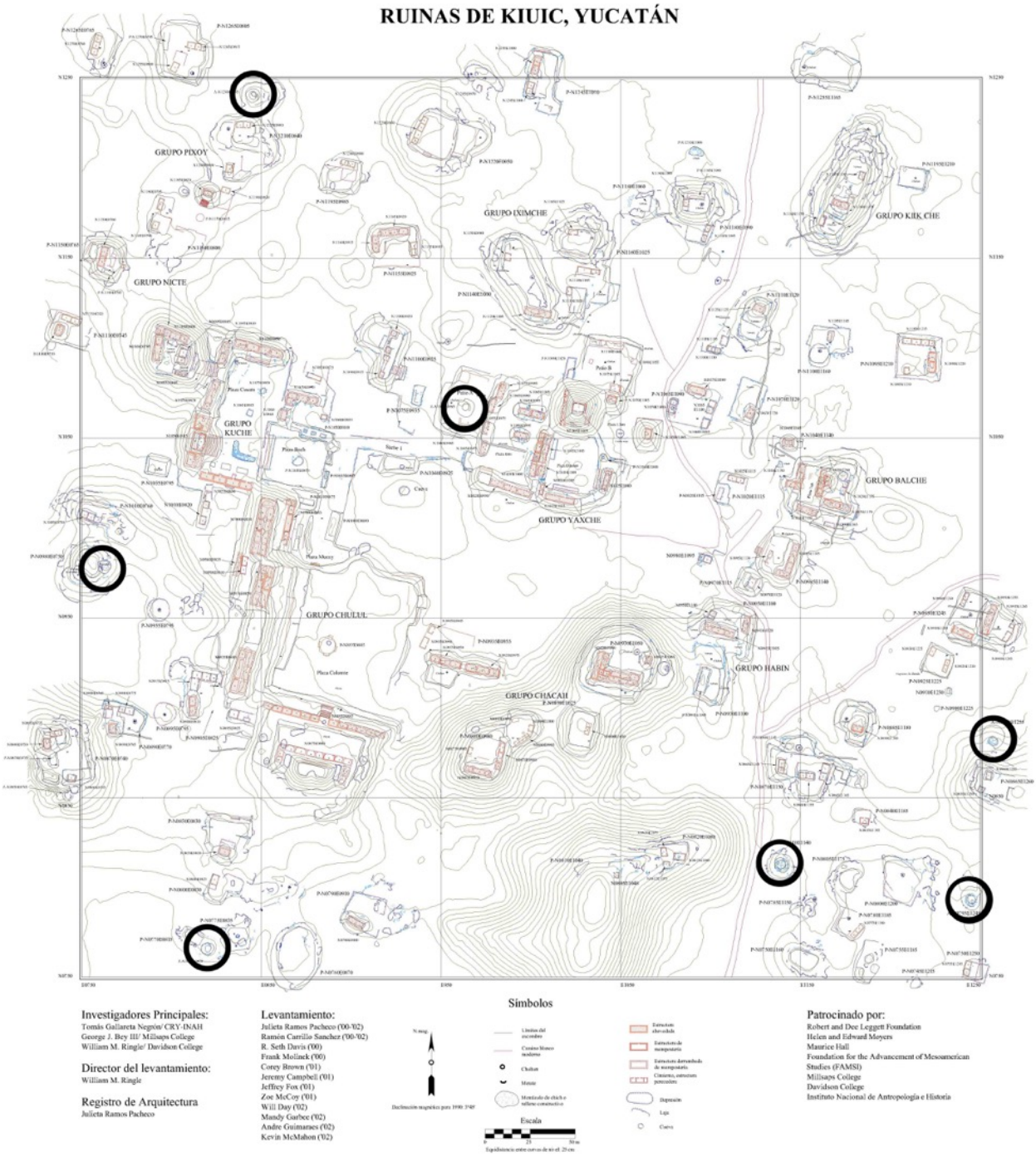


Figure 8-12: Survey map of the inner zone of the study area showing the locations of annular structures in relation to the other archaeological features of the Kiuic site center (map by William Ringle and colleagues in Gallareta Negrón et al. 2014).

Table 8-8: Number totals and percentages pertaining to the spatial relationships of annular structures and other archaeological features related to the limestone industry in the different zones of the study area.

Annular Structure Location	Outer (n)	Outer (%)	Intermediate (n)	Intermediate (%)	Inner (n)	Inner (%)
<25m from a pasel	4	36%	4	11%	0	0%
<50m from a pasel	9	82%	7	20%	0	0%
<25m from other limestone industry feature (not other AS)	2	18%	15	43%	6	86%
<50m from other limestone industry feature (not other AS)	2	18%	18	51%	6	86%
<25m from other limestone feature (including other AS)	4	36%	18	51%	6	86%
<50m from other limestone feature (including other AS)	8	73%	26	74%	6	86%
<25m from saakel bach tuunich	9	82%	27	77%	6	86%
<50m from saakel bach tuunich	11	100%	33	94%	7	100%
Located on sloping or elevated land	8	73%	30	86%	6	86%
Located on flat terrain not associated with a hill	3	27%	5	14%	1	14%
<25m from other AS	0	0%	6	17%	0	0%
<50m from other AS	6	55%	15	43%	0	0%
Isolated except for other AS	2	18%	0	0%	0	0%
Completely isolated (more than 50m from other feature)	0	0%	3	9%	0	0%

The majority (66%) of the annular structures identified in the study area are located within the intermediate zone of hills ringing the site center to the north, west, and southwest. The intermediate zone also has the highest concentration of annular structures (26.5 per km^2, compared with 18.4 per km^2 in the inner zone, 9.7 per km^2 in the intermediate zone, and 18.7 per km^2 overall) (Table 4-2). This reflects a desire on the part of lime producers to be close to both the source of the wood fuel needed for burning episodes and the residential groups to which the finished lime would need to be transported. The desire to limit the transportation investments involved in assembling the wood fuel for lime production led lime producers to the locate their annular pit-kilns near to standing forests. The hill-slopes of the intermediate zone were likely

among the more densely forested areas of the Kiuic polity during the Late and Terminal Classic Periods (Chapter 9). Competing with the need to be close to the wooded hill-slopes was the desire to stay close to the densest concentrations of residential compounds that consumed the lime. Twenty of the thirty-five (57%) intermediate zone annular structures are located within 250 m of the inner zone, which is a concentration of 55 annular structures per km^2 compared with 21 per km^2 for the rest of the intermediate zone. The inner zone has residential group density of 118 residential groups per km^2 while the intermediate zone as whole has a density of 27 residential groups per km^2 (Tables 8-9 and 8-10). A desire to limit the transportation efforts involved in the distribution of the finished burnt lime led lime producers to locate the annular pit-kilns as close to the consumers as possible. The intermediate zone best fits this balance between limiting the transportation of raw materials and of finished product.

Table 8-9: Concentrations of elite and non-elite residential groups in the intermediate and outer zones.

	Area (km^2)	**Elite Residential Groups**	**Elite groups per km^2**	**Non-elite Residential Groups**	**Non-elite groups per km^2**	**Total groups**	**Total groups per km^2**
Inner	0.38	21	55.3	24	63.2	45	118.4
Intermediate	1.32	6	4.5	30	22.7	36	27.3
Outer	1.13	0	0	0	0	0	0.0
Total	2.83	27		54		81	28.6

Table 8-10: Annular structure concentrations across the study area.

Zone	**Area (sq km)**	**Annular Structures**	**AS per sq km**
Inner	0.38	7	18.4
Intermediate	1.32	35	26.5
Outer	1.13	11	9.7
Total	2.83	53	18.7

Decentralized Production

The widespread distribution of annular pit-kilns throughout the Kiuic community and the rather limited amount of corporate groups that appear to have directly controlled access to their own pit-kilns (25%) suggests that lime production at Kiuic was largely decentralized. It appears that some groups within the community produced lime using their own annular kilns while others may have accessed or controlled relatively isolated annular pit-kilns in the hinterlands to the west of the inner zone. It is unlikely, however, due to the labor and resource investments involved, that all groups produced their own lime. These non-producing groups had to acquire the lime through some form of exchange system. Organization of lime at the household or small-scale corporate level does not preclude the possibility of centralized authorities restricting access to raw materials and/or distribution of the finished product. It is quite possible that central governing authorities and non-producing elite corporate groups procured lime from producing groups through a tax or tribute system and in this way maintained a certain degree of control over the lime industry. Regardless of the degree of control over the lime industry as a whole, lime *production* appears to have been widespread and therefore decentralized throughout the Kiuic community. It is possible that multiple household, corporate, and/or independent production schemes operated within this overarching decentralized production framework.

A total of 81 residential architectural groups were identified in the study area, all within the intermediate and inner zones. These include 27 elite residential compounds, marked as such by the presence of at least one stone vaulted structure (Figure 8-13). I use the term ‘elite’ here to serve as a general distinction of higher socioeconomic status compared with the sub- or non-elite residential groups that did not possess such a structure. Sixty-one of the eighty-one residential groups (75%) are not located within 25m of an annular structure, and 18 of 42 (57%) annular

structures in the intermediate and inner zones are not located within 25m of a residential group (Tables 8-11, 8-12). Distance alone is not the best way for determining association between features, however. Taking into account the orientation of residential groups, the location of the annular structures within those groups, and the location of the archaeological features with regard to the natural topography, the number of residential compounds that appear to have had relatively easy spatial and contextual access to lime kilns jumps to 13 of 27 elite compounds (48%) and 24 of 54 non-elite compounds (44%). This still suggests that less than half of the small corporate groups at Kiuic were producing their own burnt lime, meaning that more than half of the groups within the polity (54%) had to acquire their lime through some means of exchange. Taking this analysis a step further, only 11 out of the 42 annular structures in the intermediate and inner zones (42%) appear to have been controlled by one specific residential group based on restricted architectural access. These include nine out of thirty-five in the intermediate zone (26%) and 2 out of 7 in the inner zone (29%). Eighteen out of 42 annular structures (43%) in the intermediate and inner zones may have been shared by multiple elite and/or non-elite compounds, though it is difficult to deduce sharing strategies based solely on proximity and orientation. The main takeaway from the data is that roughly half of residential groups did not likely produce lime with their own proximal lime kilns and may have had to acquire lime from those corporate groups that did produce their own lime.

The other possibility is that those corporate groups that did not have direct access to lime kilns in close vicinity to their residences either controlled or at least had access to the more isolated pit-kilns located farther away from the site center. The outer annular structures are relatively isolated from other archaeological features compared with those of the intermediate and inner zones. However, the distance of production locales from residences does not

necessarily indicate a lack of control or access. Using De León's (2009) Aztec salt production model as a reference, it is possible that corporate groups located closer to the site center used the seemingly isolated annular structures in the hinterlands to produce lime intermittently. Only approximately 25% of residential groups appear to be directly associated with an annular structure, which suggests the majority of corporate groups were using annual structures that were not necessarily proximal to their residential compounds and/or acquiring lime from groups that did posses their own annular pit-kilns. The mere existence of the many isolated annular structures, however, suggests that people were indeed using them despite their distance from residential architectural groups. However, as mentioned above, the amount of resources required for lime production (in terms of raw materials, technical skill, and labor) would likely have limited the number of households and/or small-scale corporate groups that produced their own lime.

Table 8-11: The location of annular structures in the intermediate and inner zones in relation to residential groups.

Annular Structure Location	Intermediate (n)	Intermediate (%)	Inner (n)	Inner (%)
<25m of residential group w/ at least one vaulted structure	5	14%	3	43%
<50m of residential group w/ at least one vaulted structure	7	20%	6	86%
<25m of residential group w/o vaulted structure	7	20%	4	57%
<50 m of residential group w/o vaulted structure	12	34%	5	71%

Table 8-12: The location of residential groups in the intermediate and inner zones in relation to annular structures.

Residential Group Location	Intermediate (n)	Intermediate (%)	Inner (n)	Inner (%)	Total	Percentage
Residential group w/ vaulted structures <25m to AS	4	67%	5	24%	9	33%
Residential group w/ vaulted structures <50m to AS	5	83%	7	33%	12	44%
Residential group w/o vaulted <25m to AS	6	20%	6	29%	12	22%
Residential group w/o vaulted <50m to AS	18	60%	10	42%	28	52%
Residential group w/ or w/o <25m to AS	9	25%	11	24%	20	25%
Residential group w/ or w/o <50m to AS	23	64%	17	38%	40	49%

Nine of eleven outer annular structures (82%) are located more than 50m away from any other archaeological feature that isn't another annular structure or a small *pasel.*[1] The Prehispanic limestone foundations identified near the outer annular structures most likely represent the archaeological remains of similar temporary shelters for agricultural or even lime industry workers. While nine of the eleven annular structures (82%) are located within 50m of a *pasel* foundation, only one of the annular structures is located within 50m of multiple *paseles*.

[1] I selected 50 meters as the cutoff for determining association between archaeological features in the rural zone because features are generally more spread out in this zone than in the intermediate and urban zones. Additionally, 50 m is the approximate maximum distance that features would be mutually visible from one another in the undulating topography, even if it was completely denuded of trees. When dealing with the intermediate and urban zones, 25 meters serves as a more appropriate marker due to the higher overall concentration of archaeological features.

Considering the amount of labor necessary for lime production, it is unlikely that a sole *pasel* served the needs of workers involved in lime production. Thus, it is more likely that the Prehispanic *paseles* were related to the agricultural activities in a similar way to contemporary ones.

This leaves the outer annular structures even more isolated in terms of associated archaeological features. The lack of permanent camps around the structures suggests that workers were walking out to the structures on a daily basis when the kilns were in use. This suggests that they were not used for extended periods of time and perhaps on a seasonal basis. Lack of permanent structures also suggests a lack of permanent oversight of the kilns, which may have been open to use by different groups including multiple households and/or independent lime producers.

Looking deeper into the data, there appears to be a greater correlation between elite residential groups and annular structures in the intermediate zone (4 of 6, or 67%, within 25m of annular structure), than in the inner zone (5 of 21, or 24%). While this discrepancy might suggest a greater desire for self-sufficiency or the subsistence benefits of multi-crafting on the part of intermediate zone elites, the small sample brings the significance of the data into question ($p=0.07$ using Fisher's Exact test) (Appendix E). However, one of the six vaulted residential compounds identified in the intermediate zone of the study area is the residential/civic-ceremonial compound known as *Escalera al Cielo Sur* that makes up a sub-complex of the overall hilltop complex of *Escalera al Cielo* (EAC). Evidence gathered from excavations in the different residential compounds atop EAC suggest that the entire hilltop functioned as connected complex. In this case, the annular structure located on the hill should be seen as serving both elite compounds even if it is geographically closer to the north group. This would bring the totals

to 86% of intermediate zone elite compounds versus 24% of inner zone elite compounds with a p-value of 0.008. Another significant discrepancy is that 67% of elite residential compounds in the intermediate zone are located within 25m of an annular structure while only 17% of non-elite residential compounds in the intermediate zone are located within 25m of an annular structure (p=0.025 using Fisher's Exact test) (Appendix E). This divergence gives further credence to the possibility that intermediate zone elite groups may have placed a higher emphasis on producing their own lime for either consumption or multi-crafting subsistence purposes than other sectors of the population.

The fact that only one annular structure is located in or around the civic-ceremonial compound of the site center suggests that there was little or no direct oversight of lime *production* activities. This does not mean that central authorities or elites did not sponsor lime production at more distant annular pit-kilns or exercise a certain measure of control over the lime processing industry through restriction of raw materials and/or distribution of finished product. It is possible that some of the 11 relatively isolated annular structures in the intermediate zone, or any of the 11 outer annular structures may have been built and used by lime producers beholden to central authorities at the Kiuic site center, but there is no direct evidence suggesting such a situation. As many as 20 of the 42 annular structures (48%) located in the intermediate and inner zones were directly associated with residential compounds, suggesting that approximately half of lime production was produced in residential compound contexts.

Another contextual situation worth mentioning that highlights discrepancies in lime production is the clustering of non-elite residential compounds in the southeast of the intermediate zone of the study, just off the southwest corner of the inner zone. Here there appear to be 10 residential groups clustered around just three annular structures in a 400 sq m area. This

situation can be contrasted with a 400 sq m area just off the northwest corner of the inner zone that has a cluster of five annular structures associated with at most three residential groups (Figure 8-14). Thus, off the southwest corner of the inner zone there is a cluster with a ratio of 3.3 groups per 1 annular structure while off the northwest corner of the inner zone there is a cluster with a ratio of 0.6 groups per 1 annular structure. This discrepancy in residential group-to-annular structure ratio further suggests that some corporate groups were producing lime as a craft item surplus to be exchanged, while others may have been sharing access to annular pit-kilns. It is possible that the cluster of five annular structures on the northwestern edge of the inner zone may have been related to production for the residents of the public architecture of the site center. While it is impossible to say for sure who was controlling production at these five pit-kilns, the high concentration suggests a large output. The larger civic-ceremonial structures of the site core required a greater quantity of lime for maintenance and restoration, not to mention the fact that much lime was needed for the construction of the late Terminal Classic Period Chulul and Kuche palace groups. Thus it is possible this cluster of annular structures, which would be easier to oversee than numerous far-flung structures, may be related in some way to production for the governing authorities of the polity. However, it is also possible that they represent the workshop of a household or corporate group that specialized in lime production for distribution to non-producing corporate groups throughout the community.

