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I, Carmen A McCane, hereby submit this original work as part of the requirements for the degree of Doctor of Philosophy in Geography.

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Geoarchaeological Investigations of Human-Environment Interactions in the Maya Lowlands

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Geoarchaeological Investigations of Human-Environment Interactions in the Maya Lowlands

A dissertation submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Geography of the College of Arts and Sciences

by

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Abstract

This dissertation documents geoarchaeological investigations into human-environment interactions in the ancient Maya Lowlands. Further, this research emphasizes the growing importance and subsequent uses of complex systems and resilience theories in the creation of more robust models of ancient environments and behavior. This type of approach encourages researchers to take advantage of the growing array of instrumental techniques available to researchers (e.g., multi-proxy studies of paleoenvironments) which enables researchers to more accurately model the complexities of ancient human-environment interactions. Article 1 is a detailed review article that focuses on published geoarchaeological work in Mesoamerica since the year 2000. Five themes are identified as being central to these most recent geoarchaeological studies: 1) the correlation of environmental change and culture history; 2) anthropogenic environmental impacts; 3) ancient land cover, land use, and diet; 4) archaeological prospection; and 5) provenance studies. Article 2 is a research article that focuses on the Phase II research that was conducted at the Late Classic site of Minanha which is located on the northern portion of the Vaca Plateau in west-central Belize. This article discusses the results of preliminary research into ancient Maya settlement patterns and terrace construction, both temporally and spatially, in a peripheral agricultural community located in the Contreras Valley. Through the use of excavations, spatial statistics, and GIS these investigations were designed to both supplement and expand upon earlier investigations in Minanha’s epicenter by examining the collapse sequence from the viewpoint of a peripheral support population that is believed to have been home to a population that helped to sustain Minanha’s royal court. The Contreras inhabitants had a long occupation history in their valley,
but eventually, they too abandoned their homes just like those who had lived in the epicentral royal court complex (and in the Site Core too). It is this abandonment of the Contreras Valley that is examined in greater detail in Article 3. At the time of abandonment, several artifact assemblages, in the form of termination rituals, were deposited at three domestic groups in the Contreras Valley and these assemblages were used to recreate the abandonment context and chronology of these aforementioned domestic groups. The third article also discusses how these termination rituals/ceremonies may have helped to reshape the identity of social groups who were about to abandon their homes. Article 3 also speculates on how the last inhabitants (of a what is believed to have been a mostly abandoned landscape) lived through a process of gradual depopulation. This dissertation demonstrates that geoarchaeological research directly examines human-environment interactions which can help us to learn about the capacity of humans to adapt to environmental change. More specifically, understanding the success and failure of past societies can help us to predict the sustainability and resilience of these systems. Therefore, learning about the capacity of humans to adapt to both societal and environmental change is the most important enduring product of geoarchaeological investigations of the ancient world.
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Introduction

“Every archaeological problem starts as a problem in geoarchaeology”

Colin Renfrew (1976:2)

This dissertation documents geoarchaeological investigations into human-environment interactions in the ancient Maya Lowlands. Further, this research emphasizes the growing importance and subsequent uses of complex systems and resilience theories in the creation of more robust models of ancient environments and behavior. This type of approach encourages researchers to take advantage of the growing array of instrumental techniques available to researchers (e.g., multi-proxy studies of paleoenvironments) which enables researchers to more accurately model the complexities of ancient human-environment interactions. This dissertation demonstrates that geoarchaeological research that directly examines human-environment interactions can help us to learn about the capacity of humans to adapt to environmental change. More specifically, understanding the success and failure of past societies can help us to predict the sustainability and resilience of these systems. Therefore, learning about the capacity of humans to adapt to both societal and environmental change is the most important enduring product of geoarchaeological investigations of the ancient world.

Further, the popularity of geoarchaeology has expanded exponentially from its origins to its current widespread use at the nexus of archaeology and the geosciences (see Butzer 1982). It is now considered common practice within archaeological excavations and is offered as courses in universities worldwide (Goldberg and Macphail 2006). An introduction to the published articles included in this dissertation is provided at the end of this chapter; first, however, a brief discussion addressing the question “what is geoarchaeology?” is warranted.
**What is Geoarchaeology?**

Renfrew (1976:2) provided these insights into the nature of geoarchaeology:

> This discipline employs the skills of the geological scientist, using his concern for soils, sediments and landforms to focus these upon the archaeological “site,” and to investigate the circumstances which governed its location, its formation as a deposit and its subsequent preservation and life history. This new discipline of geoarchaeology is primarily concerned with the context in which archaeological remains are found. And since archaeology, or at least prehistoric archaeology, recovers almost all of its basic data by excavation, every archaeological problem starts as a problem in geoarchaeology."

The term geoarchaeology was later redefined by Butzer (1982:35) as “archaeological research using the methods and concepts of the earth sciences.” Therefore, geoarchaeology is the combined study of archaeological and geomorphological records and the recognition of how natural and human induced processes alter the environment (French 2003:3). As a result, the main themes in geoarchaeology are as follows: 1) recognition and decipherment of landscape formation and transformation; 2) recognition of the effect of humans in creating, enhancing or managing landscape and environmental change; and 3) identifying the effects of hydrological and burial regimes on the environment and how it has affected archaeological and paleoenvironmental preservation (French 2003:9). Therefore, as Renfrew (1976) and Butzer (1982) emphasized, geoarchaeology provides the ultimate context for all aspects of archaeology from understanding the position of a site in a landscape setting to a
comprehension of the context of individual finds and features (i.e., all problems in archaeology do begin as problems in geoarchaeology). Renfrew (1976) and Butzer’s (1982) (and ultimately French’s (2003) definitions of geoarchaeology have not been free of criticism. For example, Leach (1992) heavily criticized their aims as having no anthropological or culture historical interpretations/perspectives. As a result, Leach (1992) proposed alternative goals for the geoarchaeologist, including the following: 1) material culture – the functions of natural objects in prehistoric societies; 2) cultural attitudes – the symbolic associations of geological materials; 3) subsistence studies – the cultural manipulation of geological resources; and 4) settlement studies – the settlement pattern in the landscape over time. It is now this “blended” approach of Renfrew’s (1976), Butzer’s (1982), and Leach’s (1992) interpretation/perspectives with respect to geoarchaeology that is widely employed in archaeological research that has an interest in examining human-environment interactions. This dissertation exemplifies this type of blended approach.

**Introduction to the Research:**

Chapters 2-4 in this dissertation are published articles on the use of geoarchaeological theories, methods, and techniques in the examination of the archaeological record. Chapter 2 is a detailed review article (Article 1) that focuses on published geoarchaeological work in Mesoamerica since the year 2000. Five themes are identified as being central to these most recent geoarchaeological studies: 1) the correlation of environmental change and culture history; 2) anthropogenic environmental impacts; 3) ancient land cover, land use, and diet; 4) archaeological prospection; and 5) provenance studies. Chapter 3 is a research article (Article 2) that focuses on the Phase II research that was conducted at the Late Classic site of Minanha.
which is located on the northern portion of the Vaca Plateau in west-central Belize. This article discusses the results of preliminary research into ancient Maya settlement patterns and terrace construction, both temporally and spatially, in a peripheral agricultural community located in the Contreras Valley. Through the use of excavations, spatial statistics, and GIS these investigations were designed to both supplement and expand upon earlier investigations in Minanha’s epicenter by examining the collapse sequence from the viewpoint of a peripheral population that is believed to have helped to sustain Minanha’s royal court (e.g., agricultural products). More specifically, what was life like for the individuals living in the Contreras Valley before, during, and after the fall of the royal court. The Contreras inhabitants had a long occupation history in their valley, but eventually, they too abandoned their homes just like those who had lived in the epicentral royal court complex (and in the surrounding Site Core residential zone too). It is this abandonment of the Contreras Valley that is examined in greater detail in Chapter 4 (Article 3). At the time of abandonment, several artifact assemblages, in the form of termination rituals, were deposited at three domestic groups in the Contreras Valley. Analysis of these assemblages was used to recreate the abandonment context and chronology of the aforementioned domestic groups. The third article also discusses how these termination rituals/ceremonies may have helped to reshape the identity of social groups who were about to abandon their homes. Article 3 also speculates on how the last inhabitants (of a what is believed to have been a mostly abandoned landscape) lived through a process of gradual depopulation. Lastly, Article 3 discusses both cultural and natural formation processes that could have contributed to the absence of termination rituals at a majority of these settlement groups. These research article chapters are followed by a Conclusions chapter that briefly
summarizes the results of all three papers and highlights the importance of geoarchaeological investigations in human-environment interactions.
Review Article

Geoarchaeological Investigations in Mesoamerica Move into the 21st Century: A Review

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INTRODUCTION

Geoarchaeology has rapidly emerged as a critical component in the investigation of the ancient cultures of Mesoamerica. Although environmentally centered studies in Mesoamerican civilization can be found as early as one hundred years ago (e.g., Bennett, 1926; Cook, 1931; Huntington, 1917; Sapper, 1896), more concerted efforts truly began in the 1970s and the pace, depth, and sophistication of such investigations has increased substantially in the 21st century. Given the quantity and breadth of geoarchaeological approaches that have emerged in the past two decades, our review cannot pretend to be comprehensive. Rather, we focus chiefly on work published since 2000. Five principal themes that have received special attention in these investigations are: (1) the correlation of environmental change and cultural history; (2) anthropogenic environmental impacts; (3) ancient land cover, land use, and diet; (4) archaeological prospection; and (5) provenance studies. Although these themes will be treated separately below, it is critical to remember that the first three in particular are, in fact, strongly interrelated and to some degree inseparable. In recognition of this interconnectedness, scientists are increasingly adopting complex systems perspectives to model the dynamic interaction of natural and cultural processes that have played out in Mesoamerica (e.g., Dunning & Beach, 2004; Turner & Sabloff, 2012).

The boundaries of Mesoamerica have not been definitively delimited, nor is there universal agreement about the northern and southern extremes of this cultural region. More liberal boundaries extend to the vicinity of Lake Nicaragua in the south and the Yaqui River in Sonora, Mexico in the northwest. We follow a more conservative placement of the boundaries around the Gulf of Fonseca in El Salvador in the south and the Sinaloa River Valley in Mexico in the north.¹ Even this more constricted region is remarkably environmentally diverse (Figure 1). In the north past plate divergence produced horst and graben terrain and many interior basins that

¹For a summary of recent geoarchaeological work in other parts of upper Central America see Sheets 2009. For work on the northern fringes of Mesoamerica see Metcalfe 2006.
have been the foci of much human settlement for millennia. Across much of Mesoamerica the complex convergence of the Caribbean, Cocos, North American, and Pacific plates has created a mosaic of physiographic zones that include merging volcanic arcs, orographic uplift, and subsidence. Adjacent lowlands and basins are the repositories of tens of millions of years of sediment and accretion. Major physiographic regions include the Mexican Plateau and associated ridges and basins, the abutting uplifted masses of the Sierra Madres Oriental and Occidental, the Trans-Mexican Volcanic Arc, the Central American Volcanic Arc and associated folded and faulted highlands, and the huge, partially emerged carbonate Yucatan Platform.

Mesoamerica straddles the Tropic of Cancer, a latitudinal position that typically experiences an annual shift from wet to dry seasons as the Intertropical Convergence Zone (ITCZ) shifts northward and southward and mutes temperature extremes. The distribution of rainfall is also affected by steep elevation gradients created by the region’s mountain systems generating significant rain shadows in many interior and western coastal areas where Easterly Waves cannot bring wet season rains. On the other hand, windward slopes and eastern coast lowlands experience many months of copious rainfall. Thus, Holocene vegetation zones range from tropical rain forests to true desert. When people first entered the region in the Pleistocene, conditions across most lowland areas are believed to have been typically cooler and drier than the present whereas many interior basins were cooler, but wetter. It was within this shifting mosaic of environments that the cultures of ancient Mesoamerica developed.

Pre-Hispanic human occupation of Mesoamerica is often divided into the chronological periods as indicated in Table I. Some scholars prefer different terminology for some time periods, most notably “Formative” in place of “Preclassic.” Population growth (and decline) and cultural developments were not uniform across the entire region. In each period, some sites and regions experienced greater growth or more complete abandonment than their neighbors while others experienced much less
fluctuation. Some regions or parts of regions were abandoned for hundreds of years at a time, while others were never abandoned.

ENVIRONMENTAL CHANGE AND CULTURE HISTORY

Over the past decade plus, the procurement of deep sediment cores from several Mesoamerica lakes has given scientists the ability to reach back into the last portions of the Pleistocene and, thus, contextualize Holocene environmental change in a new light. These older sediments and their embedded proxy data also help to distinguish natural from anthropogenic change in some areas. An 85 ka sediment record from Lake Peten Itza in Guatemala includes distinct dry climate episodes (marked by gypsum precipitation) during stadial and wetter conditions during inter-stadials (Hodell et al., 2008). Extreme aridity is clearly associated with Heinrich Events and cold sea surface temperatures in the North Atlantic, reduced circulation, and the southward displacement of the ITCZ. Oscillations between wetter and drier conditions are also evident in the last 10 ky of the Pleistocene before finally giving way to more persistently warmer, moister conditions in the Holocene. Nevertheless, drier pulses are evident within the Holocene and the data from the Pleistocene raises the question that some of the increased sedimentation resulting from accelerated soil erosion following Maya occupation may have been triggered by episodes of aridity and canopy opening as well as by anthropogenic deforestation (Hillesheim et al., 2005; Mueller et al., 2009).