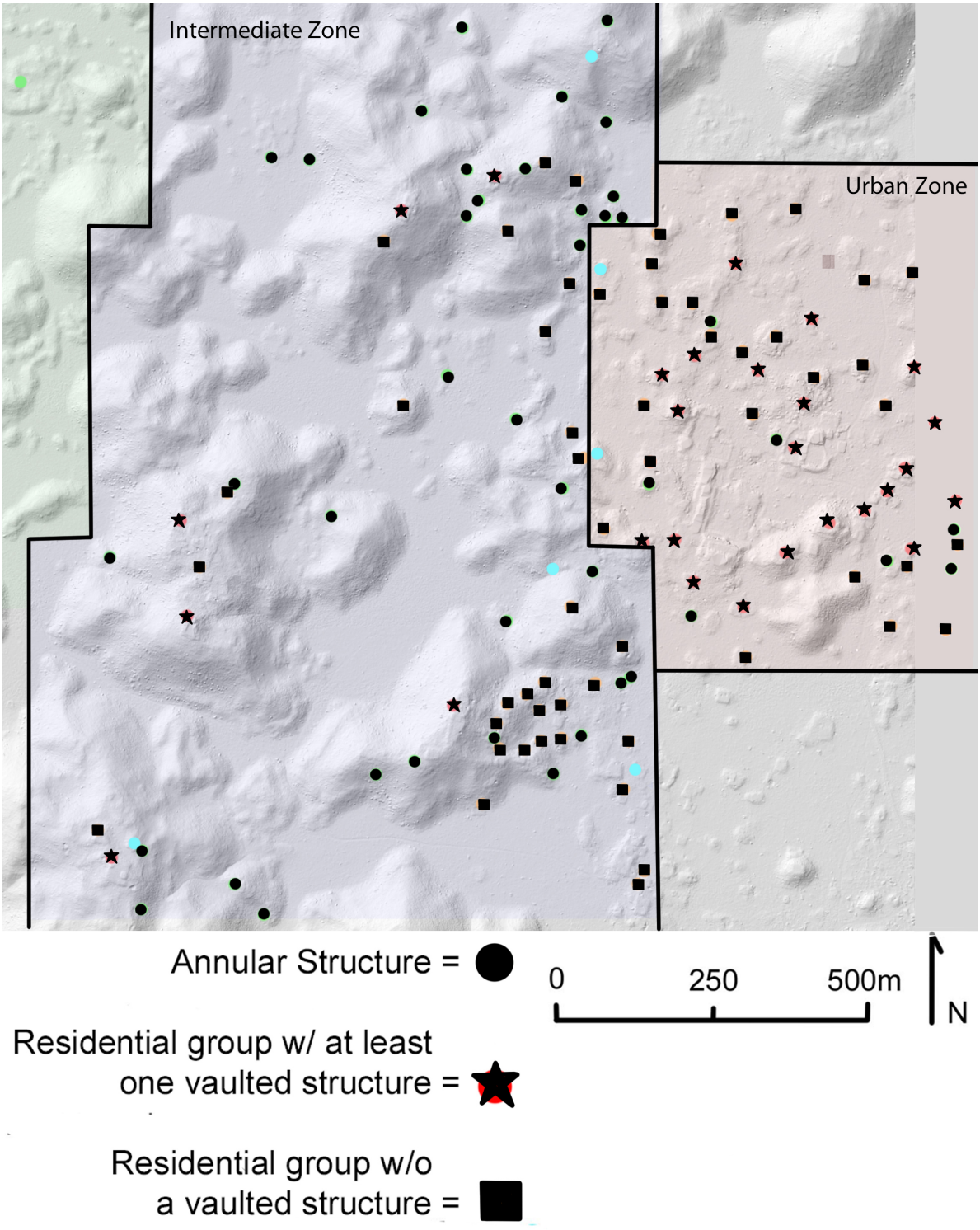


Figure 8-13: LiDAR map of the intermediate and inner zones of the study area showing the locations of annular structures and residential archaeological groups (adapted from Gallareta Negrón et al. 2014).

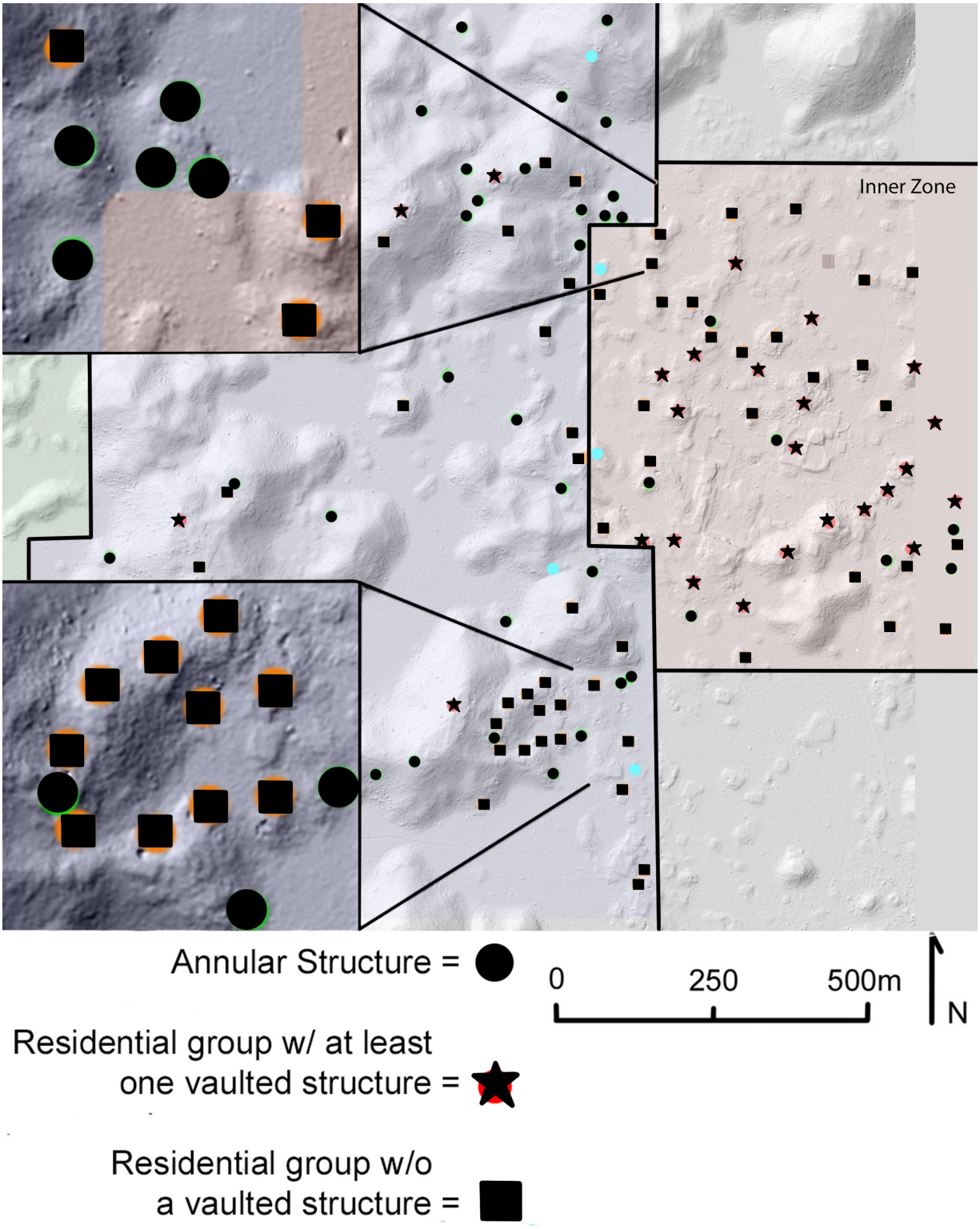


Figure 8-14: Map showing the locations and layouts of the two clusters of residential groups and annular structures that highlight the discrepancies in production and consumption rates (adapted from Gallareta Negrón et al. 2014).

Other Limestone Industry Features

Several other features possibly related to the Prehispanic limestone processing industry were identified in the archaeological record of the study area in addition to the 53 annular structures. These included: 18 limestone quarries; 13 *sascaberas*; 16 mounds or groups of mounds of *chich;* and at least four *haltúns*, and numerous *chultúns* (Tables 8-13 and 8-14). Prehispanic quarries in the Puuc are visible in the archaeological record as shallow depressions cut into limestone outcrops marked by natural angles and vertical cuts. *Sascaberas* are quarries specifically for the excavation of *sascab*: the softer, whiter limestone marl that appears in pockets below the harder surface limestone cap. *Chich* mounds are piles of small, fist-size pieces of limestone (*chich*) ranging in size from 1 to 5 m in diameter. The fact that limestone is broken down into *chich* before being fired to produce lime suggests that *chich* mounds may be a feature of lime production activities. *Haltúns* are natural depressions in the surface bedrock that fill with water during the rainy season and *chultúns* are human-made cisterns for storing water. Water is important for slaking quicklime and a stored water source would be useful for lime production during the dry season.

The correlations were not as high as I expected, although there does appear to be some connections between other limestone processing features and annular structures that provide further evidence for the annular structures' function as lime kilns. Of note are the fact that 56% of surface quarries were located within 25m of an annular structure (61% were located within 50m of an annular structure), and 62% of *sascaberas* were located within 25m of an annular structure (77% within 50m of an annular structure). While these are not overwhelming majorities they do suggest a link between annular structures and the limestone processing industry. *Sascab* grade limestone would not have been useful for producing lime, but in many instances it has

been found to serve similar purposes to lime in terms of crushed and tamped *sascab* being used to 'pave' floors. It is possible that households or groups that were producing lime were also quarrying *sascab* to distribute for similar purposes, which would suggest that certain households or groups specialized in the general category of limestone processing as opposed to just lime production.

Table 8-13: Table showing the total number of different archaeological features identified in the study area.

Type of Feature	**Outer**	**Intermediate**	**Inner**	**Total**
Annular Structure	11	35	7	53
Quarry	4	11	3	18
Sascabera	0	11	2	13
Chich Mound(s)	10	6	0	16
Haltun	3	0	1	4
Total	28	99	58	185

Table 8-14: Proximities of archaeological features associated with limestone processing to annular structures in total numbers and as percentages of the total number of those features within the different zones.

Feature	**Outer**	**Outer (%)**	**Intermediate**	**Intermediate (%)**	**Inner**	**Inner (%)**	**Total**	**Total (%)**
Quarry <25m to AS	1	25%	6	55%	3	100%	10	56%
Quarry <50m to AS	1	25%	7	64%	3	100%	11	61%
Chich mound <25m to AS	1	10%	2	33%	0	0%	3	19%
Chich mound <50m to AS	2	20%	3	50%	0	0%	5	31%
Sascabera <25m to AS	0	0%	6	55%	2	100%	8	62%
Sascabera <50m to AS	0	0%	8	73%	2	100%	10	77%

Alternative Possibilities

Although there are several convincing lines of evidence that point to the annular structures being used as lime kilns, this does not preclude their possible use for multiple purposes. In fact, the amount of labor and resources that went into their construction suggests that the Prehispanic inhabitants of the Kiuic polity used them to serve multiple functions, especially if lime production was a seasonal activity limited to the dry season. It is unlikely that the 53 annular structures were left dormant for half of the year. There are several other ways that the annular structures may have been used in addition to lime production.

As mentioned above, despite the fact that no ceramic wasters were found in the vicinity of any of the structures this does not mean that the annular kilns could not have been used to cook ceramic vessels in addition to lime. Dean Arnold found that the pottery kilns used by modern potters in the town of Ticul were kept clean of wasters (Arnold, personal communication 7/4/15), and while it is a stretch to directly link this modern analogue to Prehispanic practices in the region, it does provide an example of a possible scenario.

The multi-elemental data gathered from soil and sediment samples within and around the annular structures are inconclusive concerning the activities associated with the structure beyond general burning episodes. It is possible that several materials were burned in the kilns, and future research may shed more light on this alternative functions. It is unlikely that the kilns were used to cook food at their final depths. Studies of *piib* use have shown that earth oven pits do not sink nearly as deep as the central depressions of most of the annular structures (Salazar et al. 2012). However, it is possible that they could have functioned as *piibs*, or earthen cooking ovens when they were shallower. Their widespread distribution throughout Kiuic and association with several residential compounds is consistent with this possibility. After finding ash and lime within the

central depression of an annular structure at Sayíl, Dunning (1991:25) suggested that structures might have been used to produce fertilizer. Burning trash and/or making charcoal are two other possible functions of these structures. The annular structures could have served all of these alternative pyrotechnological functions in addition to their use for producing lime.

Although there is substantial evidence for burning, it is possible that between firing episodes the annular structures were used for storage purposes. Ethnographic research in the Puuc (Smyth 1990) has demonstrated the importance of lime for storing and preserving maize. The lime dries out the corn cobs and deters insects and rodents. The maize is then processed through *nixtamalization* before use anyway, which washes away the excess lime. While the connection between lime production and storage of maize in lime is enticing, it would be impractical to store lime in the kilns during the dry season when they were presumably used for lime production. It is possible that several lime burning events took place at the beginning of the dry season and then the structures were used to store maize until the rainy season returned, but it would be difficult to demonstrate this archaeologically. Flotation of soil samples from the lowest levels of the annular structures did not return any evidence for ecofacts that could be used to determine the presence of maize in the annular structures excavated, though future research may eventually recover such evidence.

Overall, however, the porosity of the limestone bedrock and possibility for evaporation made the structures impractical for year-round water storage. The large diameters of the annular structure openings (average=3.2m) would have made it difficult and impractical to cover them, and thus they undoubtedly filled with rainwater during the rainy season. However, this lack of a cap or seal in addition to the porosity of the limestone would have made them impractical for long-term water storage during the dry season. The *chultún* cisterns that characterize residential

water storage in the Puuc region have characteristically narrow openings (<1m diameters) in order to make them easy to seal and thus prevent evaporation or contamination. The walls of *chultúns* are also coated with plaster to make them watertight, as limestone is very porous. The lack of evidence for plaster on the interior walls of the annular structures, coupled with plenty of evidence for direct burning of the bedrock walls indicates that the pit-kilns would not have been watertight. The fact that the annular structures filled with water during the rainy season supports the hypothesis that lime production was largely limited to the dry season.

Chapter 9 – The Prehispanic Puuc Lime Industry:
Environmental Resource Management and the Socio-Economy

In the previous chapters I discussed the multiple lines of evidence that support the hypothesis that the annular structures functioned as Prehispanic lime pit-kilns. In this chapter I combine all of the data to summarize the broader implications that this investigation has for understanding pre-modern socio-economies and resource management practices. I also present my model for the organization of the Prehispanic Kiuic lime production industry specifically. In the first section of this chapter I discuss the reasons why the Prehispanic Maya of the Eastern Puuc developed the pit-kiln technology. This includes an examination of the intersection between pre-modern craft industries and resource conservation issues. In the second section of the chapter I delve into the social and economic aspects of the lime industry including the craft issues surrounding lime production the decentralized organization of lime production at Kiuic. This section also includes a brief case study of the Pixoy architectural compound to evaluate my model of small-scale corporate-level production. In the final section of the chapter I present my conclusions about the Prehispanic Puuc lime production industry and the broader impacts of my study for understanding the articulation of small-scale production strategies and community-wide resource conservation issues.

The Development of Pit-kiln Technology

In this section I describe the different reasons why the Prehispanic inhabitants of the Puuc region may have developed the annular pit-kiln technology for producing lime. The precipitating causes were likely a combination of population growth and architectural expansion during the

Late and Terminal Classic Periods. Other contributing factors were likely decreased availability of non-agricultural land and the effects of repeated burning episodes in a specific location. These lines of evidence combined with the data gathered from the pit-kiln experiments ultimately suggest that the desire to conserve natural resources was the main impetus for developing the pit-kiln technology.

Demographic Expansion

Based on the four AMS radiocarbon dates and ceramic data recovered from the fill of almost all of the excavated structures, it appears that the annular structures were in use during the Late and Terminal Classic Periods from ca. 650-850 CE. Previous archaeological research at Kiuic highlights this transitional time as a period of increased construction activity likely reflecting a population boom (Gallareta Negrón et al 2015:1.2-1.6; Gunn 2015:63-65). It is now well established that many of the larger polities to the south in what is now northern Guatemala and southern Campeche and Quintana Roo began experiencing dramatic sociopolitical transformations around this time. Starting in the 8th century CE, many site centers in the Southern Maya lowlands were largely abandoned. It is possible that significant portions of the populations from these polities migrated northwards. Archaeologists have suggested a host of factors inciting the 'collapse' of the southern polities, including: overexploitation of local resources; civil unrest stemming from an increasingly burdensome bureaucracy and the expansion of elite classes; climatic changes; endemic warfare; and foreign invasion (Aimers 2007; Demarest et al. 1997; Demarest et al. 2004; Inomata 2003; Chase and Chase 2004). While the likely causes of the demise of the southern sociopolitical systems involved a combination of

many of these factors, the important point is that large groups of people likely left the southern polities in search of new homes.

Regardless of whether the population expansion that began at Kiuic around the end of the 7th and beginning of the 8th centuries CE was a result of immigration or indigenous growth the fact was that construction programs in and around the site center increased at this time. New residential complexes were built around Kiuic, including the elite hilltop complex of *Escalera al Cielo* located 1.5 km to the west of the site center, which has been dated to the Late/Terminal Classic Period Transition ca. 810 CE (Simms et al. 2012:274). It is possible that the other residential compounds located on the other hills surrounding Kiuic were also built around this time as residents of the Kiuic polity expanded their territories outside of the Kiuic Valley. A construction boom required an increased production of lime for mortar and stucco purposes and the population growth that spawned the construction boom meant that there were more people requiring nixtamalized maize. Overall, these data suggest that lime production greatly expanded during this period as a result of demographic changes.

Conservation Issues

The pit-kiln lime production experiments demonstrated the practicality and relative fuel-efficiency of pit-kiln technology compared with the aboveground calera method. The annular pit-kiln design provided protection from wind and insulation for the fire. Compared with the average aboveground efficiency demonstrated by recent experiments (Schreiner 2002; May and Gallareta 2003; Russell and Dahlin 2007), the 3.94:1 ratio by mass of my experimental kiln is demonstrably more fuel-efficient. Considering the amount of lime that was produced for

architectural, dietary and other purposes, even a roughly 20% increase in fuel-efficiency would have gone a long way towards conserving fuel over time.

Some archaeologists hypothesize that the Prehispanic Puuc region, with its relatively deep and fertile soils, was a breadbasket for other regions of the Northern lowlands (Kurjack et al. 1979; Barrera Rubio 1982; Dunning 1991; Smyth and Dore 1992:4; Dahlin 2005; Gallareta Negrón et al. 2014:1). Thus, in addition to providing the subsistence for the growing local population at Kiuic, it is possible that the farmers in the Eastern Puuc provided populations growing elsewhere in the Northern Lowlands as well, at Terminal Classic population centers like Chichén Itzá. Even if the breadbasket hypothesis were falsified, much if not all of the flat, arable land in and around Kiuic was likely used for agricultural purposes. This limited fuel resources to the thin-soiled sloping and elevated lands. There is no evidence for terrace farming in the Puuc, which supports the hypothesis that the hillsides may have been dedicated to arboreal cultivation.

Fuel was necessary not only for producing lime, but for cooking food and firing pottery as well, and lumber was necessary for architectural purposes. The restriction of fuel resources to sloping land limited the amount of fuel available and provided an impetus for designing new, more fuel-efficient methods for such necessary activities as lime production. The ceramic data suggest that the annular pit-kilns were first constructed and used during the Late and Terminal Classic Periods. The AMS radiocarbon dates recovered from four of the kilns likewise supports a Late and Terminal Classic period of use for the pit-kilns. Thus, the combination of the chronological data, evidence for a population and construction boom and relative fuel-efficiency suggest that annular pit-kiln technology was deliberately developed to conserve fuel resources.

Landesque Capital

Landesque capital (Brookfield 1984; Fisher and Feinman 2005) refers to the investment in modifications to the physical environment in order to facilitate long-term benefits. My research demonstrates the significant investment made by the Prehispanic Maya in constructing and using permanent pit-kilns at Kiuic. My investigation also highlights the importance of examining production as being embedded in broader communal settings that involve numerous competing needs and trends. The development of annular pit-kiln technology should not solely be viewed as an independent policy decision on the part of lime producers or influential authorities in the community. Instead, lime production was one of several craft activities and industries that existed within the Kiuic community and contributed to both its socioeconomic structuring and reproduction. Thus, changes to the lime production industry such as the implementation of this new fuel-efficient technology during the Late-Terminal Classic Period were also the result of broader societal changes regarding resource management and land use strategies. The fact that similar annular pit-kilns have been identified at other Puuc sites such as Sayíl, Oxkintok and along the Sierrita de Ticul suggest that this technology may have developed on a sub-regional scale.

To this end, the construction of the annular pit-kilns can be viewed through the lens of landesque capital, meaning that the construction of structures for producing lime in specific locations throughout the landscape reflected a broader investment in landscape modification. Prior to the invention of the pit-kiln technology, the Prehispanic Maya of the Kiuic community would presumably have built open-air pyres similar to those used during the Colonial period and at Mayapán during the Post-Classic Period (ca. 1200 CE). Based on the modeling by Russell and Dahlin (2007) at Mayapán and through ethnographic research by Morris et al. (1931) and

Schreiner (2002), these open-air pyres were not situated in permanent locations but instead were located wherever stands of second-growth forest existed on the peripheries of the urban centers. This would have limited fuel transportation efforts. Two main land-use reasons may have also influenced the Prehispanic Maya of the Kiuic community to switch from building open-air pyres in new locations for each burn to using these fixed location annular lime pit-kilns: 1) The restriction of available land discussed earlier in this section; and 2) The increased efficiency afforded by continuously burning in the same location.

It is no surprise that the largest concentration of annular structures in the study area are located near the bases of these hills on the sides facing the Kiuic site center (66% of annular structures are located in the intermediate zone and 57% of these are located within 250 m of the inner zone). In restricting their lime production to permanent locations, the lime producers of Kiuic at least tried to balance fuel transportation efforts with post-production distribution transportation costs. Thus, the clustering of annular structures along the bases of the hillslopes reflects: 1) an avoidance of using the flat lands within the valley for non-agricultural/non-architectural purposes; 2) a desire to be as close as possible to existing stands of trees while avoiding construction on the steeper terrain further up the hills; and 3) an effort to limit post-production labor investments.

The experimental pit-kiln burnings elucidated another possible reason why Prehispanic lime producers in the Kiuic community repeatedly burned limestone in the same location. Each burn loosened up between 10-20 cm of the underlying bedrock/*sascab*, which made it easier to remove to use in a subsequent firing or for other purposes. Normally, it would require a significant effort to extract limestone and *sascab,* as was demonstrated through the difficulty we had removing these materials using modern iron implements. Thus, after each burn, lime

producers were presented both with easier access to limestone raw materials, and a deeper pit in which they could more efficiently burn the subsequent batch of limestone *chich*. Locating the annular structures near to or on top of *saakel bach tuunich* outcrops provided easy access to the most desirable grade of limestone for making lime. When the *sascab* layer was reached, the *sascab* was also loosened with each burn and more easily removed and put to other uses such as construction fill or as an aggregate in making lime plaster. The central pit continued to sink deeper with each burn, providing greater protection from the wind as well as the capacity to hold more fuel and raw materials for subsequent burns.

Continued investment in a permanent burning location was thus the result of both 'push' and 'pull' factors. Restriction of available land pushed lime producers to choose permanent locations for lime production. The structural and efficiency benefits provided by successive burnings in a permanent location likewise attracted them to this method of production as well. The investment in permanent firing locations resulted in long-term modifications to the landscape that likely influenced later resource management plans and settlement patterning. The significant depth of the majority of the annular structures excavated suggests that they were used over a long period of time and thus were important cultural features within the landscape.

Lime Production and the Socio-Economy

Craft Production Issues

The study of permanent lime production locales allows for the situating of this important industry into current frameworks for pre-modern craft production. Powdered lime was most definitely a craft good, as it requires a certain amount of skill and knowledge to efficiently construct a kiln or pyre and assemble the raw materials necessary to calcine limestone into

quicklime (Schreiner 2002; Al-Bashaireh 2008:41). According to Abrams, craft specialists are: "…those individuals who fill socioeconomic positions within which the specific and primary role is to produce and supply goods and/or services designed to meet a specific demand created by individuals who themselves do not produce or supply such goods and/or services" (Abrams 1987:486). While many people might have known the basic components of the lime production process, it is likely that lime specialists directed the actual production events (Abrams and Bolland 1999:283). These lime specialists may have learned their trade as apprentices in a guild-like group or from lime specialists within their small corporate groups. Those groups, such as the four or five elite residential groups located atop hills in the intermediate zone, that appeared to control their own annular pit-kilns likely had a lime specialist within the corporate group. However, despite the large number of annular pit-kilns in the study area, they do not come close to a one-to-one ratio with residential complexes (53 to 81) and thus it is unlikely that every corporate group was producing its own lime. Following Abrams's definition, the person or people that produced the lime for the non-producing families would therefore be considered specialists. While communal access to annular pit-kilns both near and far from the site center raises the possibility that each corporate group could have theoretically produced their own lime, the labor and resource investments involved lessen the likelihood of this scenario.

The issue of whether lime production should be a specialized craft is not as straightforward when we incorporate other suggested qualifications for defining specialized craft production. One of the archaeological indicators used to identify specialized crafting is the homogeneity of products, which is thought to reflect standardization of production (Blackman et al. 1993). While we cannot study the product per se, we can study the production technology in the form of the annular structures. The proliferation of annular kilns throughout the landscape of

Kiuic indicates that there was some level of standardization, albeit with minor variations in the form and quality of the general pit-kiln technology. An example from the Central Mexican area of Tepeaca demonstrates how the lime industry's place along the continuum of specialized craft production should be judged on a case-by-case basis. After excavating several small pit-kilns in the Tepeaca Basin, Castanzo and colleagues determined that the size and crudeness of these kilns indicated a low degree of specialization, suggesting part-time lime production (Castanzo 2004). This is interesting not just because Castanzo does not believe lime production to have been a specialized industry in this region, but that he equates part-time production with lower standards of quality. Other studies have shown that part-time craft production should not be equated with lower skill in production or lower quality products, but instead should be viewed within the context of multi-crafting or multiple subsistence strategies on the part of households (Hirth 2006, 2009; Gonlin 2012; Masson et al. 2016).

As there are different grades of lime powder produced today, there were likely different grades or types of lime powder produced in Prehispanic times (Carmean et al. 2011). Different grades may have been based both on the raw materials used in the production process and the length of time that the burnt lime was allowed to site and 'mature.' This line of reasoning does not stem from the direct historical approach or carelessly projecting modern circumstances back thousands of years, but rather from preliminary analyses of lime plaster and stucco recovered from various Prehispanic Maya centers (Littmann 1959, 1960, 1966; Carmean et al. 2011; Murakami et al. 2013). There are different types and grades of limestone that yield different types and grades of lime powder that would then be used to produce different types and grades of products including plasters, mortars, and lime for nixtamalization. Thus, while lime might generally be considered a utilitarian material, there were likely certain grades of lime that were

more highly valued and thus restricted in their production, distribution and consumption. Following this line of reasoning, lime powder might be best viewed on a spectrum from utilitarian to prestige-level materials. It is possible that the larger, more regularly formed double-ring pit-kilns of the site center reflect a greater level of technical skill or knowledge on the part of elite corporate groups and may have been used to produce higher quality lime. Future analyses of different reconstituted calcium carbonate samples from the different annular structures may shed light on whether pit-kilns associated with different structure types or residential groups were used to produce different qualities of lime.

Decentralized Small-Scale Lime Production

The distributional and contextual data are strongly consistent with a decentralized, small-scale organization scheme for lime production at Kiuic. This has implications for understanding how small corporate groups may have used lime production to provision both themselves and the Kiuic state. The Kiuic lime production model serves as a framework for understanding smaller community political and socio-economic organization schemes, and how they articulated with domestic-level production organization.

Agricultural production in the Puuc was largely limited to rainy half of the year and much of the arable land was likely controlled by a restricted number of wealthy families (Gallareta Negrón et al. 2014). Under these circumstances, multi-crafting strategies were likely an important way for both landowning and sub-elite groups to supplement their income and ensure their survival. According to Brumfiel and Nichols (2008) part-time craft production "…should typify the vast majority of Prehispanic societies…" (Brumfiel and Nichols 2008:241). Lime production is an ideal candidate for incorporation into a multi-crafting, part-time production

strategy. First off, lime production was likely restricted to certain parts of the year, which means that like agriculture it would not have been the only means of subsistence for those corporate groups that practiced it. Secondly, the substantial amount of raw materials and labor involved, suggests that these may have been limiting factors that restricted year-round production, especially with more than 50 pit-kilns operating in the community. Approaching lime production as part of a multi-crafting strategy is consistent with the distributional and contextual data and provides a basis for understanding its role within the broader polity-wide and perhaps even society-wide socio-economy.

The six annular structures located in the inner zone (minus the abnormal one in Patio A of the Yaxche Group) are all associated with residential compounds that likely represent the residences of small corporate groups. However, the majority of residential compounds within and around the Kiuic inner zone are not directly associated with an annular structure. The presence of the isolated pit-kilns in the outer and intermediate zones suggests that some households or small corporate groups deliberately located their lime production locales away from their residences. This removed production scenario is similar to that outlined for Aztec salt-producing households (De León 2009). The importance of wood fuel in the face of dwindling resources and the significant labor requirements for lime production at these isolated sites suggests that they were used and possibly controlled by small corporate groups. It is likely that specialists directed the lime production process either as members of these groups or as independent artisans brought in on an intermittent basis to oversee production episodes.

The importance of lime to so many aspects of daily life likely led to a fairly constant demand for the product and thus it was likely a reliable additional source of income. Most lime-producing groups with access to at least one annular structure were likely able to produce much

more lime in one or two burns than they consumed annually for both dietary and architectural purposes. This extra lime could potentially have been stored for later use, but there are no locations yet identified as storage units aside from the pit-kilns themselves. More likely, the lime-producing groups distributed their extra lime to groups that did not produce their own lime. They also would have contributed lime for the construction of the monumental buildings at the site center and to meet the dietary needs of the governing authorities. The fact that non-producing groups still required lime for a multitude of daily activities suggests that they were acquiring it from groups or independent specialists that produced it. Thus, small corporate groups that did produce lime could have used it as a means of supplemental income.

Gunn's (2015) study of pottery distribution at Kiuic indicates that market exchange existed from early on in the Late Classic Period at Kiuic and expanded through the Terminal Classic Period. The universal consumption and restricted production of lime suggests that it may have been exchanged within the same market networks as the ceramics. The location of at least 16 annular structures within the confines of residential compounds suggests that at least some small-scale producers maintained a degree of autonomy in their production activities. The presence of the 11 annular structures identified in the outer zone of the study area, far from residential compounds and outside the confines of the Kiuic Valley, further suggests a lack of centralized oversight. It is difficult to identify any centralized control over the the lime distribution economy without the clustering of all annular structures in one place or large facilities for gathering and storing lime before redistribution. However, the absence of these indicators does not preclude the possibility that central authorities controlled some aspects of the lime industry by restricting access to raw materials. The available spatial and contextual data are most consistent with a tax or tribute-based political economy, similar to the systems recorded for

early 16th-century CE Yucatecan polities (Foias 2002:226) and Central Mexican city-states (Palma Linares 2009:231). In this scenario, small-scale producers would provide some of their products to the central governing authorities on a regular basis and/or whenever monumental construction episodes took place at the site center.

Seasonal Production

The requirement of at least a 20-hour dry period for the production process and availability of labor suggest that lime production mainly occurred during the dry half of the year. However, arguing against this notion of lime production being restricted to the dry season is the necessity of water to slake the resulting quicklime before it can be used as hydrated lime for dietary or construction purposes. The weather patterns in the Puuc region also affected the nature and organization of lime production, as a fairly predictable rainy season likely limited production to the dry half of the year (December through May). Nearly 90% of precipitation occurs between the months of August and January in the Eastern Puuc (McAnany 1990). The calcining of limestone requires a dry period of at least 20 hours and often longer (Abrams 1987; Russell and Dahlin 2007). Thus, avoidance of rainfall episodes ruining a burning episode would be an argument for limiting lime burning to the dry season. Furthermore, the fact that the agricultural season coincides with the rainy months of the year provides another reason to believe that lime production was limited to the dry season. Labor that would normally have been put towards agricultural pursuits was freed up during the drier months for other endeavors, such as lime production and construction. Not to mention the fact that frequent rain during the wetter months likely turned the open annular pit-kilns into intermittent wells with standing water at the bottom.

Although it would be possible to hydrate the lime manually, a scenario reflected by the location of several annular structures near to water storage features, reliable rainfall episodes would have provided a much more labor cost-effective strategy for hydrating the quicklime. Russell and Dahlin (2007) suggest that the benefit of rainfall resulted in the restriction of lime production to the rainy season. The experimental burns conducted as part of this investigation, one during the dry season and one during the wet season, demonstrated the risks and rewards that attend production in either season. It is possible that lime producers that needed to complete multiple burns in quick succession burned their lime during the rainy season when the resulting quicklime could have been quickly slaked. This would limit the labor investments necessary for transporting water and acquiring the water in the first place. On the other hand, producers of high quality architectural lime production that required a long maturation period may have burned lime during the dry season when time was not a factor.

Overall, the evidence favors a restriction of production to the dry season and perhaps the purposeful use of annular pit-kilns as temporary wells during the rainy season. A seasonal production scheme supports the notion that lime production was a part-time craft activity and likely part of multi-crafting small-scale subsistence strategies. Lime specialists, or at least those employed in the gathering and assembling of raw materials for lime production episodes likely pursued different specialties or practiced different occupations at other times of the year.

Inner Zone Case Study – Pixoy Group

Six of the seven annular structures located in the inner zone are spatially affiliated with either a residential compound. Those inner zone residential compounds that do have direct access to an annular structure are located near just one. This suggests that access to an efficient lime pit-

kiln allowed these inner zone residential or corporate groups to produce enough lime to be self-sufficient in terms of their architectural and dietary lime requirements. As suggested by the multi-crafting subsistence model, they may have even produced lime surpluses in order to supplement the income of the corporate group. Here I estimate the labor and raw material requirements, as well as the lime production output for the Pixoy Group.

The Pixoy Group is located on a low, long ridge of limestone outcrops approximately 250m to the northwest of the Yaxche Group of the site center (Gallareta Negrón et al. 2002:2-6). Taking into account the maximum possible extent of this residential complex, it consists of five platforms/terraces, eight masonry structures (at least five of which would likely have been residential), and one stone-vaulted structure located atop a small pyramid. The group is laid out roughly in the shape of the number 7, with the sole annular structure located at the corner of the '7' (Figure 9-1). Close to the kiln are a fairly large limestone quarry and two small *haltúns*, which were likely useful for lime production activities. The annular structure is composed of a double-walled ring surrounding an interior pit that measures 3.1 meters in diameter and approximately 4.2 m deep (Figure 9-2). Evidence for repeated lime burning episodes were recovered from the excavation of this structure during the 2014 summer field season.

I draw on data regarding lime consumption gathered by Russell and Dahlin (2007:418) from contemporary informants from the village of Chunchucmil in the Northwestern Yucatán to estimate that the average person consumes approximately 0.0160396 cu m of lime per year (8.1 kg per year / 505 kg per cu m density). Based on ethnographic information they also estimated that the average residence required 2 cu m of lime to construct, a ceremonial structure required 6 cu m of lime, and a miscellaneous structure required just 1 cu m of lime. They drew on Abrams's (1994:75) study of architectural energetics at Copán to estimate that each structure would require

1/5 of its original lime input each year post-construction for maintenance purposes (Russell and Dahlin 2007:418). Russell and Dahlin specifically presented their calculations and estimates in terms of burnt lime consumption and not lime *plaster* consumption, which would have involved discerning local lime-to-aggregate ratio averages.