A 52,000 year sediment record in the Zacapu Basin in Michoacan, Mexico shows moist conditions from 52 ka until a drying trend initiates around 35 ka (Ortega et al., 2002). An undefined event occurs at 25 ka which the authors suggest as a depositional hiatus due to tectonic modification of the basin. Further drying continues throughout the Pleistocene–Holocene transition from 14 to 4.8 ka. After 4.8 ka the authors were unable to separate climatic and anthropogenic environmental changes. A 48,000 year sediment record from nearby Lake Patzcuaro in the volcanic highlands of Michoacán in western Mexico exhibits comparatively little fluctuation in atmospheric moisture. In a 17,000 year record from Lake Zirahuen, Lozano-Garcia et al. (2013) found evidence for cooler and drier conditions in the Pleistocene with a transition to moister conditions beginning around 13.5 ka. Particularly warm periods were noted for 9.5–9.0 ka, a notable cold snap around 8.2 ka, and an especially moist period from 7.5–7.1 ka matching records from elsewhere in Mesoamerica and the North Atlantic. In contrast to other paleoenvironmental records from central Mexico, the Lake Patzcuaro study indicates relatively moist conditions during the Last Glacial Maximum, whereas the other studies suggest generally greater aridity. After 10 ka, the lake began to experience increased eutrophication possibly as the result of losing its former connectivity with the Lerma River. Sequences of paleosols associated with paleolakes in the Basin of Mexico indicate that drying conditions in the early Holocene gave way to greater moisture in the mid-Holocene and brief lake resurgence, before drying conditions resumed in the late Holocene (Sedov et al., 2001). The gradual retreat of the basin paleolakes and the development of better drained soils set the stage for the regional expansion of agriculture in the late Holocene (Sedov et al., 2010).

Perhaps no issue has received more attention in Maya archaeology over the past two decades than the role droughts have played in the course of Maya civilization. Proxy data were originally obtained from a pair of lakes in the northeast Yucatan Peninsula (Chichancanab and Punta Laguna) and focused on changing composition of sediments (e.g., precipitation of gypsum) and oxygen isotope values in ostracods and gastropods (Curtis, Hodell & Brenner, 1996; Hodell, Brenner, & Curtis, 1995). These early studies and other syntheses (e.g., Gill, 2000) were greeted with considerable skepticism by many Maya archaeologists who viewed them as deterministic and also questioned the chronological precision or correlations between apparent drought and the archaeological record (e.g., Aimers, 2007; Demarest, Rice, & Rice, 2004; McAnany & Gallareta Negron, 2010). However, evidence for episodic or cyclical droughts has mounted over the past decade with additional proxies, additional study sites, and enhanced chronological control. These data have led to an acceptance by most Maya archaeologists acknowledging the damaging role droughts may

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<th>Table I</th>
<th>Mesoamerican pre-Hispanic chronological periods.</th>
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<td>Major Period</td>
<td>Sub-period</td>
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<td>Paleolindian</td>
<td>Pre-7000 B.C.</td>
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<tr>
<td>Archaic</td>
<td>7000 – 2200 B.C.</td>
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<td>Preclassic</td>
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have played an active role in the course of Maya civilization, albeit how causal that role was versus other cultural factors remains contentious (cf. the various chapters in Iannone, 2014).

Limnological studies continue to add important data to understanding climate change in the Maya Lowlands. In the northern Maya Lowlands more detailed studies have been conducted at Laguna Chichancab and Laguna Punta Laguna (Hodell, Brenner, & Curtis, 2005; Hodell et al., 2007), Lake Coba (Leyden, Brenner, & Dahlin, 1998), Aguada Xcaamal (a clay-plugged cenote; Hodell et al., 2005), and Lake Tzib (Carrillo-Bastos et al., 2010). In the southern Maya Lowlands, further study of Lake Peten Itza, Lake Salpeten, and Lake Quezil has not only pushed the paleoenvironmental record back tens of thousands of years, but has also resulted in a more refined chronology (Anselmetti et al., 2006; Mueller et al., 2009; Rosenmeier et al., 2002). While earlier studies of the central Peten lakes were unable to distinguish between anthropogenic and climate change signals, newer studies using multiple proxies and enhanced dating have had more success. A brief summary of important findings follows. Since the onset of the Holocene, climate conditions were considerably variable especially with respect to effective rainfall, that is, the amount of rainfall that falls during the typical growing season (Brenner et al., 2002; Hodell, Brenner, & Curtis, 2005). Wetter conditions in the mid-Holocene gave way to a general, progressive drying trend that began about 4000 years ago (Mueller et al., 2009). For the late Holocene, it has been proposed that short-term (centennial scale) fluctuations in rainfall may have been driven by the 208-year cycle of solar output (Hodell et al., 2001; Wahl et al., 2006). Statistical analysis has been used to question the validity of the role of solar periodicity in Maya droughts, but does not question the fact that severe droughts have occurred (Carleton, Campbell, & Collard, 2014).

Mounting paleoenvironmental data indicate that periods of particularly intense drought may have afflicted wide areas of the Maya Lowlands in the 4th century B.C., and the 2nd, 9th, and 11th centuries A.D. Notably, these were not single "megadroughts," but generally a temporally concentrated series of droughts (Brenner et al., 2003). Although most attention has been given to the Terminal Classic droughts of the 9th century A.D., earlier droughts are beginning to garner more attention, especially those centered on the second century A.D. (Figure 2). These droughts had a devastating effect on Late Preclassic Maya populations, including abandonment of many large and small centers, changes that may have helped set the stage for the emergence of Classic Maya civilization (Dunning et al., 2002, 2014a; Hansen et al., 2002; Wahl, Byrne, & Anderson, 2014; Wahl et al., 2006, 2007).

Strong corollary proxy paleoclimate data have been obtained from outside of Mesoamerica, most notably from the Cariaco Basin offshore Venezuela (Haug et al., 2003; Peterson & Haug 2005). Anaerobic conditions in this deep basin have preserved biannually laminated wet/dry season sediments that record droughts in the lower Caribbean that seem to correlate well with the Maya Lowlands record: droughts in both places are linked to the timing and strength of seasonal shifts in the ITCZ.

Detailed records of paleoprecipitation have been obtained from speleothems harvested from caves in Yucatan, Mexico, and Belize. From cave laminae in southern Belize, Webster et al. (2007) used color, luminescence, δ 13C, and δ 18O as precipitation proxies to suggest Preclassic climate flux from drought to pluvial, Late Preclassic (5 B.C. and A.D. 141) severe droughts, Classic Period wetter conditions sandwiching a drought in the Middle Classic (A.D. 517), and Late Classic through Postclassic (A.D. 780, 910, 1074, and 1139) severe droughts. Analysis of a speleothem from Yok Balum Cave in Belize also show clear periodic drought in the Terminal Classic, but with the most extreme peak in the period between A.D. 1000 and 1020, a period not flagged by most other Maya paleoclimate records (Kennett et al., 2012). In northern Yucatan paleoprecipitation records gathered from a speleothem (dubbed “Chaak” for the Maya rain god) found in Tzab Na Cave near Tecoh indicate that the northern lowlands experienced a similar chronological pattern of decreased rainfall including a series of eight multi-year droughts, 3–18 years in length, between A.D. 806 and 935 (Medina-Elizade et al., 2010; Medina-Elizade & Rohling, 2012). These studies show the high potential of speleothems as paleoclimate proxies in the karst Maya Lowlands, including the possibility of providing measures of annual precipitation proxies, by far the finest chronological resolution available. However, it needs to be borne in mind that these records can be severely affected by localized land use changes that may accentuate drought signals for some periods. For example, land use change, possibly including the construction of plastered surfaces above a cave, will undoubtled effect infiltration and percolation. Hence, speleothem records, despite their potential for fine-grained chronological resolution, will be most meaningful when multiple records can be obtained for a locality and region. Other attempts to analyze speleothems are ongoing, but have been limited by dating problems associated with low Th levels and disruptions found in individual speleothem formation processes (e.g., Dahlin, 2011; Smyth et al., 2011).