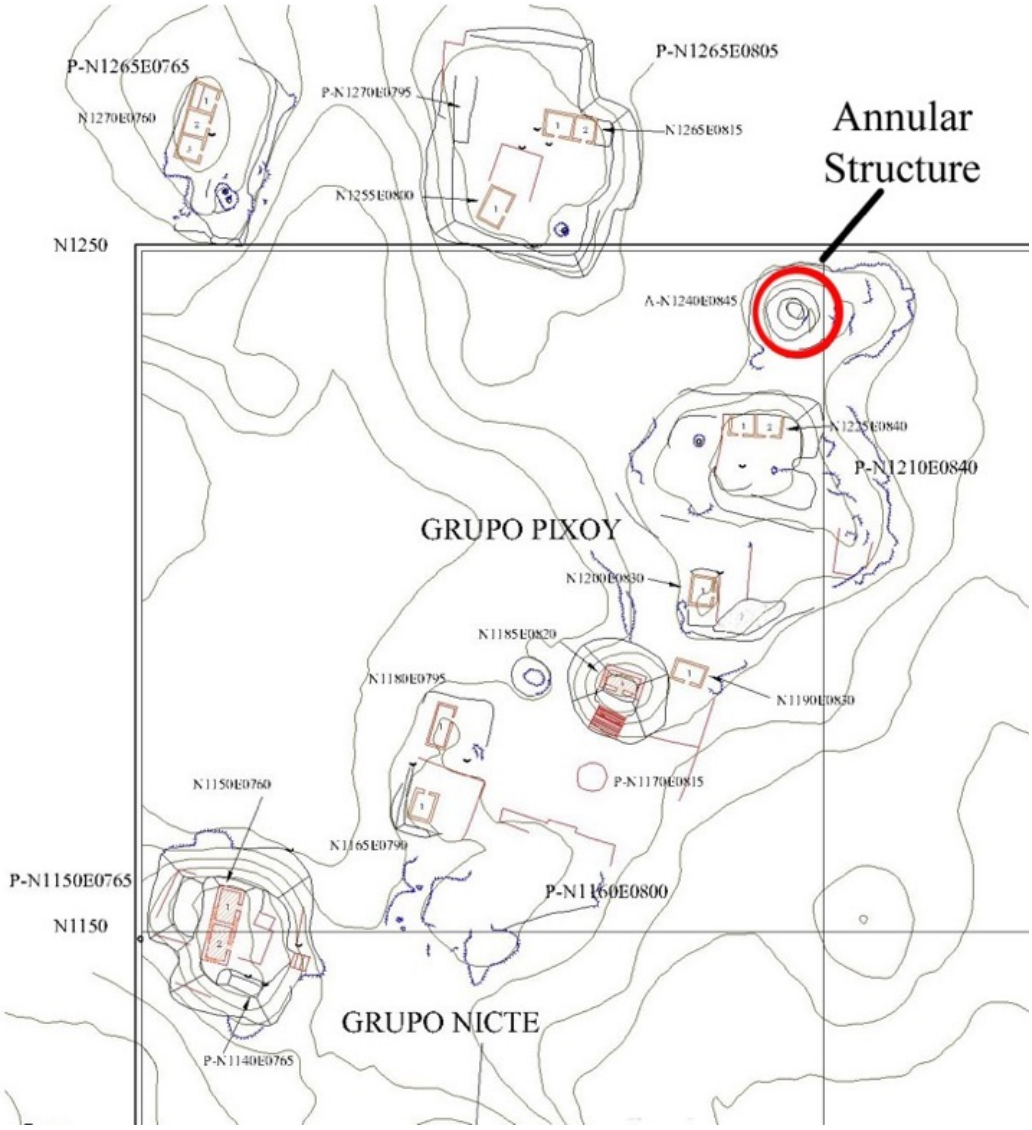


Figure 9-1: Map of the Pixoy Group highlighting the location of the annular structure (Gallareta Negrón et al. 2014).



Figure 9-2: Photograph of the north interior wall of the Pixoy Group annular structure.

All of the structures located within the Pixoy Group are believed to have supported a Late and Terminal Classic Period occupation. Based on the number of likely residential structures (n = >5) and number of total rooms in these structures (n = >9), I estimate that the Pixoy residential or corporate group consisted of at least 9-27 members (assuming 1-3 people could have occupied each room). This results in a range of lime consumption for dietary purposes of 0.14-0.43 cu m. Disregarding the lime necessary for the original construction of the group's structures, annual architectural maintenance requirements would equal roughly 4.8 cu m per year (0.4 cu m per masonry structure and 1.2 cu m for the small pyramid). At most an additional 1 cu m of lime may have been used for miscellaneous uses such as agricultural, maize storage or extra

architectural purposes. Thus, I estimate that the group or groups that inhabited the Pixoy complex used approximately 6 cu m of lime annually. In order to estimate the amount of lime that may have been produced in the Pixoy lime kiln with each episode, I used the ratio of 3.94:1 fuel-to-lime calculated from the second lime kiln experiment. The final interior volume of the Pixoy lime kin is a little less than 31.7 cu m (π x 1.55m^2 x 4.2m). Using the 3.94:1 ratio, and assuming the central pit was filled to capacity, the Pixoy lime producers were able to produce as much as 6.4 cu m of lime per burn (31.7/4.94) (Table 9-1).

Table 9-1: The volume of raw materials used for lime production in the final form of the Pixoy annular pit-kiln.

Material	**Volume (cu m)**	**Hours of labor required to assemble**
Wood	25.3	177.1
Raw Limestone	6.4	44.8
Total	31.7	221.9

Table 9-2: Estimation of the labor force required to complete the assembly of lime production materials in different amounts of time.

Labor force	**Number of person-hours required**	**Days Required (12-hour work days)**	**Days Required (10-hour work days)**	**Days Required (8-hour work days)**
5	44.4	3.7	4.4	5.6
10	22.2	1.9	2.2	2.8
15	14.8	1.2	1.5	1.9
20	11.1	0.9	1.1	1.4

A maximum capacity burn in the Pixoy annular pit-kiln includes a maximum estimated quantity of approximately 25.2 cu m of wood fuel used per burn in the final form of the Pixoy pit-kiln (3.94 x 6.4 cu m). Russell and Dahlin (2007:419) calculated that 900 sq m of wooded area was required to produce 0.5 cu m of lime. This translates to 1800 sq m of wooded area per 1 cu m of burnt lime. Their estimate was based on their own lime production experiment, which produced burnt lime with a ratio of approximately 8.5:1 wood fuel to lime. Substituting my 3.94:1 ratio recorded during the second experimental pit-kiln burn would reduce the amount of wooded area necessary to produce 1 cu m of burnt lime from 1800 sq m to approximately 835 sq m (or a little less than a 30 m x 30 m patch). Using 835 sq m of wooded land per 1 cu m of lime as a rough estimate, an ideal production episode in the Pixoy pit-kiln that resulted in 6.4 cu m of burnt lime would require ~5,345 sq m of forest to be cut down, or roughly a 73 m x 73 m patch. It is unclear how many trees would have been cultivated for fuel within the Terminal Classic Period Pixoy compound, but it is likely the bulk of wood fuel would have come from the slopes of the hills that ringed the valley suggests that annual lime production could have been sustained by gathering wood from these areas. Conversely, an aboveground pyre with a fuel-to-product ratio of around 8.5:1 would require approximately 11,520 sq m of wooded land to be cut down (or a 107 m x 107 m). Considering that there were at least 52 other annular structures in use at Kiuic during the Late and Terminal Classic Periods, and that trees would ideally need at least 25 years to regenerate (Russell and Dahlin 2007:419-420), the pit-kiln provided a much more fuel-sustainable method of lime production.

During my lime production experiment I recorded that approximately 28 person-hours of labor were required to gather the raw materials for my burns that used approximately 4 cu m of raw materials (wood and limestone). This results in a rough estimate of 7 person-hours necessary

to gather 1 cu m of raw materials. The Pixoy pit-kiln in its final form could hold 31.7 cu m of raw materials, which would have required an estimated ~222 person-hours of labor (31.7 x 7). Using an estimated residential population of approximately 20 persons within the Terminal Classic Pixoy Group, perhaps half of these would have been able-bodied workers that could have participated in lime production episodes. Ten workers would require about two ten-hour workdays to meet the labor requirements for gathering the raw materials for the burn (Table 9-2). Labor requirements were likely greater if the bulk of the fuel wood was harvested from distant hillslopes. In order to limit the overall production time, the Pixoy corporate group may have either combined their efforts with other corporate groups and shared the resulting burnt lime, or employed laborers from outside the corporate group. Either way, the labor required for the lime production episodes was likely organized at the small corporate group level.

Based on these estimates, the residents of the Pixoy Group required approximately only one full-scale lime production episode in their annular kiln per year to supply their own annual lime needs. Two production events almost certainly covered their annual consumption needs. The appropriation of wood fuel would thus most likely have been the limiting factor in the amount of burns conducted annually, as lime requirements would appear to have been met rather easily. However, having invested in the construction of the kiln it is quite possible that the Pixoy corporate group(s) purposely produced surpluses for exchange with non-producing groups.

Isolated Production

I have proposed that the most likely circumstances leading to the high concentration of annular pit-kilns on the periphery of the inner zone was a balance in proximity to the centers of lime consumption and access to the raw materials, as well as a desire to reserve flat land for

agricultural purposes. What factors influenced the construction of several isolated lime kilns in the intermediate and outer zones? Desire to limit the hazardous effects of smoke pollution, powdered lime dust pollution, and quicklime burns may have factored into the decision to locate production areas away from residences, but this does not explain why some structures are so remote. In this section I discuss the logistics involved in lime production at relatively isolated locations based on data gathered during the experimental kiln firings.

Four of the fifteen intermediate zone annular structures located more than 250 meters outside the inner zone are located near no other archaeological feature except the crude limestone foundation of a small perishable structure, or *pasel*. Nine out of the eleven outer area annular structures in the study area are likewise isolated from all other archaeological features except *paseles*. Weighing construction labor efforts against the transportation efforts of the powdered lime product, the most likely scenario is that these isolated annular structures were the sites of intermittent lime production events.

Although the farthest of these isolated annular kilns is only approximately 2 km from the inner zone as the crow flies, the actual ground routes from the hinterlands to the residential groups within the intermediate and inner zones were longer. Powdered lime is heavy and thus it is unlikely that there was daily transportation of the finished product from these isolated sites. It is also unlikely that these isolated structures, especially the larger ones like Annular Structure 6, were constructed for a single production episode. The experimental construction of an annular kiln in February 2015 demonstrated the difficulty of excavating through the bedrock of a limestone outcrop and the layer of *sascab* below. Nearly 180 person hours were required to excavate a 3-meter diameter pit into the side of a limestone outcrop to a depth of 40 cm below the level surface at the base of the outcrop, and this was accomplished using iron tools. The

tremendous amount of effort that went into excavating the 2.5-meter-plus annular structures in the outer hinterlands to the west of the intermediate hills suggests that they were used repeatedly in the production of lime. The absence of permanent residential structures coupled with the significant labor investment in the construction of the kilns themselves thus points to these isolated annular structures being the sites of periodic lime production camps. Additionally, no artifacts involved in food production such as *metates* for grinding maize were found near any of these isolated structures. This indicates that the workers producing the lime at these locations were either traveling to the production site daily during production periods, or bringing with them a multiple days' supply of sustenance.

The mechanics of lime production are such that labor intensiveness is cyclical. Once a tremendous amount of labor had been expended to dig the central pits and build the annular structures, approximately 28 person hours of labor were required to assemble the fuel and raw limestone necessary for our burn that required approximately 4 cu m of raw materials. After the materials were assembled in the pit-kiln and the fire was started, only one or two individuals were required to oversee the 20-30 hours of the burn. Assuming consecutive firing episodes at the same kiln, this day of diminished labor requirements would be followed by increased labor input once again. After each burn laborers had to gather and apply the water necessary to slake the quicklime and then remove the resulting powdered lime from the pit-kilns. This would theoretically be followed by a repetition of the production cycle until the desired amount of powdered lime had been produced. In this scenario, the laborers who assembled the fuel and raw materials and then slaked and excavated the powdered lime from the pit-kiln would be able to return to their residences while only one or two individuals stayed to oversee the entirety of the burning episode.

Eight out of the thirteen ‘isolated’ annular structures (those located more than 150 meters from the nearest platform, terrace, or vaulted structure) are located in close proximity to *pasel* foundations, and three of these eight are located near multiple paseles and other lime industry features. Annular Structure N2224600E0231100 (UTM coordinates) is located approximately 1.2 km to the northwest of the westernmost intermediate zone residential complex and is situated atop a small limestone outcrop within 80 meters of three pasel foundations that are likewise situated atop elevated rocky land (Figure 9-3). I discussed earlier how the paseles were most likely constructed for use by agriculturalists in a similar manner to maize farmers in the region today. However, if agricultural production and lime production were both seasonal activities practiced at opposite times of the year, it is possible that some paseles could have been used by both lime producers and farmers. These paseles could have thus been used as temporary shelters by the laborers who worked at the lime pit-kiln and/or the individuals who oversaw the day-long burning episodes carried out in the pit-kiln. A similar pattern of paseles surrounds Annular Structure N2224424E0231206, in addition to two groups of chich mounds that were also likely associated with the lime kiln. A final example of these outer area lime production camps is provided by Annular Structure N2224251E0231745, which is surrounded by 4 paseles, a quarry, and located approximately 80 meters from a *haltún*.

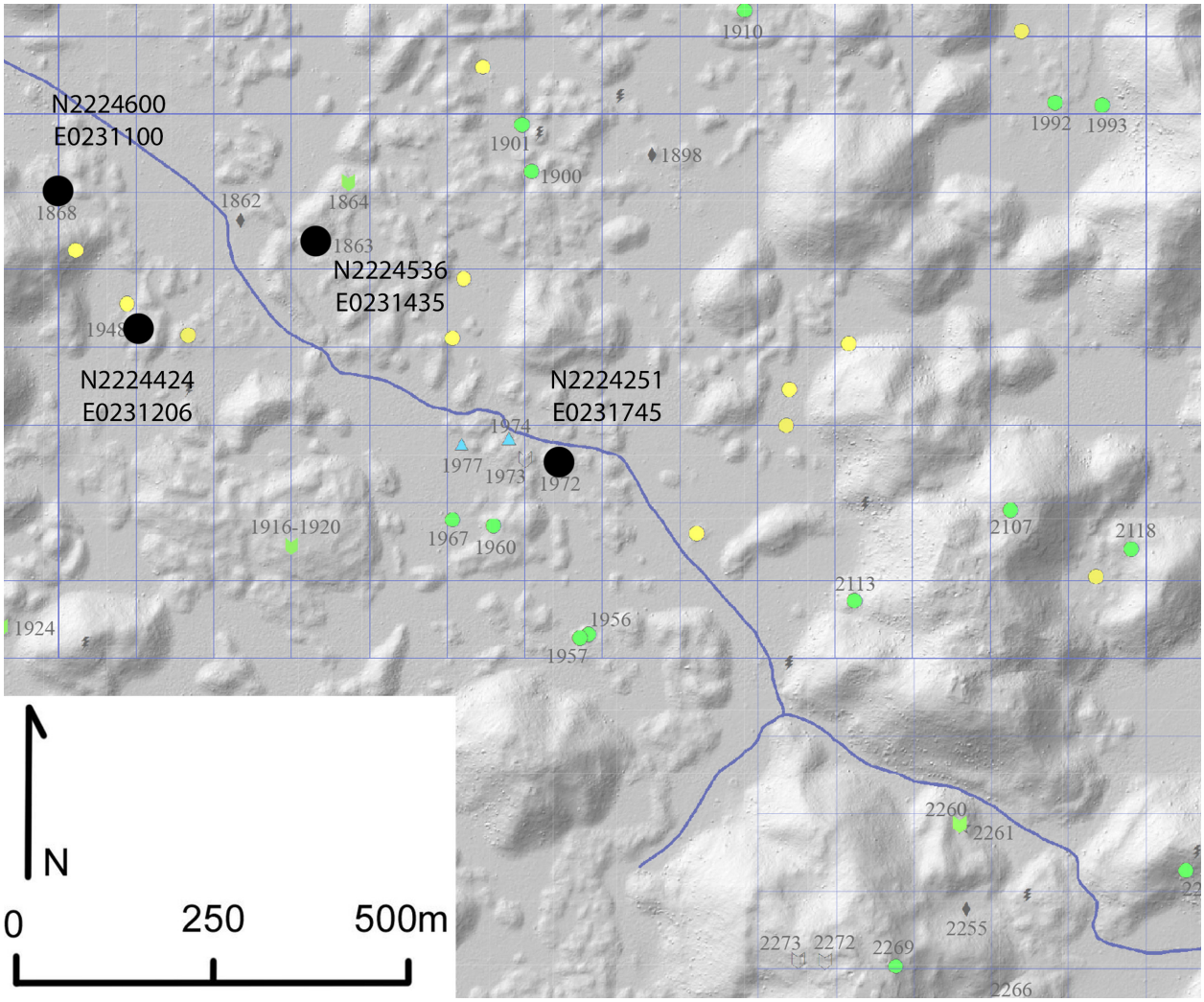


Figure 9-3: The locations of the four isolated annular structures discussed in this section (adapted from Gallareta Negron et al. 2014).

The reason for the establishment of these annular pit-kilns in the hinterlands might relate to high concentrations of *saakel bach tuunich* limestone at these locales. Producers likely endeavored to limit the transportation efforts of the raw limestone and it is thus makes sense that they would construct the kilns near to the source of the raw limestone materials. Just as engineers knew which grades of limestone were more suitable for construction purposes (Carmean et al. 2011), lime producers knew which grades of limestone were best for producing high quality lime. The desire for certain types of raw materials would explain the seemingly far-flung

distribution of several of these outer area kilns when transportation effort was an important factor to consider.

The chronological data provide an additional dimension with which to address the isolated production issue. The expansion of lime production activities into the outer hinterlands of Kiuic, far from the population and architectural clusters that required the lime may have reflected the diminishing availability of wood fuel within the Kiuic polity core. The AMS radiocarbon date for Annular Structure 1 in the inner core places its use around 675-775 Cal AD at 2σ). Annular Structures 4 and 8, both located in the intermediate zone, were dated to 675-775 Cal AD at 2σ and 688-887 Cal AD at 2σ, respectively. While all of these include rather wide ranges, the earlier edge of this range appears to date to the 7th century CE and thus to the beginning of the Late Classic-Terminal Classic transition population and construction boom. The sole radiocarbon date available for one of the hinterland annular structures (766-892 cal AD at 2σ for Annular Structure 6) places its period of use at least a century after this. Likewise, while many of the annular structures excavated in the polity core had at least some evidence of Late Classic ceramics in the structure fill, the two hinterland structures excavated only had Terminal Classic ceramic sherds in their fill. While the sample size is admittedly very small, it raises the possibility that changes in the fuel availability over time influenced the construction of these more far-flung annular structures. Isolated production increased post-production transportation efforts for the burnt lime. However, locating the hinterland structures near to *saakel bach tuunich* outcrops and remaining wood fuel sources limited overall production investments.

Conclusion

The annular structures identified in and around the Prehispanic community of Kiuic in the Eastern Puuc region of the Northern Maya Lowlands were used as fuel-efficient pit-kilns for producing burnt lime. The data suggest that the Maya of the Eastern Puuc developed the annular pit-kiln technology during the Late and Terminal Classic Periods (ca. 650-850 CE) in response to a rapid demographic expansion that stressed environmental resources. The demographic and construction boom that occurred at this time led to the clearing of large swaths of land for agricultural activities at the same time demand would have increased for burnt lime for dietary, architectural and other purposes. Available wood fuel resources were likely increasingly limited to the hill-slopes that surrounded the Kiuic Valley where the site center was located. In the face of growing demand and dwindling resources, the lime pit-kilns provided a more fuel-efficient method to produce lime compared with aboveground open-air pyres. The concentration of annular structures in the intermediate hill zone just outside the most densely populated area of the inner zone suggests that the Prehispanic lime producers sought to locate their kilns as close to the available fuel resources as possible while limiting post-production transportation investments.

The chronological data suggest that fuel-efficiency was a significant factor influencing the development and use of the annular pit-kiln technology. The widespread use of annular pit-kilns during the Late and Terminal Classic Periods suggests that many if not all of the lime producing corporate groups at Kiuic opted for the more fuel-efficient technique at at time of demographic stress. In terms of labor efforts, aboveground pyres were cheaper and easier to construct and use for lime production. Devoting the resources to the initial creation and then the maintenance and expansion of annular pit-kilns reflects a concerted effort to achieve a goal that

would likely have greater benefits in the long run. A depletion in fuel would affect all members of the community who relied on wood not just for building, cooking, and warmth, but for the production of lime necessary for dietary purposes as well. It is unclear whether this was a top-down policy decision or the result of a more communal decision, but the fact that annular structures were built and used throughout the polity beginning around the same time suggests that most lime producers embraced the pit-kiln technology around the same time.

Previous research on sociopolitical trends in the Puuc points to the development of a power-sharing form of government in the Western Puuc during the Late Classic that spread to the Eastern Puuc and may have culminated with the *multepal* system at Chichén Itzá (Cobos 2007; Gunn 2015). At a smaller community like Kiuic, where large sectors of the population likely interacted on a frequent basis, communal decisions about land-use strategies would have been more viable than at the larger Classic Period centers to the South. The smaller-scale of Kiuic allows for such a study and demonstrates the importance of investigating production and consumption at both the small corporate- and polity- scales.

The distribution of the annular pit-kilns across the inner, intermediate, and outer zones of Kiuic suggest a largely decentralized lime production industry. Some small corporate groups, especially those residing in hilltop compounds to the west of the site center, possessed their own large annular pit-kilns. These groups likely produced lime for their own consumption as well as for exchange with non-producing groups. The fact that all social groups within the polity required burnt lime for a variety of daily activities and yet not all appear to have produced their own suggests that some sort of exchange system existed for the distribution of lime throughout the Prehispanic Kiuic community. Previous studies of ceramics suggest that vessels were distributed at Kiuic through both market and gift-giving exchange systems. Lime and lime

products span a spectrum of utilitarian and prestige purposes, similar to ceramics, which suggests that lime may have been exchanged through the same or similar intra-community distribution networks. Ruling groups at the site center consumed lime just like any other small corporate group but didn't necessarily produce lime or oversee the production of lime themselves. The lack of evidence for any centralized control of lime production leaves a tax or tribute system as the most likely system for lime-producing households to provision the state. Thus, the lime production industry was at the crux of multi-crafting domestic subsistence strategies and the overarching political economy of the Kiuic polity.

Lime production became an increasingly important economic activity throughout the Late and Terminal Classic Periods as construction programs expanded and a growing population required more nixtamalized maize. Increased demand for lime likely made lime production an important part-time craft activity and a valuable alternative source of income for those small corporate groups that produced it. The amount of labor required for the construction of the pit-kilns, the gathering of raw materials for burns, and the slaking and removal of burnt lime following the burn suggests that production episodes were organized at the small corporate level and directed by specialists. The several stages involved in lime production suggest that different specialists may have directed different steps in the production process and also provided elites or central governing authorities with opportunities to control different aspects of the industry. Thus, although the *production* of lime in pit-kilns was decentralized and dispersed throughout the community, this does not preclude some degree of centralized control over certain stages in the lime production process. Lime production also factored greatly into resource management policies within the Prehispanic Kiuic community, for while the forests of the polity core may have initially provided plenty of fuel to meet annual consumption needs, gradual increases in

demand over time likely depleted available resources. The importance of lime for daily activities, its restricted production, and the stress that its production placed on local forest resources combine to suggest that burnt lime production was a significant local industry that played an important role in the local socio-economy.

This study contributes to a growing body of work that focuses on the articulation of small-scale subsistence strategies with broader community-wide networks in pre-modern societies. The Kiuic lime production investigation introduces a discussion of the Prehispanic lime industry into socioeconomic frameworks that were developed for the study of more durable goods like ceramics and lithics. It highlights the importance of considering the impacts of the production and distribution of similarly perishable craft goods within pre-modern economies that may not be readily visible in the archaeological record. This case study also introduced evidence that the Prehispanic Maya took steps to increase the fuel efficiency of their production methods in the face of demographic stress. The Prehispanic Maya of the Eastern Puuc took steps to increase the efficiency of their fuel consumption and were able to sustain a rapidly growing population through a period of sociopolitical turmoil and decline elsewhere in the Maya area. With regard to pre-modern human-environment relationships more broadly, the Kiuic case study demonstrates the importance of using multiple research scales to consider how small-scale subsistence practices structured and were structured by community-wide developments.

Future Directions

The research presented in this dissertation provides a strong foundation for continuing to investigate the socio-economic and ecological importance of the Prehispanic lime production

industry in both the Puuc region and beyond. Future areas of study include trying to source the lime products used in different architectural projects to different kilns or quarry systems, though this will be difficult. More achievable may be an in-depth study of the quality of the lime produced in the already excavated kilns and evaluating the quality of the lime products used in different compounds throughout the Kiuic polity. Other important areas of investigation center on the continued mapping of the eastern side of the Kiuic Valley to fill in settlement data gaps and allow for more viable population and consumption estimates. Knowing exactly how many vaulted buildings and annular structures are located to the east of the site center may require the tweaking of parts of my proposed models for the socioeconomic organization of lime production. An in-depth analysis of soil variation in the Prehispanic Kiuic community would also help to provide a more detailed understanding of where the most productive agriculture lands may have been within the polity and whether this influenced where lime kilns were constructed.

The excavations of more annular structures in the future will help to either support or refute some of the postulations that I put forth during this investigation. It is always possible that the randomly chosen nine annular structures were not representative of the forms and functions of the broader category of structures. Thus, future projects may excavate more annular structures to shore up the lime production data. Future studies at Kiuic may also use the socioeconomic data gathered during this investigation as a starting point for examining broader socioeconomic differences within the Kiuic polity. Understanding what sorts of multi-crafting strategies were available to households of disparate socioeconomic means would go a long way towards narrowing the gap between what is known about elites in Prehispanic Maya society versus non-elites. It is even possible that non-elite members of the community did not experience the rapid abandonment and/or collapse of the local sociopolitical system in the same way that elites living

in the site center did. Future studies of lime production should also investigate other sites around the Puuc Region where annular structures are present to compare lime production organization schemes with the models proposed here for Kiuic.

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Appendix A: Survey of Annular Structures in and around Kiuic

In this Appendix I present a brief summary of the characteristics of a sample of 43 annular structures identified during the Labná-Kiuic inter-site survey by Gallareta Negrón and colleagues and the mapping of the Kiuic site center by William Ringle and colleagues (Gallareta Negrón et al. 2000-2014). The annular structures are categorized into inner, intermediate and outer zones. I note their forms as they appear in the archaeological record and their locations within the broader Kiuic landscape and topography. This appendix does not include those annular structures selected for systematic excavation.

Inner Zone

Annular Structure N0810 E1140

East: 0233362, North: 2224012

Figures: A-1, A-2

This structure is situated upon and within a low limestone outcrop located alongside the modern road that leads into the Kiuic site center from the south. It is located amidst several residential complexes just to the east of the base of a hill. This structure uses much of the natural limestone outcrop to form the interior and exterior walls of the structure. Several very large, crude boulders are placed in a ring formation atop the natural outcrop, defining the exterior wall of what appears to have been a double-ring construction, though almost all of the interior ring stones have fallen into the central depression. The exterior walls, partially made up of the bedrock outcrop, are covered with small stones (*chich*), a large portion of which exhibit evidence of having been exposed to flame. A small depression is half-covered by the fill collapse of the southeastern side and appears to be the remnants of a *sascabera*.

Measurements: The internal depression is a rough circle measuring approximately 2.8 m in diameter. The maximum diameter of the ring formed by the apical double-wall is 4.3 m. The maximum extent of the fill collapse measures 15 m N-S by 16 m E-W in diameter. The highest standing point of the structure measures 2.3 m in height above the surrounding terrain. The largest stone used in the apical ring measures 85 x 75 x 44 cm, while the average size of stones used in the apical ring is 68 x 61 x 47 cm.



Figure A-1: View of the sascabera adjacent to and partially beneath Annular Structure N0810 E1140 (Photograph by K. Seligson, 2013).



Figure A-2: The interior of Annular Structure N0810 E1140 (Photography by K. Seligson, 2013).

Annular Structure N0795 E1245

East: 0233468, North: 2224001

Figures: A-3, A-4, A-5

This structure is located in the southeastern sector of the Kiuic inner zone, about 250 m to the southeast of the Yaxche Group. It is built into a gentle incline approximately 100 m to the east of Annular Structure East: 0233362 North: 2224012, near a group of limestone quarries and two small platforms with vaulted structures. The incline that this structure is built into slopes from south down to north. Thus, the terrain to the south of the ring continues to slope slightly upward, while the terrain to the north and northeast slopes down approximately 2.35 m to the surrounding flatter terrain. The surface of this northern slope is littered with burnt *chich* similar to the scatter found around most of the annular structures. While many of the larger stones of the northern ring

have either fallen down the slope or into the central depression, the southern side remains relatively intact, demonstrating the original double-wall structure of the ring. Both walls of the rings are constructed of crude large boulders, some of which have moss growing on them, which is often an indicator of the remnants of lime plaster.

Measurements: The internal depression is a rough circle measuring approximately 3.5 m in diameter. The maximum diameter of the ring formed by the apical double-wall is 6.1 m. The maximum extent of the fill collapse measures 13.3 m N-S by 11.5 m E-W in diameter. The highest standing point of the structure measures 2.35 m in height above the surrounding terrain (to the north). The largest stone used in the apical ring measures 85 x 60 x 30 cm, while the average size of stones used in the apical ring is 66 x 55 x 46 cm.



Figure A-3: Ring of Annular Structure N0795 E1245 (Photograph by K. Seligson, 2013).



Figure A-4: Burnt *chich* on the slope below Annular Structure N0795 E1245 (Photograph by K. Seligson, 2013).



Figure A-5: View of Annular Structure N0795 E1245 from the north looking south up the slope (Photograph by K. Seligson, 2013).

Annular Structure N0980 E0750

East: 0232970, North: 2224071

Figures: A-6, A-7

This structure is located approximately 100 m to the west of the Chulul Palace Group of the Kiuic site center. It is located atop a small hill near a small *sascabera* and a few small limestone outcrops that appear to have served as quarries. The annular structure is located on the south side of the hill, halfway down the slope, so that the terrain to the north continues to slope upward, while the scatter of the collapse falls approximately 3.05 m down to the base of the hill to the south and southwest. The north and northwest sides of the interior wall of the structure are cut directly into the limestone bedrock of the hill. There are three large boulders on the east side of the structure that represent the original exterior arc of the structure while majority of the ring's stones appear to have either fallen into the central depression or down the southern slope. Beneath the three stones, the eastern wall is made out of a cut in the bedrock in which there is a hole that potentially crossed through the wall when the structure was still in use. In addition to the partially burnt *chich* scattered down the slope, the bedrock of the northern interior wall exhibits evidence of burning in the form of blackened coloring. A portion of the northern wall has fallen off into the central depression, giving the structure's central depression a teardrop shape.

Measurements: The internal depression is a rough circle measuring approximately 4.7 m in diameter. The maximum diameter of the ring formed by the apical double-wall is 7.4 m. The maximum extent of the fill collapse measures 15.2 m N-S by 12.3 m E-W in diameter. The highest standing point of the structure measures 3.05 m in height above the surrounding terrain.

The largest stone used in the apical ring measures 80 x 55 x 40 cm, while the average size of stones used in the apical ring is 59 x 50 x 45 cm.



Figure A-6: Interior of Annular Structure N0980 E0750 from the south (Photograph by K. Seligson, 2013.



Figure A-7: Annular Structure N0980 E0750 from the East (Photograph by K. Seligson, 2013).

Annular Structure N0765 E0835

East: 0233042, North: 2223975

Figures: A-8 and A-9

This ring structure is located approximately 120 meters southwest of the Chulul Palace Group of the Kiuic site center. It is situated on the east end of a low limestone outcrop that contains a small limestone quarry excavated into its western terminus. This structure is poorly preserved, making it difficult to assess its original form beyond noting the existence of a particularly wide double-wall. From the few stones that remain in place on the apex, it appears that the double-ring may have been as wide as 1.75 m across. There was a scatter of burnt *chich* around the outside of the double-ring.

Measurements: The internal depression is a rough circle measuring approximately 3.7 m in diameter. The maximum diameter of the ring formed by the apical double-wall is 6.8 m. The maximum extent of the fill collapse measures 14 m N-S by 12.2 m E-W in diameter. The highest standing point of the structure measures 1.85 m in height above the surrounding terrain. The largest stone used in the apical ring measures 85 x 65 x 60 cm, while the average size of stones used in the apical ring is 62 x 52 x 45 cm.



Figure A-8: Annular Structure N0765 E0835 looking southeast (Photograph by K. Seligson, 2013).



Figure A-9: Annular Structure N0765 E0835 looking northeast (Photograph by K. Seligson, 2015).

Intermediate Zone

Annular Structure with GPS point 1992

East: 232383, North: 2224715

This annular structure was not well preserved but appears to have been formed completely of medium-sized stones surrounding the central depression. There was no evidence on the surface for the structure having been burned.

Measurements: The internal depression measured 2 m in diameter and the ring measured 4 m in diameter.

Annular Structure with GPS point 1993

East: 232444, North: 2224712

This was a relatively well-preserved large annular structure that appeared to have been formed of a double ring. The interior wall of the ring was constructed of large boulders and the exterior of the ring was formed by slightly smaller stones. The fill of the double-wall was made up of smaller stones and earth. There was no evidence on the surface for this structure having been burned.

Measurements: The internal depression had a diameter of 3.65 m and the double-ring had a maximum diameter of 9.8 m.

Annular Structures (2) with GPS point 2007

East: 232691, North: 2224920

These two, small annular structures were located adjacent to one another, separated by only 5 m. They were both formed by single rings of large boulders and took advantage of a ridge for part of their wall structures. Neither exhibited evidence on the surface of having been burned.

Measurements: The first annular structure, located to the south of the other, measured 2.3 m in internal diameter and 3.5 m in external diameter. The second structure measured 2 m in internal diameter and 2.8 m in external diameter.

Annular Structure with GPS point 2011

East: 232922, North: 2224932

Figures: A-10 and A-11

This annular structure was very large and deep and was constructed at the apex of a high hill. It was made up of at least 3 vertical rows of large boulders arranged in regular rows. There were also some smaller, medium-sized stones used to fill in gaps in the standing walls. It was located on the same hill as a residential group complete with a chultún marked by GPS points 2009-2014. It did not exhibit any evidence on the surface of having been burned.

Measurements: Its central depression measured 2.6 m N-S by 3.2 m E-W, and the ring measured 7 m N-S by 7.2 E-W.



Figure A-10: Annular Structure with GPS point 2011 (Gallareta Negrón et al. 2014: 3-104).

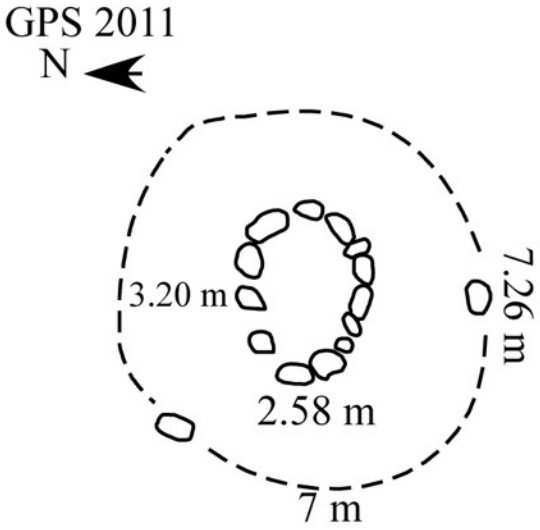


Figure A-11: Annular Structure with GPS point 2011 sketch aerial view (Gallareta Negrón et al. 2014: 3-102 close-up).

Annular Structure with GPS point 2016

East: 232851, North: 2224811

Figure: A-12.

This was a relatively large annular structure constructed atop a ridge. The southern interior wall of the structure was cut vertically into the bedrock of the ridge and the rest of the ring was formed of a single row of large boulders. There was no evidence on the surface for the ring having been burned.

Measurements: The internal depression measured approximately 5.4 m in diameter and the ring measured approximately 8 m in diameter.

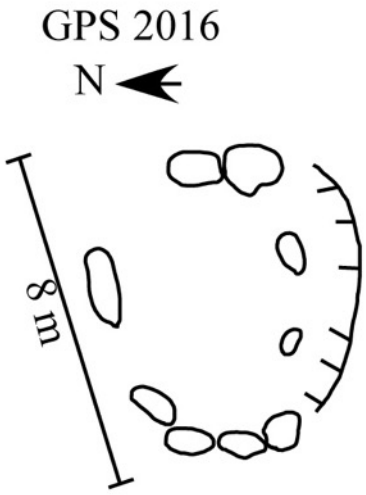


Figure A-12: Sketch aerial view (Gallareta Negrón et al. 2014: 3-102).

Annular Structure with GPS point 2019

East: 232625, North: 2224788

This was a large annular structure formed a double-wall consisting of an interior ring of very large boulders surrounded by a ring of slightly smaller boulders and earth. It was not very well preserved and exhibited no evidence on the surface of having been burned.

Measurements: The internal depression measured 3.4 m N-S by 4.5 E-W, and the exterior of the ring measured 9.3 m N-S and 9.5 m E-W in diameter.

Annular Structure with GPS point 2023

East: 232920, North: 2224769

This annular structure was relatively small and constructed on the slope of a hill. It consists of a single row of very large boulders. There was no evidence on the surface for this structure having been burned.

Measurements: The internal depression had a diameter of 1.8 m and the ring measured 2.7 m in diameter.

Annular Structure with GPS point 2029

East: 232792, North: 2224697

Figure: A-13.