The record of recurrent aridity also includes many regional soils. The development of Vertisols on alluvium in the lower Usumacinta drainage has been interpreted...
DUNNING ET AL.

Figure 2 Aguada Tintal, San Bartolo, Guatemala: a) Coring aguada floor in 2005; b) sediment composition and pollen frequency of Aguada Tintal core (adapted from Dunning et al. 2014a, Figure 4). The oxidized sediment in Zone 3 marks a Late/Terminal Preclassic drought above an earlier cultivated landscape; dredging removed later Classic period sediment, followed by abandonment and reforestation. Pollen analysis by John G. Jones.

to indicate relative aridity during the Preclassic (Solis-Castillo et al., 2013). In northern Quintana Roo, the punctuated development of Calcisols in depression soils indicates fluctuating moisture levels that likely reflect climate change, though changes in wetland hydrology also likely contributed to varying pedogenic processes (Wolwage et al., 2012). Cave sediments may also reflect cyclical aridity (Polk, van Beynen, & Reeder, 2007).

Although the paleoenvironmental proxy data for ancient droughts in the Maya Lowlands is now compelling, it is also clear that the actual distribution of precipitation was highly variable across both space and time (as it is today, especially during drought years). Such variability is undoubtedly part of the reason that there is an imperfect correlation between the drought record and Maya culture history, especially from the perspective of individual sites and sub-regions. Certainly some regions and sites were more vulnerable to drought, particularly the Elevated Interior Region of the Yucatan Peninsula (EIR in Figure 1) where access to both surface and subterranean water was negligible (Dunning, Beach, & Luzzadder-Beach, 2012). The complex series of historical events that played out across the Maya Lowlands over time make it clear that the ability of different communities and leaders to cope and adapt to drought and other stresses indeed varied greatly (Aimers & Hodell, 2011; Iannone, 2014; Yeager & Hodell, 2008). Nevertheless, it is also clear that droughts have had devastating effects on the Maya Lowlands and its inhabitants for millennia (Gill et al., 2007). The Maya themselves may well have also contributed to the intensification of droughts by removing regional forest cover interfering with water capture and regeneration via transpiration (Cook et al., 2012; Griffin et al. 2014; Oglesby et al., 2010; Shaw, 2003).

Pollen and sediment composition in a core taken from Lake Pompal in the Tuxla Mountains of Veracruz indicate lower water levels and forest canopy opening consistent with a drying trend after 2600 $^{14}$C yr B.P. and peaking around 1300 $^{14}$C yr B.P., though the record is complicated by the concurrent intensification of regional agriculture during this same period (Goman & Byrne, 1998). Farther north in Veracruz, Hudson and Heitmuller (2003) documented the evolving system of natural river levees in the lower Pánuco River Basin linking these to changing basin hydrology through the Late Pleistocene and Holocene.

A speleothem from Cueva del Diablo north of Acapulco in the Mexican state of Guerrero was analyzed by Bernal et al. (2011) for $\delta^{18}$O variation within the carbonate, and used to infer the environmental conditions during the periods of speleothem formation and growth. Moist conditions are largely tied with the influx of glacial meltwater to the Atlantic with precipitation decreasing from the Caribbean as a result of cooler Atlantic sea surface temperatures driving a southern migration of the ITCZ. Pacific climate patterns are suggested to interfere with Caribbean and Atlantic patterns after ~ 4.3 ka, specifically an overall decrease in precipitation resulting from increased influence of El Niño-Southern Oscillation (ENSO) and marked periods of moisture decrease during ENSO warm phases. The two largest climatic anomalies of the Holocene at 10.3 ka and 8.2 ka, expressed elsewhere by low lake levels at Patzcuaro (the 10.3 ka anomaly) and glacial advances on the Iztaccihuatl Volcano, are represented as hiatuses of speleothem growth followed by lower $\delta^{18}$O values. Association with these known climatic anomalies driving the hiatuses, as opposed to other processes, is supported by uranium ratios representing increases in the lighter isotope.
Unfortunately, the speleothem record terminates at 1.24 ka and could not provide paleoclimate data on Terminal Classic and Postclassic droughts that plagued parts of Mesoamerica.

Not unexpectedly, ENSO cycles are fairly apparent in the sediment records of several west and central Mexican lakes (Metcalfe, 2006). Historical records of droughts affecting central Mexico between A.D. 1450 and 1900 indicate a close correlation between ENSO cycles and droughts (Mendoza et al., 2005).

Sediment cores recovered from lakes Tixtla and Huiziltépec, in the West Mexican state of Guerrero document forest cover change from ~ 2.70 ka to 1.95 ka indicative of drier conditions giving way to higher humidity than the modern environment, ~ 1.95 ka to 1.07 ka (Berrío et al., 2006). In Oaxaca, pollen and geomorphic data recovered from the lower Rio Verde suggest that periods of increased aridity and canopy opening in highland watersheds centered around 6.17 ka and 5.34 ka led to increased erosion in upper portions of the watershed and aggradation downstream prior to any significant human impacts (Joyce & Mueller, 1997). Increased ENSO frequencies are also thought to underlie an increase in hurricane strikes in coastal Oaxaca in the mid-late Holocene (Goman, Joyce, & Mueller, 2005).

The most detailed record of past precipitation recovered to date in Mesoamerica comes from Montezuma Baldy, a cypress (Taxodium mucronatum) growing in Queretaro in central Mexico (Stahle et al., 2011). Growth rings in these trees have provided a 1238 year rainfall record including droughts at A.D. 810, A.D. 860, and several between A.D. 897–922, a record that only partly correlates with that of the Maya Lowlands but clearly indicates that Terminal Classic droughts also affected central Mexico. Importantly, periods of droughts are also evident for A.D. 1149–1167, during the decline of the Toltec state, and A.D. 1514–1539 during the Spanish conquest of the Aztec state.

In the Guatemalan Highlands analysis of diatoms in a long sediment core from Lake Amatitlán indicate lowered lake levels during two periods (250 B.C. to A.D. 125, and A.D. 875 to 1375), probably indicative of periods of relative aridity (Velez et al., 2011). On the southeastern edge of Mesoamerica Dull (2004) obtained an 8000-year sediment record from a crater lake in the Sierra de Apaneca, El Salvador. Vegetation and chemical proxies indicate a warm, humid climate during the mid-Holocene optimum (a warm period 9.0 and 5.0 ka), the onset of a cooling, drying trend around 5.5 ka, then stabilization into climate similar to the present day around 3.5 ka. Tephra from the Tierra Blanca Joven (TBJ) eruption of Ilopango Volcano is prominent within the core, followed abruptly by indications of local abandonment and reforestation.