This was a small annular structure that was cut partially into bedrock on its northern and eastern sides and was completed by a single ring of very large stones. It was probably associated with the platform group (GPS 2028) located approximately 1.7 m to the northwest.

Measurements: The internal depression measured 2.8 m in diameter and the ring measured 4.2 m in diameter.

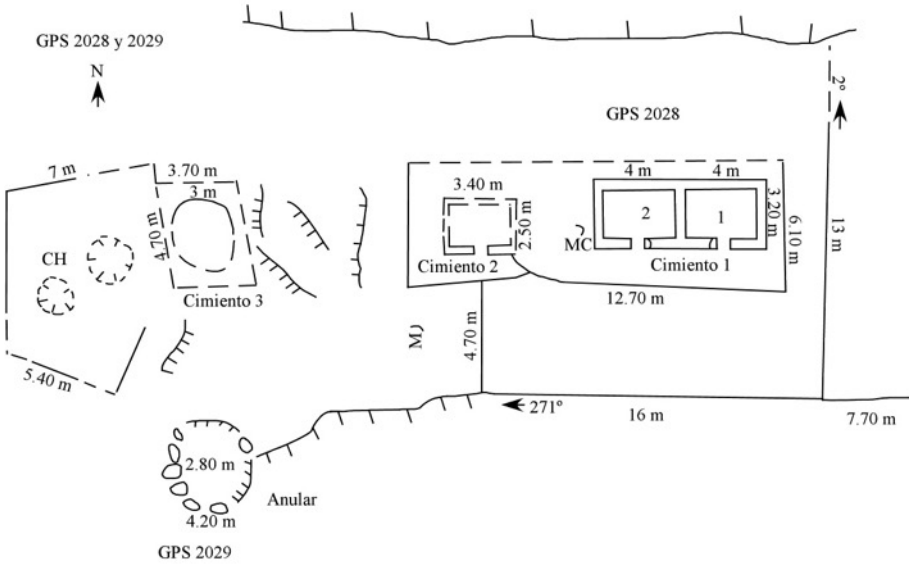


Figure A-13: Structure complex including Annular Structure with GPS point 2029, sketch aerial view (Gallareta Negrón et al. 2014: Figure 3-26).

Annular Structure with GPS point 2031

East: 232697, North: 2224694

Figure: A-14.

This was a relatively large annular structure consisting of a single ring of very large boulders surrounding the central pit. There was no evidence on the surface for the structure having been burned.

Measurements: The internal diameter measured 3.8 m across while the ring measured 6 m in diameter.

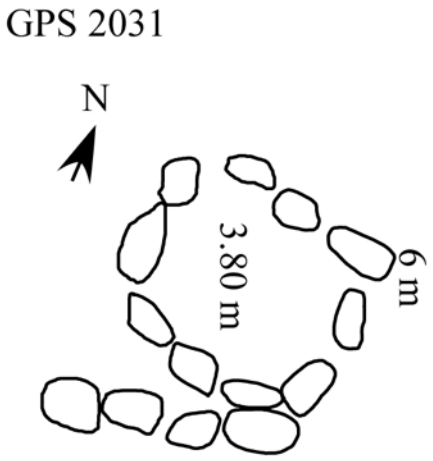


Figure A-14: Annular Structure with GPS point 2031, sketch aerial view (Gallareta Negrón et al. 2014: 3-103).

Annular Structure with GPS point 2033

East: 232717, North: 2224645

This was a very small annular structure consisting of a single ring of big boulders surrounding a central depression. It was fairly well preserved but did not exhibit any evidence on the surface of having been burned.

Measurements: The internal depression measured 1.8 m in diameter and the ring measured 2.7 m in diameter.

Annular Structure with GPS point 2039

East: 232696, North: 2224618

Figure: A-15.

This was a small annular structure constructed at the base of a hill. The north and west sides of the structure were cut into the bedrock while the rest of the ring consisted of a single row of large boulders. There was no evidence on the surface of the structure having been burned.

Measurements: The internal depression measured 3.2 m in diameter and the external diameter of the ring measured 4.75 m.



Figure A-15: Annular Structure with GPS point 2039, sketch aerial view (Gallareta Negrón et al. 2014: 3-103).

Annular Structure with GPS point 2044

East: 232921, North: 2224619

This was a large annular structure constructed of a double-ring made up of an interior wall of medium-sized boulders and an exterior wall of large boulders. There was no evidence on the surface for the structure having been burned.

Measurements: The internal diameter of the structure measured 4 m and the exterior extent of the ring measured 6.8 m in diameter.

Annular Structure with GPS point 2046

East: 232931, North: 2224651

Figure: A-16.

This was a large annular structure whose southern and western walls were cut vertically into bedrock and the rest of the ring was formed of medium-sized boulders on the interior and an exterior ring of larger stones. It was located approximately 5 m to the northwest of a platform supporting a two-room residential structure (GPS 2045). There was no evidence on the surface for this structure having been burned.

Measurements: The interior of the structure had a diameter of 4.5 m and the maximum extent of the ring measured 10 m in diameter.

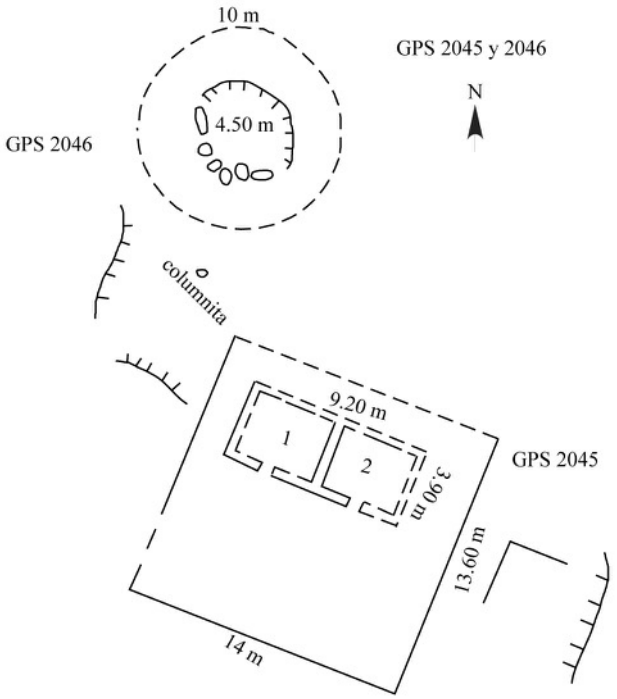


Figure A-16: Structure group including Annular Structure with GPS point 2046, sketch aerial view (Gallareta Negrón et al. 2014: 3-95).

Annular Structure with GPS point 2047

East: 232946, North: 2224614

Figure: A-17.

This was a large annular structure cut mainly into bedrock. It was located immediately to the north of a fairly large quarry complete with many partially cut outcrops. There was also a structure foundation and terrace with a metate located nearby. There was no evidence on the surface for the annular structure having been burned.

Measurements: The internal diameter of the structure measured only 1.6 m in diameter but the external diameter measured 8.4 m.

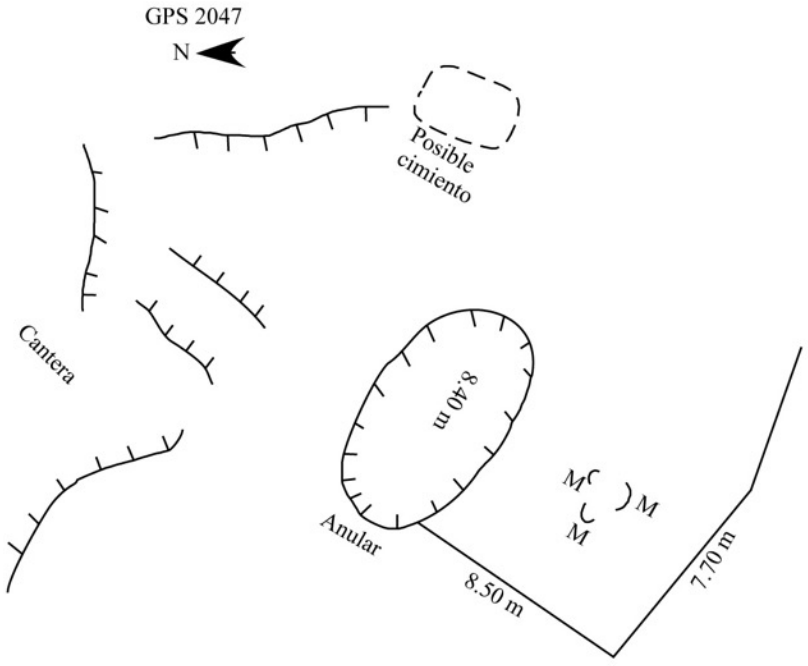


Figure A-17: Structure group including Annular Structure with GPS point 2047, sketch aerial view (Gallareta Negrón et al. 2014: 3-103).

Annular Structure with GPS point 2052

East: 232880, North: 2224572

This was a small annular structure constructed of a double ring of large boulders. It did not exhibit any evidence on the surface of having been burned.

Measurements: The internal diameter measured 3.8 m across and the exterior of the ring measured 5 m across.

Annular Structure with GPS point 2063

East: 232665, North: 2224365

Figure: A-18.

This was a small annular structure located on flat terrain. It consisted of a double-ring whose interior wall was made up of medium-sized stones and external ring was made up of very large boulders. It was located approximately 4.5 m to the south of rectangular structure foundation (GPS 2602). There was no evidence on the surface for the structure having been burned.

Measurements: The structure measured 2.8 m in internal diameter and 4.8 m in external diameter.

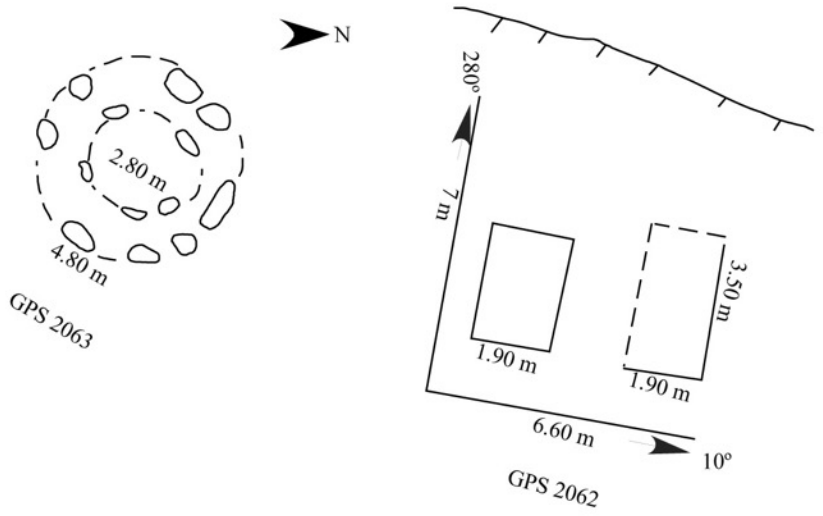


Figure A-18: Structure Group including Annular Structure with GPS point 2063, sketch aerial view (Gallareta Negrón et al. 2014: Figure 3-74).

Annular Structure with GPS point 2074

East: 232776, North: 2224295

Figure: A-19.

This annular structure was made up of a single ring of very large boulders. It was located approximately 11 m to the northeast of a fairly large quarry. There was no evidence on the surface for the structure having been burned.

Measurements: The interior diameter of the structure measured 4.7 m and the exterior diameter measured 7.3 m



Figure A-19: Annular Structure with GPS point 2074 looking northwest (Photograph by K. Seligson, 2015).

Annular Structure with GPS point 2083

East: 232850, North: 2224183

Figures: A-20 and A-21.

This was a large annular structure with a fairly well-preserved interior southern and western wall consisting of three vertical rows of large boulders. The northern and eastern walls consisted of at least one row of large stones placed atop a vertical cut into the bedrock. This interior ring was surrounded by a larger ring of large stones. There was no evidence on the surface of the structure having been burned.

Measurements: The interior diameter of the circle measured 5 m across and the exterior extent of the ring measured 11.5 m in diameter.



Figure A-20: Annular Structure with GPS point 2083 looking northwest (Photograph by K. Seligson, 2015).



Figure A-21: Annular Structure with GPS point 2074 looking northwest (Gallareta Negrón et al. 2014: 3-103).

Annular Structure with GPS point 2088

East: 232900, North: 2224050

Figures: A-22 and A-23.

This was a large annular structure consisting of a ring of large boulders stacked in one or two vertical rows surrounded by a sloping mound of stones, though no definable exterior wall. There was no evidence on the surface for the structure having been burned.

Measurements: The interior diameter of the structure measured 3.6 m and the exterior measured 7 m in diameter.



Figure A-23: Annular Structure with GPS point 2088 looking southeast (Photograph by K. Seligson, 2015).

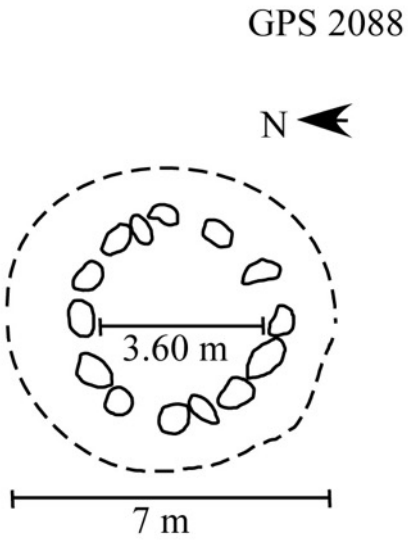


Figure A-24: Annular Structure with GPS point 2088, sketch aerial view (Gallareta Negrón et al. 2014: 3-103).

Annular Structure with GPS point 2118

East: 232481, North: 2224140

This was a small annular structure constructed of a single ring of medium-sized stones. It was located approximately 7 m to the north of small rectangular platform (GPS 2119). There was not evidence on the surface of this structure having been burned.

Measurements: The interior diameter measured 2 m and the exterior diameter measured 4 m.

Annular Structure with GPS point 2208

East: 232835, North: 2223727

This was a small annular structure consisting of a southern wall cut into bedrock and the rest was a single ring of very large boulders. There was no evidence on the surface for this structure having been burned.

Measurements: The structure measured 2.8 m in interior diameter and 3.8 m in exterior diameter.

Annular Structure with GPS point 2213

East: 232552, North: 2223727

Figure: A-25.

This annular structure was situated on the slope of a hill and consisted of a single ring of very large boulders. There was no evidence on the surface for this structure having been burned.

Measurements: The structure had an interior diameter of 4.3 m.



Figure A-25: Annular structure with GPS point 2213 looking southeast (Photograph by K. Seligson, 2014).

Annular Structure with GPS point 2216

East: 232882, North: 2223787

Figures: A-26, A-27, and A-28.

This was a large annular structure located on the slope of a ridge. It was constructed of at least 2 vertical rows of large boulders on its western side, and at least one row of large boulders on its eastern side, giving it an uneven height. It was surrounded by a scattering of burnt *chich*, indicating the burning episodes had taken place there.

Measurements: It measured 5.1 m in internal diameter and 6.2 m in exterior diameter.



Figure A-26: Annular Structure with GPS point 2216 looking east (Photograph by K. Seligson, 2013).



Figure A-27: Example of burnt *chich* scatter around Annular Structure with GPS point 2216 (Photograph by K. Seligson, 2013).

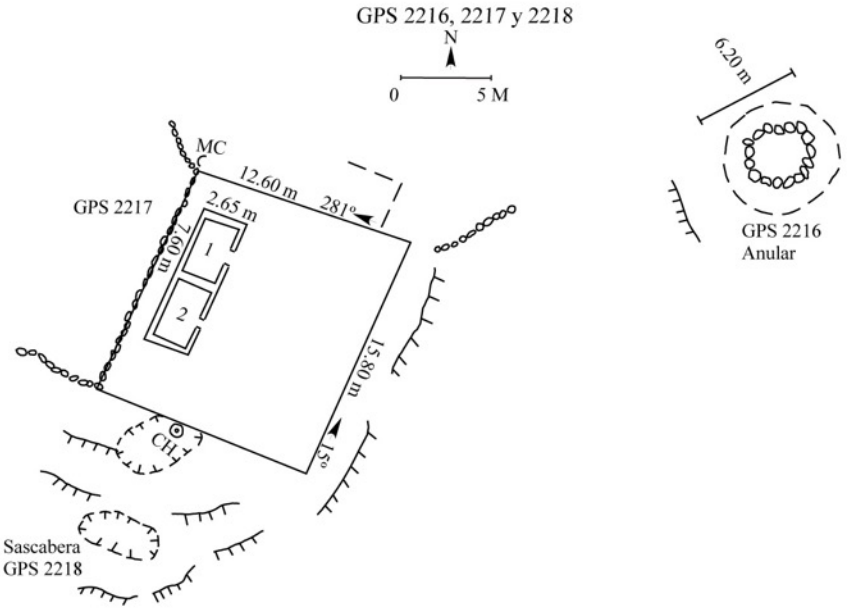


Figure A-28: Structure group including Annular Structure with GPS point 2216 (Gallareta Negrón 2014: Figure 3-27).

Annular Structure with GPS point 2223

East: 232741, North: 2223784

Figures: A-29 and A-30.

This structure is located on the eastern slope of the hill to the east of *Escalera al Cielo* called *Box Peek' Pocpocxic*. It is located on a steeper incline than any of the other rings surveyed. Due to the steepness of the incline, many of the stones from the southeastern side of the ring have fallen down the hill-slope. The western and northwestern interior walls of the structure are cut straight into the bedrock and exhibit evidence of having been burnt. Due to the poor preservation, it is unclear whether the ring consisted of a single or double wall, but the depth of the central depression on the surface indicates that is was likely a deep pit. The slope to the east and southeast of the structure is scattered with burnt pieces of *chich*.

Measurements: The internal depression is a rough circle whose diameter measures at least 2.5 m across, but is difficult to clearly determine. The maximum diameter of the ring formed by the apical double-wall is approximately 5.8 m. The maximum extent of the fill collapse measures 9.6 m N-S by 9.1 m E-W in diameter. The largest stone used in the apical ring measures 80 x 75 x 50 cm, while the average size of stones used in the apical ring is 64 x 44 x 34 cm.



Figure A-29: Annular Structure with GPS point 2223 looking northwest (Photograph by K. Seligson, 2014).

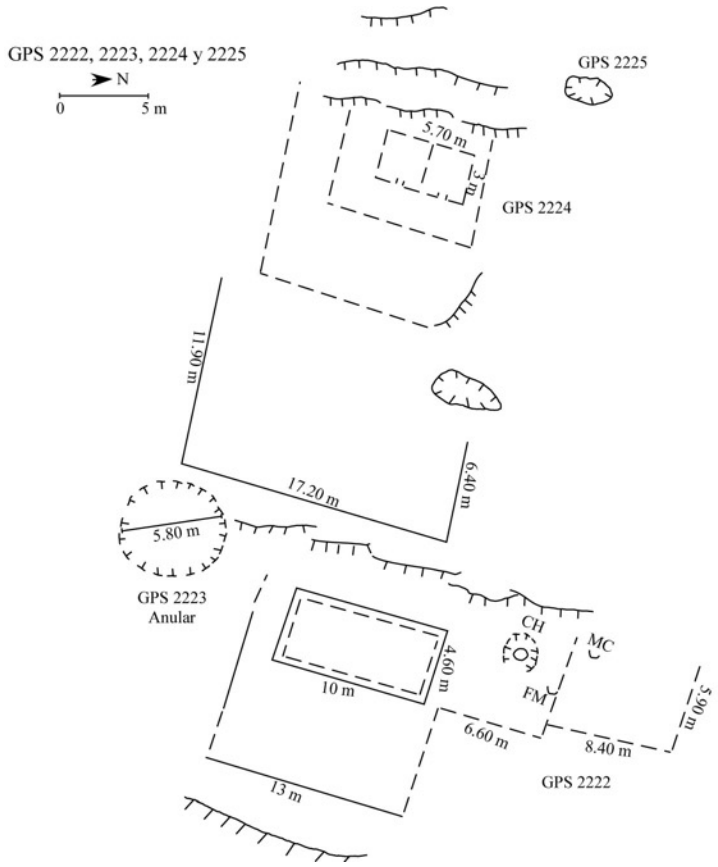


Figure A-30: Structure group including Annular Structure with GPS point 2223, sketch aerial view (Gallareta Negrón et al. 2014: Figure 3-28).

Annular Structure with GPS point 2246

East: 232761, North: 2223971

Figures: A-31, A-32, and A-33.

This was a large annular structure consisting of a double ring of large boulders and possessed as many as 3 vertical rows of stones. It was fairly well preserved except for the eastern side. It was located just to the south of two mounds of *chich* that each measured approximately 3 m across. There was no evidence on the surface for the structure having been burned.

Measurements: The structure had an interior diameter of 5.5 m and a maximum exterior diameter of 11 m.



Figure A-31: Annular Structure with GPS point 2246, looking northwest (Photograph by K. Seligson, 2013).



Figure A-32: Annular Structure with GPS point 2246, looking west (Gallareta Negrón et al. 2014: 3-109).

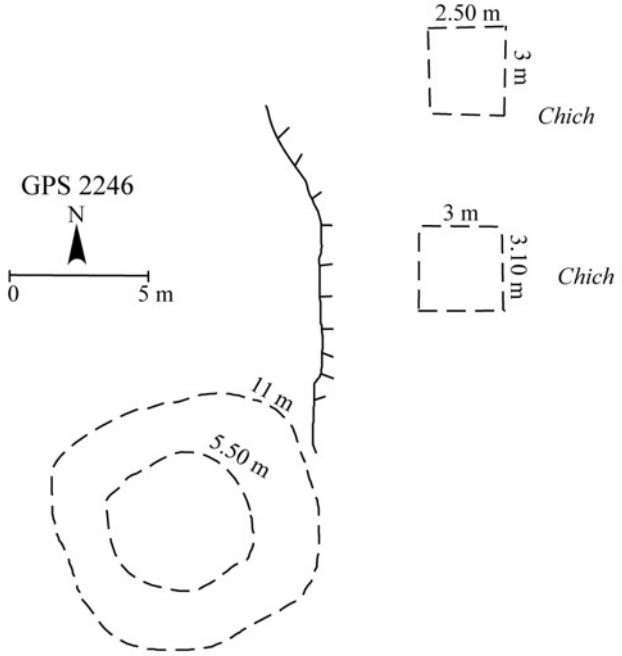


Figure A-33: Structure group including Annular Structure with GPS point 2246, sketch aerial view (Gallareta Negrón et al. 2014: 3-103).

Annular Structure with GPS point 2264

East: 232372, North: 2223502

Figure: A-34.

This was a small, well preserved annular structure made up of one ring of medium-sized stones. It was associated with a platform group (GPS 2262 and 2263). There was no evidence on the surface for the structure having been burned.

Measurements: The structure measured approximately 1.6 m in diameter.



Figure A-34: Annular Structure with GPS point 2264 looking north (Photograph by K. Seligson, 2015).

Annular Structure with GPS point 2266

East: 232324, Norte: 2223548

Figures: A-35 and A-36.

This was a structure located atop a hill and made up of a single ring of at least two vertical rows of medium-sized stones. It was fairly well preserved except for the eastern side. There was a platform supporting a structure foundation approximately 15 to the northwest at a lower level of the hill (GPS 2265). There was no evidence on the surface for the structure having been burned.

Measurements: The structure had a maximum diameter of about 5.8 m.



Figure A-35: Annular Structure with GPS point 2266 looking northeast (Photograph by K. Seligson, 2015).

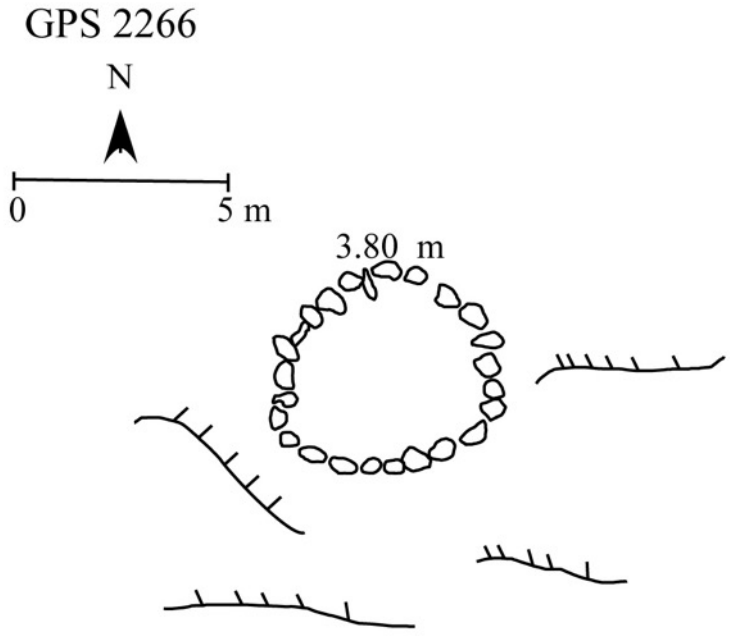


Figure A-36: Annular Structure with GPS point 2266, sketch aerial view (Gallareta Negrón et al. 2014: 3-103).

Annular Structure with GPS point 2267

East: 232176, North: 2223510

Figures: A-37 and A-38.

This was a large annular structure made up of medium-sized boulders arranged in a ring of at least two vertical rows. There was no evidence on the surface of this structure having been burned.

Measurements: The maximum extent of the ring had a diameter of approximately 5.8 m.



Figure A-37: Annular Structure with GPS point 2267 looking west (Photograph by K. Seligson, 2013).



Figure A-38: Annular Structure with GPS point 2267 looking southwest (Photograph by K. Seligson, 2015).

Annular Structure with GPS point 2269

East: 232178, North: 2223603

Figure: A-39.

This was a large annular structure that has mostly collapsed and the extent of the ring is not clearly visible around the central depression. It is located immediately to the southeast of platform with a chultún (GPS 2268). There was no evidence for the structure having been burned.

Measurements: The maximum extent of the structure measured approximately 5 m in diameter.



Figure A-39: Annular Structure with GPS point 2269 looking southwest (Photograph by K. Seligson, 2014).

Outer Zone

Annular Structure with GPS point 1868

East: 0231099, North: 2224601

Figure: A-40.

This structure was located on relatively flat ground and used the bedrock for part of the construction form. The structure was outlined by a ring of very large, rough boulders that were probably cut from nearby limestone outcrops and the structure exhibited evidence of having been burnt. The remnants of the structure appeared to have an oval shape. It was located about 0.7 m northwest of a small quarry that measures about 1.7 by 1.4 m.

Measurements: The central depression had a diameter of approximately 5 m (N-S) and 3.5 m (E-W). The ring of boulders had a diameter of 6.5 m.

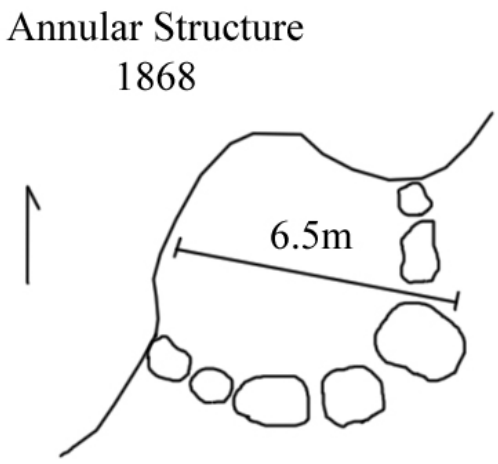


Figure A-40: Annular Structure with GPS point 1868, sketch aerial view (K. Seligson, 2013).

Annular Structure with GPS point 1900

East: 0231709, North: 2224627

This structure was located on low terrain to the east of two ridges that measured 5-6 m in height, the southern of which had a structure foundation on its apex. The annular structure was constructed using the bedrock for part of the structure and the rest was completed by a ring of very large boulders. It appeared to be fairly well preserved and exhibited an oval shape. There was no apparent evidence for burning of the structure as viewed on the surface.

Measurements: The central depression had a diameter of approximately 6.5 m N-S and 2.4 m E-W. The ring of boulders had a diameter of 7.4 m N-S and 3.8 m E-W.

Annular Structure with GPS point 1901

East: 0231697, North: 2224687

This structure was situated at the base of a ridge located immediately to the east of a quarry. The annular structure was constructed of medium-sized rough boulders, but was not well preserved

so it is unclear whether larger stones may have collapsed into the central depression. It did not exhibit any evidence of having been burned.

Measurements: The central depression had a diameter of approximately 3.4 m and the ring of boulders had a diameter of 5 m.

Annular Structure with GPS point 1910

East: 0231984, North: 2224834

This structure was located atop a ridge, the bedrock of which was used for part of the construction. The rest of the interior ring was constructed of very large boulders and an external ring was constructed of smaller stones. There was no evidence on the surface for the structure having been burned.

Measurements: The internal depression had a diameter of 3 m and the ring of the structure measured 7 m in diameter, suggesting the presence of a double-ring in its original form.

Annular Structure with GPS point 1948

East: 0231206, North: 2224424

Figure: A-41.

This was a relatively small annular structure located atop a small ridge constructed of medium-sized boulders on the interior and smaller stones on the exterior. There was no evidence on the surface of the structure having been burned.

Measurements: The internal diameter of the structure measured 2 m and the diameter of the ring measured 3.8 m.

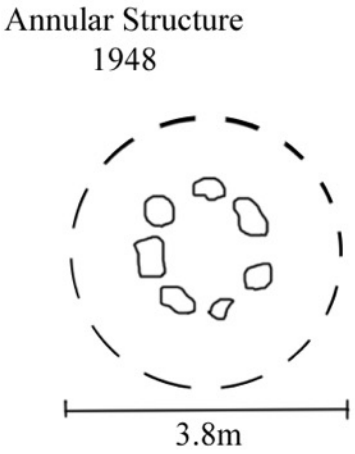


Figure A-41: Annular Structure with GPS point 1948, sketch aerial view (K. Seligson, 2013).

Annular Structure with GPS point 1956

East: 231783, North: 2224031

Figure: A-42.

This annular structure was relatively small and its northern wall was partially constructed out of a limestone outcrop located on a ridge. The eastern, western and southern walls of the structure consisted of medium-sized boulders. There was no evidence on the surface of the structure having been burned.

Measurements: The internal depression of the structure measured 3.4 m in diameter and the ring measured approximately 5.5 m in diameter.

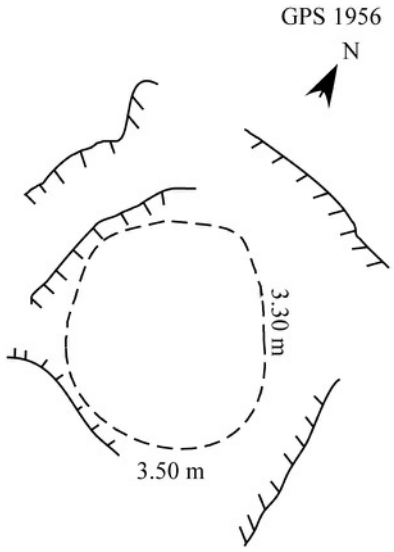


Figure A-42: Annular Structure with GPS point 1956, sketch, aerial view (Gallareta Negrón et al. 2014: 3-102).

Annular Structure with GPS Point 1957

East: 231772, North: 2224027

Figure: A-43.

This was a relatively small annular structure made up of very large boulders. It is surrounded by four *chich* mounds on its southern, western, and northern sides, one of which measures as much as 3 m in diameter. There is no evidence on the surface for the structure having been burned.

Measurements: The internal diameter of the structure measured 4 m N-S by 3 m E-W. The external diameter measured approximately 5 m.

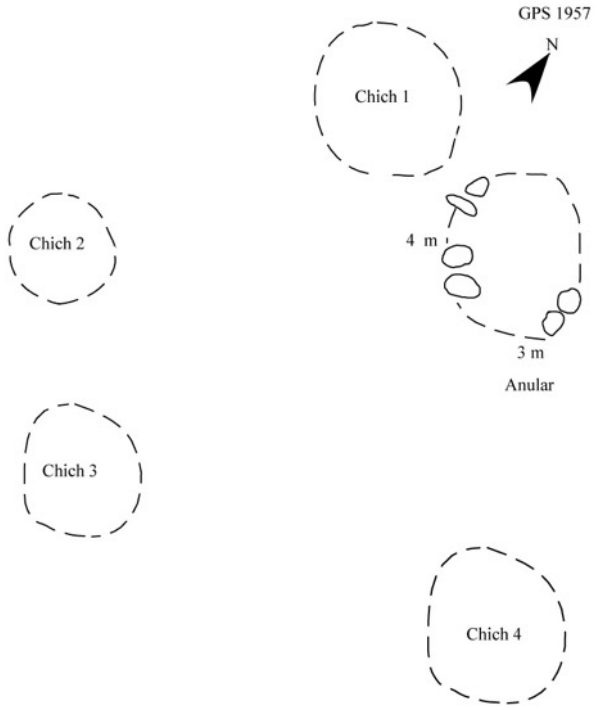


Figure A-43: Group including four *chich* mounds and Annular Structure with GPS point 1957, sketch aerial view (Gallareta Negrón et al. 2014: 3-102).

Annular Structure with GPS Point 1960

East: 231660, North: 2224170

Figures: A-44 and A-45.

This annular structure was located at the base of a hill and was made up of large boulders. There was no evidence on the surface of the structure having been burned.

Measurements: The internal depression of the structure measured approximately 2.6 m in diameter. The external diameter measured 3.5 m.



Figure A-44: Annular Structure with GPS point 1960 looking southeast (Photograph by K. Seligson, 2013).

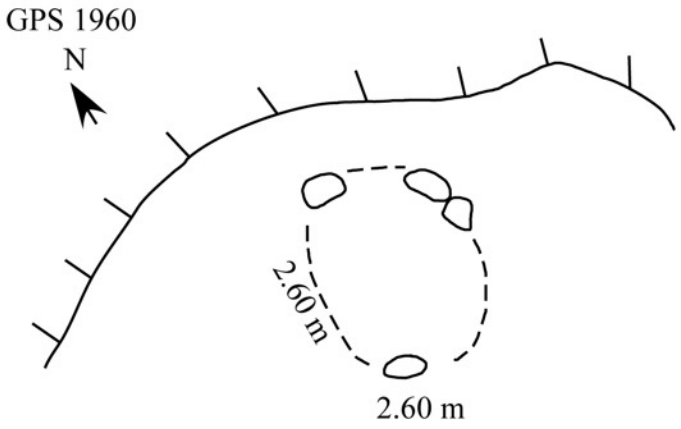


Figure A-45: Annular Structure with GPS point 1960, sketch aerial view (Gallareta Negrón et al. 2014: 3-102).

Annular Structure with GPS point 1972

East: 231745, Norte: 2224251

This annular structure was relatively small and almost completely excavated into bedrock outcrop (no ring boulders were apparent, though they may have collapsed into the central depression). There was no evidence on the surface for the structure having been burned.

Measurements: The internal diameter measured 2.3 m across and the ring measured 3.6 m in diameter.