Volcanic eruptions have been linked to climate disruptions and longer term changes around the globe. The largest known stratospheric aerosol loading event of the past 2000 years occurred in A.D. 536 and disrupted global climate until around A.D. 550 and creating agricultural problems in many parts of the world, including possibly within the Maya Lowlands (Dahlin & Chase, 2014). Although the catastrophic TBJ eruption of Ilopango Volcano in El Salvador was originally dated to A.D. 260 ± 114 yrs, a new suite of radiocarbon dates indicate the eruption occurred sometime between A.D. 440 and 550 suggesting a possible link to the A.D. 536 event (Dull et al., 2010; Kutterolf, Freundt, & Peréz, 2008). Regardless of whether or not the TBJ eruption occurred in A.D. 536, it had catastrophic effects across southeast Mesoamerica leading to widespread abandonment of settlements and migration to neighboring areas (Dull, Southon, & Sheets, 2001).

Given the location of Mesoamerica astride convergent tectonic plate boundaries, it is not surprising that volcanism and earthquakes played a significant role in shaping the region’s cultural history—as well as the cultures themselves, particularly their cosmologies (Gill & Keating, 2002; Sheets, 1999, 2008). Although much less studied, earthquake activity also clearly influenced Mesoamerican cultures and their histories (Kovach, 2004). In some instances, effusive volcanic eruptions have also provided archaeologists with astounding opportunities where towns and villages have been rapidly entombed by ejecta. The village of Ceren in El Salvador has now been the subject to decades of productive investigation (further discussion follows below). Another buried site that has revealed a great deal about daily life in Mesoamerica is Tetimpa on the slopes of Popocatepetl Volcano in Puebla, Mexico (Plunket & Uruñuela, 1998). Sheets (2009) astutely points out that given the widespread deposition of tephras dating to the period of human occupation in Mesoamerica, other buried sites surely exist and await discovery; he suggests that deposits around Ceboruca Volcano (see Sieron & Siebe, 2008) in Nayarit might be an especially promising place to look.

The diffusion of volcanic ash is also now known to have played a significant role in the agricultural potential of non-volcanic regions of Mesoamerica. Ash is likely the primary inorganic component in many soils of the southern Maya Lowlands (Tankersley et al., 2011, 2015), and is a significant contributor of clay minerals, silica, and nutrients to soils in the northern Maya Lowlands in addition to Saharan dust (Das et al., 2011; Cabadas-Báez et al., 2010).

Another natural hazard with a frequent recurrence interval in Mesoamerica is hurricanes and tropical storms.
Paleotempestology is still in its infancy in the region, but initial findings are promising. McClosky and Keller (2009) uncovered a 5000-year record of hurricane strikes in two coastal lagoons in southern Belize. Unfortunately, an enormous hurricane in the 15th century A.D. apparently scoured large amounts of sediment from both lagoons, creating a 1700-year gap in the record spanning much of the course of ancient Maya civilization. A more complete sediment record has been recovered in a series of cores taken in the Blue Hole, a submerged Pleistocene sinkhole on the Belizean Barrier Reef (Gischler et al., 2008). These cores indicate numerous hurricanes over the past 1500 years (the limit of the cores), including two major strikes in the second half of the 8th century A.D. Further analysis of the cores indicate that hurricane frequency appears to correlate more strongly with global climate than with local conditions (Denommee, Bentley, & Drowxler, 2014).

Dunning and Houston (2011) examined ethnographic, historic, hieroglyphic, and geomorphic evidence for the effects of hurricanes on Maya history and culture and on the Maya Lowlands environment. Given the high frequency of hurricane strikes across the Maya Lowlands, it is not surprising that these sometimes devastating storms are deeply embedded in Maya cosmology warranting their own deity, a malevolent “sparking serpent.” In the historic and modern era, hurricanes have generated major flooding even in interior regions and are a powerful geomorphic agent presenting clear records in fluvial sediments. Targeted examination of fluvial sequences and coastal deposits in other parts of the Maya Lowlands (e.g. Beach et al., 2009) and elsewhere in Mesoamerica (e.g., Goman, Joyce, & Mueller, 2005; Neff et al., 2006a) will undoubtedly reveal other records of hurricane strikes. Mud layers within a speleothem from northern Yucatan have been interpreted as proxies for tropical storms (Frappier et al., 2014), but are notably suppressed during intense drought episodes when low regional groundwater levels inhibited the filling of caves with water and sediment during storms.

Another environmental change affecting Mesoamerica owes its origin to orbitally driven, long-term climate fluctuations that influence global sea levels. Fluctuating sea levels are especially important on the low-lying Yucatan Platform including the submergence of large portions with sea-level rise at the end of the Pleistocene (~ 17,000–10,000 years ago) and during the early Holocene (~ 10,000–5000 years ago). Although the rate of sea level rise slowed dramatically by the middle Holocene, it continued to affect coastal regions and residents (Van Hengstum et al., 2009).

Geoarchaeological investigations around La Joyanca along the Rio San Pedro Matir, a major tributary of the Usumacinta in the northwestern Peten, Guatemala have uncovered evidence for dynamic environmental changes associated with the Pleistocene-Holocene transition and with the ancient Maya occupation of the region (Galop et al., 2004; Metalle et al., 2003). In this region of muted ridge and valley terrain, late Pleistocene stream channels draining grabens were aggraded, probably as the result of base-level changes in the Holocene. Continued changes in the Preclassic and Classic compelled the Maya to adapt to continued slow sea level rise and spread of wetlands in the coastal plains. In the Holbox Fracture in northern Quintana Roo, wetlands connected to the coast gradually changed and likely triggered cycles of site abandonment and reoccupation and Maya attempts to manipulate wetland hydrology (Fedick et al., 2000; Sedov et al., 2008). In the coastal lowlands of northern Belize and adjacent areas of Mexico, sea level rise triggered changes in groundwater chemistry and aggradation in the region’s low gradient river systems (Figure 3) (Beach et al., 2009; Luzzadder-Beach & Beach, 2009; Luzzadder-Beach, Beach, & Dunning, 2012). Associated wetland field systems were sometimes adapted to changing hydrology, but at other times abandoned. Wetland field systems in coastal Veracruz were likewise affected by sea level rise (Heimo, Siemons, & Hebda, 2004). Sea level rise is also implicated in changing fluvial hydrology and associated settlement at the mouths of the Pˇanuco River in northern Veracruz (Hudson, 2004), the Rio Verde in Oaxaca (Goman, Joyce, & Mueller, 2005) and several drainages on the Pacific coast of Guatemala (Neff et al., 2006).