Appendix B: Archaeometric Data

Sample Labels		Al 396.152	Ba 455.403	Ca 422.673	Fe 238.204	K 766.491	Mg 279.553	Mn 257.610	Na 589.592
		PPM IN SOLUTION: MICROGRAMS PER MILLILITER OF SOLUTION							
S1	EA1 Pozo 1 Capa 4	7.21	0.09	431.55	2.02	9.32	2.56	0.123	2.64
S2	EA1 Sondeo 3 Capa 2	0.55	0.01	507.22	0.08	1.68	0.88	0.009	0.96
S3	EA1 Sondeo 3 Capa 4	1.01	0.03	544.78	0.06	0.86	1.3	0.003	0.87
S4	EA 2 Pozo 2 Capa 6	0.92	0.02	563.19	0.17	0.69	1.3	0.034	1.6
S5	EA2 Sondeo 8 Capa 1	0.67	0.03	531.56	0.16	0.43	4.01	0.006	1.49
S6	EA2 Sondeo 8 Capa 2	0.58	0.04	650.64	0.2	0.41	4.87	0.013	1.17
S7	EA3 Pozo 3 Capa 2	1.43	0.05	498.72	0.34	0.66	6.5	0.019	1.03
S8	EA 3 Pozo 3 Capa 5	6.08	0.08	450.29	2.59	0.54	2.45	0.049	0.68
S9	EA4 Pozo 4 Capa 6	0.6	0.06	591.32	0.15	0.3	0.71	0.004	0.84
S10	EA4 Pozo 4 Capa 7	1.78	0.05	376.48	0.59	0.64	1.58	0.363	0.69
S11	EA5 Pozo 5 Capa 2	3.16	0.05	568.8	1.06	0.31	1.27	0.046	0.83
S12	EA6 Pozo 6 Capa 4	0.49	0.08	409.8	0.06	0.27	4.2	0.025	0.79
S13	EA7 Pozo 8 Capa 2	0.83	0.07	568.38	0.09	0.3	3.2	0.011	0.9
S14	EA3 Pozo 3 Capa 9	0.76	0.04	349.79	0.14	0.7	62.01	0.046	1.36
Sample Labels		P 213.618	S 181.972	Sr 407.771	Ti 336.122	Zn 210.442	Sr/Ca	Ba/Ca	Ba/Sr
S1	EA1 Pozo 1 Capa 4	1.18	4.81	0.226	0.13	1.09	5.23	2.01	0.384
S2	EA1 Sondeo 3 Capa 2	0.1	0.79	0.03	0		0.59	0.29	0.492
S3	EA1 Sondeo 3 Capa 4	0.04	0.86	0.062	0	0.51	1.14	0.51	0.449
S4	EA 2 Pozo 2 Capa 6	0.51	0.34	0.21	0.01	0.66	3.72	0.41	0.111
S5	EA2 Sondeo 8 Capa 1	0.13	0.49	0.144	0	0.42	2.71	0.65	0.241
S6	EA2 Sondeo 8 Capa 2	0.06	0.78	0.261	0		4.01	0.67	0.167
S7	EA3 Pozo 3 Capa 2	0.06	0.89	0.226	0	0.42	4.52	1.02	0.226

S8	EA 3 Pozo 3 Capa 5	0.16	0.52	0.122	0.14	0.54	2.7	1.71	0.635
S9	EA4 Pozo 4 Capa 6	0.02	0.57	0.152	0.01		2.58	0.96	0.373
S10	EA4 Pozo 4 Capa 7	0.04	0.82	0.051	0.01		1.34	1.28	0.95
S11	EA5 Pozo 5 Capa 2	0.23	0.55	0.133	0.07		2.34	0.94	0.402
S12	EA6 Pozo 6 Capa 4	0.03	0.92	0.188	0		4.6	2.06	0.449
S13	EA7 Pozo 8 Capa 2	0.03	0.9	0.107	0	0.35	1.89	1.18	0.625
S14	EA3 Pozo 3 Capa 9	0.07	0.57	0.286	0	0.36	8.16	1.05	0.129
MICROGRAMS PER GRAM OF SAMPLE					(=PPM X VOL / WT)				
Sample Labels		Al 396.152	Ba 455.403	Ca 422.673	Fe 238.204	K 766.491	Mg 279.553	Mn 257.610	Na 589.592
S1	EA1 Pozo 1 Capa 4	5044	60.6	302083	1412	6526	1790	86.4	1851
S2	EA1 Sondeo 3 Capa 2	385	10.2	355053	59.4	1177	615	6	674
S3	EA1 Sondeo 3 Capa 4	707	19.5	381345	38.7	604	913	2.4	609
S4	EA 2 Pozo 2 Capa 6	646	16.3	394232	119.6	486	908	23.8	1120
S5	EA2 Sondeo 8 Capa 1	468	24.3	372089	115.4	303	2810	4.3	1040
S6	EA2 Sondeo 8 Capa 2	405	30.5	455448	142.5	287	3406	8.8	819
S7	EA3 Pozo 3 Capa 2	1002	35.7	349107	241.3	461	4550	13.5	723
S8	EA 3 Pozo 3 Capa 5	4253	54	315203	1813.2	381	1712	34.1	476
S9	EA4 Pozo 4 Capa 6	419	39.8	413925	108	213	496	2.5	586
S10	EA4 Pozo 4 Capa 7	1245	33.6	263535	414.9	446	1107	254.4	481
S11	EA5 Pozo 5 Capa 2	2211	37.5	398158	742.1	219	886	32	578
S12	EA6 Pozo 6 Capa 4	343	59.2	286857	40.5	186	2937	17.5	556
S13	EA7 Pozo 8 Capa 2	582	47	397867	64.4	212	2242	7.7	632
S14	EA3 Pozo 3 Capa 9	529	25.7	244850	100.7	491	43408	32.3	949
MICROGRAMS PER GRAM OF SAMPLE					(=PPM X VOL / WT)				

Sample Labels		P 213.618	S 181.972	Sr 407.771	Ti 336.122	Zn 210.442	Sr/Ca	Ba/Ca	Ba/Sr
S1	EA1 Pozo 1 Capa 4	829	3367	157.9	91.51	760	5.23	2.01	0.38
S2	EA1 Sondeo 3 Capa 2	73	550	20.8	1.52		0.59	0.29	0.49
S3	EA1 Sondeo 3 Capa 4	29	605	43.5	0.53	354	1.14	0.51	0.45
S4	EA 2 Pozo 2 Capa 6	354	241	146.7	5.28	463	3.72	0.41	0.11
S5	EA2 Sondeo 8 Capa 1	92	345	100.7	1.49	292	2.71	0.65	0.24
S6	EA2 Sondeo 8 Capa 2	42	543	182.7	1.61		4.01	0.67	0.17
S7	EA3 Pozo 3 Capa 2	41	623	157.9	2.96	291	4.52	1.02	0.23
S8	EA 3 Pozo 3 Capa 5	112	361	85.1	97.13	377	2.7	1.71	0.63
S9	EA4 Pozo 4 Capa 6	15	402	106.6	4.08		2.58	0.96	0.37
S10	EA4 Pozo 4 Capa 7	28	572	35.4	7.58		1.34	1.28	0.95
S11	EA5 Pozo 5 Capa 2	164	388	93.2	50.62		2.34	0.94	0.4
S12	EA6 Pozo 6 Capa 4	23	641	131.8	0.8		4.6	2.06	0.45
S13	EA7 Pozo 8 Capa 2	21	629	75.2	1.06	242	1.89	1.18	0.63
S14	EA3 Pozo 3 Capa 9	49	396	199.9	2.32	250	8.16	1.05	0.13

Sample #	**Annular Structure**	**Depth below surface**	**$\delta^{13}C$ (1)**	**$\delta^{13}C$ (2)**	**$\delta^{18}O$ (1)**	**$\delta^{18}O$ (2)**
1	1	3.4 m	-22.08	-22.49	-15.06	-14.07
2	1	Sascabera	-11.15	-11.08	-4.09	-4.11
3	1	Sascabera	-11.19	-11.35	-4.22	-4.38
4	2	3.45 m	-24.42	-26.54	-19.5	-16.2
5	2	3.95 m	-10.45	-10.27	-4.46	-4.35
6	2	4.2 m	-9.7	-9.84	-4.47	-4.42
7	3	1.75 m	-10.14	-10.01	-4.59	-4.83
8	3	2.8 m	-24.19	-25.72	-19.11	-22.3
14	3	3.99 m	-10.83	-9.74	-3.09	-3.75
9	4	2.8 m	-26.61	-25.6	-20.33	-22.21
10	4	3.06 m	-10.9	-10.3	-4.37	-3.08
11	5	Surface	-23.34	-24.91	-20.23	-22.1
12	6	3.7 m	-8.28	-10.02	-3.9	-3.92
13	7	1.75 m	-10.4	-10.64	-3.99	-4.49

Appendix C: Annular Structure Typology Data

GPS #	Type	Zone	Diameter Internal (m)	Diameter External (m)	Terrain
1993	double ring	intermediate	3.65	9.8	flat
2011	double ring	intermediate	2.9	7	flat (on top of hill)
2019	double ring	intermediate	3.9	9.4	flat
2044	double ring	intermediate	4	6.8	slope
2052	double ring	intermediate	3.8	5	slope
2063	double ring	intermediate	2.8	4.8	flat
2246	double ring	intermediate	5.5	11	flat (base of hill)
N0765E0835	double ring	inner	3.7	6.8	atop hill
N0795E1245	double ring	inner	3.5	6.1	slope
N0810E1140	double ring	inner	2.8	4.3	flat
N0880E1255	double ring	inner	2.3	4.8	slope
1863	double ring (Oxkintok)	outer	5	6.2	flat
1910	double ring (with retention)	outer	3	7	slope
2047	other (mainly bedrock)	intermediate	1.6	8.4	slope
2223	other (unclear)	intermediate	2.5	5.8	slope
2046	partial double ring built into slope	intermediate	4.5	10	slope
2083	partial double ring built into slope	intermediate	5	11.5	slope
2242	partial double ring built into slope	intermediate	2.8	5.4	flat
N1240E0845	partial double ring built into slope	inner	3.2	5.5	slope
1900	partial single built into slope	outer	4.4	5.6	slope
1956	partial single built into slope	outer	3.4	5.5	slope
1972	partial single built into slope	outer	2.3	3.6	slope
2016	partial single built into slope	intermediate	5.4	8	slope
2023	partial single built into slope	intermediate	1.8	2.7	slope

2029	partial single built into slope	intermediate	2.8	4.2	slope
2039	partial single built into slope	intermediate	3.2	4.75	slope
2007(1)	partial single built into slope	intermediate	2.3	3.5	slope
2007(2)	partial single built into slope	intermediate	2	2.8	slope
N0980E0750	partial single built into slope	inner	4.7	7.4	slope
1901	partial single built into slope (with retention)	outer	3.5	5	slope
1967	partial single built into slope (with retention)	outer	1.4	2.3	slope
2113	partial single built into slope (with retention)	intermediate	2.1	4.3	slope
1868	partial single ring built into slope	outer	4.4	6.5	flat/slope
2208	partial single ring built into slope	intermediate	2.8	3.8	slope
2213	partial single ring built into slope	intermediate	4.3		slope
2216	partial single ring built into slope	intermediate	5.1	6.2	slope
2227	partial single ring built into slope	intermediate	2.5	3.5	slope
2241	partial single ring built into slope	intermediate	5.8	7.1	slope
2269	partial single ring built into slope	intermediate		5	slope
1948	single ring	outer	2	3.8	slope
1957	single ring	outer	3.5	5	NA
1960	single ring	outer	2.6	3.5	flat
1992	single ring	intermediate	2	4	flat
2031	single ring	intermediate	3.8	6	flat (on hill)
2033	single ring	intermediate	1.8	2.7	flat (on hill)
2074	single ring	intermediate	4.7	7.3	slope
2088	single ring	intermediate	3.6	7	flat (base of hill)

2107	single ring	intermediate	3	6	flat (on top of hill)
2118	single ring	intermediate	2	4	flat (on hill)
2264	single ring	intermediate	1.6		flat (on hill)
2266	single ring	intermediate		5.8	flat (on hill)
2267	single ring	intermediate		5.8	flat (on hill)
N1065E0965	single ring	inner	6	9.1	flat

	Double ring	Partial double	Single ring	Partial single	Other
Simple structure	1	0	0	0	1
Quarry/sascabera	3	2	1	5	0
Residential group	2	0	0	1	0
Chich mounds	1	0	1	0	0
Haltún	1	0	0	0	0
Platform	0	1	4	3	0
Nothing	5	1	8	12	1
Total #	13	4	14	20	2

	Double ring	Partial double	Single ring	Partial single	Other
Very large boulders	3	0	3	7	0
Large boulders	4	1	4	7	1
Medium boulders	0	0	7	5	0
Combination	6	3	0	0	0
Unclear	0	0	0	1	1
Total #	13	4	14	20	2

Appendix D: Ceramic Data

2014 Annular Structure Field Season (as compiled by Betsy Kohut)

Ceramic Complex	Ceramic Type	Sherd (n)	Sherd (%)	Weight (kg)	Weight (%)
Chiic/Yuc	Balanza Negra	1	0.0232	16	0.0201
Chiic/Yuc	Batres Rojo	14	0.3253	189	0.2379
Chiic/Yuc	Charote Rojo	11	0.2556	228	0.2870
Chiic/Yuc	No identificado, Clasico Tardio	8	0.1859	97	0.1221
Chiic/Yuc	Timucuy Naranja	23	0.5344	406	0.5110
Chiic/Yuc	Timucuy Naranja Policromo	7	0.1626	132	0.1661
Chiic/Yuc	Yucatan Lustrosa, erosionado	54	1.2546	654	0.8232
Chiic/Yuc	Say Pizarra	75	1.7426	1762	2.2177
Chiic/Yuc	Say Pizarra, chorreado	37	0.8597	1489	1.8741
Ceh	Akil Impreso	5	0.1162	202	0.2542
Ceh	Becal Inciso	51	1.1849	331	0.4166
Ceh	Chum sin engobe	194	4.5074	5267	6.6293
Ceh	Chumayel Rojo-sobre-pizarra	1	0.0232	36	0.0453
Ceh	Muna Pizarra	1486	34.5260	27391	34.4758
Ceh	Muna Pizarra, chorreado	286	6.6450	10691	13.4563
Ceh	Muna-Teabo bicromo	14	0.3253	216	0.2719
Ceh	Nohcacab Compuesto	5	0.1162	187	0.2354
Ceh	Pizarra Negra	1	0.0232	9	0.0113
Ceh	Pizarra pintada	2	0.0465	79	0.0994
Ceh	Sacalum Negro-sobre-pizarra	1	0.0232	202	0.2542
Ceh	Teabo Rojo	313	7.2723	2502	3.1492
Ceh	Tekax Negra-sobre-rojo	5	0.1162	82	0.1032
Ceh	Tekit Inciso	8	0.1859	288	0.3625
Ceh	Ticul Pizarra Delgada	20	0.4647	132	0.1661
Ceh	Yaxachen Estriado	22	0.5112	1069	1.3455
Ceh	Yaxnic Modelado	1	0.0232	48	0.0604
Ceh	Yokat Estriado	1287	29.9024	20370	25.6388
Zodz	Mama Red	36	0.8364	154	0.1938
No identificado	Bolita ceramica	1	0.0232	1	0.0013
No identificado	No identificado	28	0.6506	429	0.5400
No identificado	No identificado, bi/policromo	2	0.0465	41	0.0516
No identificado	No identificado, con engobe	44	1.0223	445	0.5601
No identificado	No identificado, erosionado	98	2.2770	1281	1.6123
No identificado	No identificado, estriado	1	0.0232	20	0.0252
No identificado	No identificado, sin engobe	25	0.5809	260	0.3272
No identificado	Pizarra, erosionado	137	3.1831	2744	3.4537

		4304	100	79450	100

2015 Annular Structure Field Season (compiled by Betsy Kohut)

Vajilla	Grupo	*Tipo*	#	%	Peso (g)	%
Lustrosa no identificado	No identificado	*Vajilla Lustrosa, erosionado*	4	0.2653	32	0.0903
Lustrosa no identificado	No identificado	*Vajilla Lustrosa, no identificado*	1	0.0663	7	0.0198
No identificado	No identificado	*No identificado*	29	1.9231	357	1.0076
No identificado	No identificado	*No identificado, con engobe*	45	2.9841	1094	3.0879
No identificado	No identificado	*No identificado, erosionado*	40	2.6525	529	1.4931
No identificado	No identificado	*No identificado, estriado*	1	0.0663	31	0.0875
No identificado	No identificado	*No identificado, sin engobe*	1	0.0663	3	0.0085
Pizarra Delgada	Ticul	*Ticul Pizarra Delgada*	3	0.1989	25	0.0706
Pizarra Puuc	Acanceh	*Acanceh Aplicado*	1	0.0663	90	0.2540
Pizarra Puuc	Muna	*Akil Impreso*	15	0.9947	535	1.5101
Pizarra Puuc	Muna	*Muna Pizarra*	567	37.5995	13441	37.9378
Pizarra Puuc	Muna	*Muna Pizarra, chorreado*	156	10.3448	5466	15.4280
Pizarra Puuc	Muna	*Tekit Inciso*	1	0.0663	40	0.1129
Pizarra Puuc	Muna	*Yaxachen Estriado*	4	0.2653	193	0.5448
Pizarra Puuc	No identificado	*Pizarra, erosionado*	40	2.6525	876	2.4726
Puuc Rojo	Teabo	*Teabo Rojo*	23	1.5252	355	1.0020
Puuc sin Engobe	Chum	*Chum sin engobe*	77	5.1061	1948	5.4983
Puuc sin Engobe	Chum	*Yokat Estriado*	496	32.8912	10321	29.1315
Yucatan Lustrosa	No identificado	*Yucatan Lustrosa, erosionado*	4	0.2653	86	0.2427
			1508	100.0000	35429	100.0000

Appendix E: Fisher's Exact Tests

The variation between partial-double and double ring annular structures on the one hand and partial-single and single ring annular structures on the other hand in terms of inner-intermediate-outer distribution:

	Singles	Doubles	Total	combin(a,b)(c,d)	combin((a+b+c+d),(a+c))
Inner	2	5	7	21	1.47711E+13
Intermediate	32	12	44	21090682613	
Total	34	17	51		
		p=	0.029984582	p(1)=	0.029984582
		P=	0.035046914	p(2)=	0.003634495
				p(3)=	0.001427837
				sum(1-3)=	0.035046914

The correlation of intermediate annular structures with other archaeological features related to lime production activities compared to those in the outer zone:

	outer	intermediate	total	combin(a,b)(c,d)	combin((a+b+c+d),(a+c))
<50m	0	20	20	1	13340783196
>50m	11	15	26	7726160	
total	11	35	46		
				p(1)=	0.044499974
				p(2)=	0.007963153
		P =	**0.053042265**	p(3)=	0.000579138
				sum(p1-3)=	0.053042265

Correlation between elite residential groups and annular structures in the intermediate zone compared with the inner zone:

	vault suburb	vault inner	total	combin(a,b)(c,d)	combin((a+b+c+d),(a+c))
<25	6	3	9	84	296010
>25	0	18	18	1	
total	6	21	27		
	p=	0.000283774			
			p(1)=	0.065126178	
	P=	**0.073071856**	p(2)=	0.007661903	
			p(3)=	0.000283774	
			sum(p1-3)=	0.073071856	

Elite residential compounds in the intermediate zone located within 25m of an annular structure compared with non-elite residential compounds in the intermediate zone located within 25m of an annular structure:

			combin(a,b)(c,d)	combin((a+b+c+d),(a+c))
5	13	18	8568	1947792
1	17	18	18	
6	30	36		
			p(1)=	0.02270571
	p=	0.079178886	p(2)=	0.001746593
	P=	**0.024495429**	p(3)=	4.31258E-05
			sum(p1-3)=	0.024495429