A natural disaster of the distant past has also had a lasting impact on the cultural history of part of the northern Maya Lowlands. Though buried under later carbonate sediments, the massive 65 million-year-old Chicxulub Meteorite Crater underlying the northwestern Yucatan Peninsula continues to profoundly influence groundwater movement and the development of water-bearing caves and sinkholes (cenotes), and larger structural and solution depressions in the overlying limestone (Hildebrand et al., 1995; Perry et al., 2010). Differences in bedrock chemistry and topography associated with the buried crater also influenced soil development (Pope et al., 1996). These hydrologic and pedologic factors have, in turn, influenced settlement distribution and history across the region (Winemiller, 2007).

ANTHROPOGENIC ENVIRONMENTAL CHANGE

The Lake P´atzcuaro Basin in Michoacan, Mexico has been the focus of a controversy centering on the timing of, and agency behind accelerated soil erosion. Although the lake
has been cored multiple times since the 1940s, much of the controversy has been in the last 20 years. A study by O’Hara, Street-Perrott, and Burt (1993) based on cores taken from many different parts of the large lake reported a positive correlation between Prehispanic population growth and sedimentation rates within the basin as a whole indicating erosion peaking in the Classic and Postclassic. A detailed study of a portion of the southern basin by Fisher et al. (2003) based on deep stratigraphic excavations refuted this correlation finding that soil erosion was at its highest during Preclassic land clearance and settlement, then stabilized as population increased in the Classic and Postclassic periods and heavy investment was made in agricultural terracing, and finally accelerated again in the early Colonial period when regional population crashed and soil conservation measures were abandoned. Detailed analyses of four cores taken from several parts of the basin lend support to the original model of accelerating soil erosion correlating with Prehispanic population growth and agricultural expansion (Metcalfe et al., 2007). It is likely that the more detailed stratigraphy and chronological control provided by excavations in a part of the southern basin reveal more nuanced, but perhaps localized effects that may not be representative of the lake basin as a whole. Similar stratigraphic excavations in other parts of the basin could help resolve this controversy.

At lakes Tixtla and Huiziltepec, in the West Mexican state of Guerrero increases in watershed cultivation (indicated by maize pollen) are documented for the first millennium A.D. (Berrío et al., 2006). Small pulses of increased soil erosion are indicated sporadically in both
lakes during this period, but the most notable increase in erosion is associated with the post-Conquest period. At Lake Zirahuen disturbance is first noted around 3 ka and continues with some oscillations before peaking in the Postclassic around 1350 A.D. (Lozano-García et al., 2013; Ortega et al., 2010). However, the evidence for anthropogenic erosion is complicated by indicators of episodic aridity that may also have induced erosion/sedimentation. Similarly, Park et al.’s (2010) study of two shallow central Mexican maar lakes produced conflated signals for aridity and anthropogenic erosion with peaks in both the Preclassic and Classic times. Another study of Lake Zirahuen and Lake Juanacatlán in Jalisco documented increases in erosion and metal contaminants linked to Colonial agriculture and mining (Davies et al., 2005). In sum, each drainage basin that has been examined exhibits a unique history of anthropogenic change.

In the Maya Lowlands, scholars have for many years linked the decline of Classic Maya civilization with soil erosion and environmental degradation (e.g., Bennett, 1926; Cooke, 1931; Morley, 1946). Combined paleoenvironmental and archaeological studies at Lake Yaxha and other central Peten, Guatemala lakes were used to develop a more quantitative version of this model that posited a direct relationship between population growth, forest clearance, and soil erosion (Deevey et al., 1979; Rice, 1993). While this model does indeed appear to be representative of some investigated catchments, it does not seem to be a universal fit. At Lake Yaxha, high sedimentation rates may have been linked as much to urbanization (the large site of Yaxha sprawled across one side of the lake) as with agriculture. In many areas, the relationship between population growth and land degradation is much less direct. For many studied catchments, soil erosion peaks not with maximum population numbers (typically in the Late Classic), but during the first centuries of forest clearance and agricultural expansion (Anselmati et al., 2006; Dunning et al., 1998; Dunning & Beach, 2000, 2010). Evidence suggests that early farmers were less conservative while land pressure was slight, sometimes with catastrophic results when sloping, unprotected land was subject to erosive tropical rainfall (Beach et al., 2006). By sometime in the Late Preclassic, soil conservation measures such as terracing began to appear in some areas (Beach et al., 2008; Dunning & Beach, 2000; Carazzo, et al., 2007; Garrison & Dunning, 2009; see also further discussion below).

The relationship between population pressure and soil erosion in the Maya Lowlands was sometimes complex. For example, Carozza et al. (2007) document pulses of erosion/sedimentation around La Joyanca, Guatemala. Light population in the Middle Preclassic initiated little erosion, rising population in the Late Preclassic generated large amounts of erosion, but greater population growth in the Late Classic produced notably less erosion, presumably because of the implementation of conservation measures. Following Terminal Classic abandonment, a recolonizing Postclassic population renewed the erosion cycle. There is no question that at times some ancient Maya groups generated catastrophic soil erosion as evident in the utter denudation of hillslopes and the burial of downslope/downstream locations including older occupation sites (Dunning & Beach, 2000; Holley et al., 2000), but more conservative land management was practiced in other places and times and soilslopes were stabilized (Dunning et al., 2009).

An aspect of urbanization in the Maya Lowlands that undoubtedly contributed to land degradation was the quarrying of limestone both for stone and for making lime plaster. This form of degradation may have been most acute in the Late Preclassic, when architectural style favored massive pyramid complexes coated in extremely thick layers of lime stucco, such as in the Mirador Basin area (Hansen et al., 2002; Wahl et al., 2007).

Not surprisingly, soil erosion linked to land clearance, especially for agriculture, has been documented throughout Mesoamerica. McAuliffe et al. (2001) documented severe Prehispanic soil erosion in the Tehuacan Valley of central Mexico, probably during both the Classic and Postclassic periods, and continuing into Colonial and modern times. Prehispanic soil conservation terracing was present in some parts of the valley, but not others. Where present, the terraces were eventually neglected and have largely disintegrated. At Tlaxcala, Borejsza et al. (2008) uncovered a complex landscape that experienced severe erosion in the Preclassic period, followed by abandonment, then reclamation with extensive agricultural terracing in the Postclassic (Figure 4). Some of that erosion was generated by swidden agriculture in high elevation areas (tierra fria) that were brought into production by either population pressure of political economic exclusion (Borejsza, Frederick, & Lesure, 2011). Ancient, Colonial, and modern soil erosion on sloping lands has been widespread in central Mexico (Córdova & Parsons, 1997; Heine, 2003) resulting in the burial of ancient land surfaces within basins and valleys (McClung de Tapiá et al., 2003; Sánchez-Pérez et al., 2013).

Around Laguna Pompl in the Tuxla Mountains of Veracruz, the first forest clearance for agriculture began around 4830 14C yr B.P., but was followed by a hiatus of nearly 1500 years before cultivation resumed around 2600 14C yr B.P. (Goman & Byrne, 1998). Forest clearance was then pervasive until about 1300 14C yr B.P. reflecting the spread and intensification of agriculture in the Preclassic (Formative) and Classic periods, though without generating a notable increase in the deposition
of inorganic sediments indicative of accelerated soil erosion. An earlier study of nearby Lake Catemaco found a similar record of forest clearance with little increase in sedimentation (Byrne & Horn, 1989). Whether the lack of indicated erosion is the result of local watershed characteristics, natural resistance of the region’s Andisols to erosion, or ancient soil conservation practices is unknown.

The Rio Verde drainage basin includes the Nochixtlán Valley, Ejutla Valley, and the Valley of Oaxaca. Many years of research have demonstrated that episodes of soil erosion were triggered by land clearance for agriculture in the upper watersheds during the Preclassic as early as 1500 B.C. and continued episodically through the Classic period, punctuated by periods of stability and soil formation in individual tributaries (Joyce & Goman, 2012; Joyce & Mueller, 1992, 1997; Pérez Rodríguez, Anderson, & Neff, 2011). Erosion in the upper watershed initiated sedimentation in the lower Rio Verde drainage, creating alluvial soils that became a new focus for agricultural intensification and population concentration, though this aggradation also created new flooding problems. Deposition at the coastal outlet of the Rio Verde created a dynamic lagoon environment with new, but shifting resources (Goman, Joyce, & Mueller, 2005).

A core taken from Aguada Petapilla in a small valley near Copan, Honduras showed two peaks in deforestation: around 900 B.C. when agriculture began in the area, and around A.D. 400 when a Maya kingdom was established at Copan (McNeil, Burney, & Burney, 2010). These findings are contrary to earlier studies of Petapilla that indicated accelerating deforestation in the region through the Classic period (Abrams & Rue, 1988; Rue, 1987). The new finding, however, fails to account for the evidence
of significant soil erosion in the Copan Valley during the Classic period (Abrams et al., 1996).

In the Guatemalan Highlands, Velez et al. (2011) correlate increased inorganic sedimentation with forest clearance and soil erosion brought on by population increases in the Middle Preclassic, Early Classic, and Late Postclassic. On the nearby Pacific coast, periods of population growth also correlate with increased fluvial sedimentation (Neff et al., 2006a, 2006b). Population levels, forest clearance, and agriculture are also linked in Laguna Cuzcachapa in El Salvador (Dull, 2007).

In reality, human–environment interactions are often highly intertwined and modeling these interactions requires a complex systems perspective. A good example of the complexity of such interrelationships can be illustrated by the effects of forest removal in the Maya Lowlands (Dunning, Beach, & Luzzadder-Beach, 2012; Turner & Sabloff, 2012), a set of interactions that begins with the nature of bedrock on the Yucatan Peninsula. Much of this limestone bedrock is nearly pure calcite. In the southern Lowlands the inorganic fraction comprising regional soils is largely derived from windblown volcanic ash; in the north the parent material is a compound of volcanic ash, Saharan and North American eolian dust, plus local calcite. While these soils are fairly fertile, they are notoriously low in phosphorus. Over the long term, P is recharged by new inputs of volcanic ash. On an annual basis, P is recharged by inputs of eolian dust (Das et al., 2011; Lawrence et al., 2007). However, as forest is progressively removed from a location, the capture of dust is proportionally diminished leading to decreasing P levels in the soil. Thus, as agriculture was intensified across the Maya Lowlands, P levels in regional soils would have progressively declined. Reductions in forestfallowing would also likely decrease nitrogen levels by reducing inputs from leguminous Leucaena species, which comprise a significant portion of regional forests. Declining soil fertility would have had cascading effects. Yields would have declined necessitating clearance of more forest if available. Plant health would have declined making crops more vulnerable to diseases such as maize mosaic virus. Declining soil fertility would also increase vulnerability to field invasion by weedy species, most notably of bracken fern (Pteridium aquilinum), an aggressive species that thrives in nutrient poor soil and which is noted for invading over-cropped fields in the Southern Maya Lowlands and for being difficult to remove once established (Dunning & Beach, 2010; Pérez-Salicrup, 2004). Thus, ironically, while the high base status soils and tropical climate of the Maya Lowlands were favorable for cultivating maize and supporting high population densities, population growth led to the incremental reduction of forest for construction material, fuel, and farm land would have created a risk spiral within the region, especially when coupled with other environmental and cultural risk factors (Dunning, Beach, & Luzzadder-Beach, 2012; Turner & Sabloff, 2012).

The Maya are a forest people who have accumulated a cultural storehouse of the economic properties associated with trees and other plants including food, timber, fuel, fiber, and medicine among others. Hence, it is likely that for millennia the Maya selectively removed some species and encouraged others. For many years, it has been suspected that even in areas abandoned for centuries, the species composition of the tropical forest in the Maya Lowlands partly reflects ancient forest management (e.g., Gomez-Pompa et al., 1987). Surveys of forest mantling ancient Maya sites have been used to document the species that were likely incorporated into gardens, orchards, or managed forest (Ford, 2008; Ross, 2011; Ross & Rangle, 2011; Thompson et al., 2015). Analysis of wood and charcoal recovered from archaeological excavations also sheds light on the changing composition of ancient forests (Hageman & Goldstein, 2009; Lentz et al., 2014, 2015). At Tikal, Lentz and Hockaday (2009) found that Manilkara zapata, a tree favored for lintels in monumental architecture, was likely carefully managed but eventually became scarce enough to be replaced by another less desirable species. Charcoal recovered from many sites indicate that pine may have become intentionally cultivated in areas outside its natural range because it was favored in ritual contexts (Lentz et al., 2005; Morehart, Lentz, & Prufer, 2005). Genetic analysis is beginning to add a new dimension to understanding the management of tree species through domestication or “wild” management (e.g., Galindo-Tovar et al., 2008; Petersen, Parker, & Potter, 2012; Thompson et al., 2015).

Anthropogenic land use changes also had lasting impacts on hydrology. Forest clearance, agriculture, and quarrying triggered erosion on sloping land surrounding closed depressions (bajos) in the southern Maya Lowlands and the resulting sedimentation often resulted in the blockage of groundwater recharge of once perennial wetlands (Beach et al., 2003; Dunning et al., 2002; Dunning, Beach, & Luzzadder-Beach 2006; Hansen et al., 2002). Sedimentation, eutrophication, and climate drying all likely contributed to the long-term transformation of many perennial wetlands and shallow lakes into seasonal swamps in which deep clay Vertisols developed. However, although many wetlands or parts of wetlands were “degraded”, other parts were actually enhanced from a Maya point of view. Wide aprons of calcium-rich colluvial and alluvial sediment derived from upslope erosion accumulated along the margins of bajos. These aprons of deep, high-base-status soils developed into some of the best agricultural land available in the southern lowlands...
and became the focus of intensive cultivation (Dunning et al., 2002; Dunning, Beach, & Luzzadder-Beach, 2006; Gunn et al., 2002). In some perennial wetlands in riparian settings in the coastal lowlands, canals were dug to facilitate drainage and agriculture (see further discussion below). More than a thousand years later, these canal systems often continue to influence wetland hydrology, ecology, and pedogenesis (Figure 3) (Beach et al., 2009). In the Valley of Guatemala, a canal system associated with former Lake Miraflores may have abetted the permanent desiccation of the lake in conjunction with drying climate (Popenoe de Hatch et al., 2002).

**LAND COVER, LAND USE, PALEODIET**

By 1000 B.C., much of Mesoamerica was becoming an ever-changing patchwork of forest and fields (Dunning & Beach, 2010). Charting how this increasingly humanized landscape changed over time and space has become an ever more sophisticated scientific endeavor. As discussed above, investigations of ancient forests have utilized palynology, macrobotanical analysis of wood and charcoal, surveys of contemporary forests, and studies of genetic variation. As will be discussed in the next section, analysis of carbon isotopes in soil organic matter also offers information about changing vegetation composition. The nature of forest cover can also be partly reconstructed by analysis of fauna recovered in archaeological investigations. The diversity of animal species exploited by residents of investigated Maya sites suggests that a wide range of habitats were visited by hunters (Emery & Thornton, 2008a; Freiwald, 2010). Carbon isotope ratios in the bones of species such as white-tailed deer and peccary indicate that these animals consumed a significant quantity of maize and were probably procured from farmer’s fields (Emery, 2003), though there are indications at some sites that deer were captured and fed maize before slaughter, a practice also used with dogs (White, Longstaffe, & Law, 2001). Variation in strontium isotopes in animal skeletons indicates that at some larger Maya sites animals were being procured from considerable distances, perhaps through trade or tribute (Freiwald, 2010; Thornton, 2011). In the northern Maya Lowlands, species composition of animals recovered from archaeological contexts indicate that most animals were likely procured locally, though higher status households consumed more exotic species as well (Gotz, 2008; Masson & Lope, 2008). In sum, these studies indicate that most Maya sites were surrounded by a mosaic of fields and forest, some fairly mature, some secondary scrub. However, the specific composition of this field/forest mix varied greatly across space and time as reflected in varying mixes of exploited animals (Emery, 2008; Emery & Thornton, 2008b; Somerville, Fauvelle, & Froehle, 2013).

Estimates of the amount of forest cover that existed during regional population zeniths (most typically in the Late Classic) range from as high as 75% to as low as 15%. This range likely reflects both actual place-to-place variation as well as differences in the methods used to reconstruct vegetative cover. Pollen percentages are the most commonly used method, but can lead to underrepresentation of many tree species (e.g., the many insect-pollinated species predominant in tropical forest; Ford, 2008). Macrobotanical remains recovered from archaeological contexts can provide a partial picture of actual forest use, though one biased by both cultural and preservation filters – as well as recovery methods (Hageman & Goldstein, 2009). At Teotihuacan and neighboring sites, the relatively consistent use of certain woody species for fuel and for construction from Preclassic through Postclassic times suggests that some type of forest management was in play within at least this part of the Basin of Mexico to ensure the continued availability of these trees and shrubs (Adriana-Morán & McClung de Tapia, 2008). Nevertheless, widespread sedimentation over long periods in the Teotihuacan Valley indicate that substantial forest clearance occurred resulting in persistent erosion on surrounding highlands (Sánchez-Pérez et al., 2013). Similarly, soil erosion in many watersheds in the Maya Lowlands and other regions of Mesoamerica indicates periods of widespread land clearance, though sedimentation rates also indicate that denudation varied greatly across space and time (see above).

The buried village of Ceren, El Salvador and surrounding land provide the best evidence on the nature of agriculture thus far recovered in Mesoamerica (Sheets, 2002, 2008). At Ceren, rapidly deposited volcanic ash entombed not only the small town, but the gardens and fields worked by its inhabitants (Figure 5). Excavations for many years were concentrated within the village site and its immediate environs. These excavations revealed areas of intensive garden production that included small plots of maize and manioc, as well as beans, squashes, hog plum (Spondias), avocado, guava, calabash, and cacao, among others species (Lentz & Ramírez-Sosa, 2002; Sheets, 2008). These gardens were clearly carefully planned and well tended. More recently, investigations have been extended into the buried landscape beyond the margins of the village site and have revealed extensive fields of maize and manioc (Sheets et al., 2011, 2012). While manioc has been posited as a major crop in Mesoamerica, data had been previously lacking to support this hypothesis. Since the cultivation of manioc and other root crops does not involve...
pollination and the plants naturally produce little pollen, its absence in most archaeological pollen studies is not surprising. Nevertheless, examples of manioc and other root crops are increasingly being found in pollen and macrobotanical records (e.g., Akpinar-Ferrand et al., 2012; Dunning et al., 2003; Lentz et al., 2014, 2015). Although lacking the advantageous burial by ash, investigations at the Maya village site of Chan in Belize have produced paleobotanical and archaeological data that closely parallels that found at Ceren with a diversified and intensified agricultural system that additionally included agricultural terracing (Robin, 2012).

Agricultural terracing was used widely in Mesoamerica occurring to greater or lesser extents in any region with sloping land. In Oaxaca, terracing began to appear in the Middle Preclassic likely in response to increasing soil erosion as land was brought into cultivation (Joyce & Goman, 2012; Kowalewski et al., 2009; Pérez Rodríguez & Anderson, 2013). Similar land degradation processes probably prompted other early investments in terracing in other parts of Mesoamerica including Michoacan and the Basin of Mexico, the highlands of Veracruz, and the Maya Lowlands (Beach et al., 2009; Fisher, 2005; Garrison & Dunning, 2009; Heine, 2003). Terraces systems show great variation in scale and degree of organization. In most cases, accretionary growth appears evident, typically in close association with rural household groups; this association and the lack of apparent central planning indicate that the terraces systems evolved informally as farmers brought more sloping land into production (Beach et al., 2002; Dunning, 2004; Dunning et al., 2003; Dunning & Beach, 2010; Lemonnier & Vanniere, 2013; Wyatt, 2012). In other instances, centralized organization is evident in large-scale, carefully orchestrated systems. Most dramatically, the Maya city of Caracol, Belize grew amidst a system of tens of square kilometers of terracing in a hilly landscape (Figure 6) that would otherwise not have allowed such a large urban population concentration (Chase & Chase, 1998; Dunning & Beach, 2010; Chase et al., 2011). Concentrated terrace systems also were a significant part of urbanization at the major centers of Monte Albán in Oaxaca and Anaguacu near Lake Patzcuaro, Michoacan (Fisher, 2005; Fisher, Leisz, & Outlaw, 2011; Pérez Rodríguez & Anderson, 2013; Joyce & Goman, 2012).

One puzzling aspect of land use in Mesoamerica is the lack of agricultural terracing in some places where such an investment would seem to have been highly beneficial. The ancient Maya city of Tikal is a case in point. Much of urban Tikal lies on gently to steeply sloping land in a region where terracing has been found at nearby sites (e.g., San Bartolo and Xultun; Garrison & Dunning, 2009), only a handful of probable agricultural terraces have been identified at Tikal despite numerous surveys and detailed mapping (Dunning et al., 2015). Carbon isotopes recovered from organic matter within sediments in two of Tikal’s reservoirs, as well as a slow rate of sedimentation in those reservoirs, suggest that the urban residential catchment areas feeding these reservoirs were protected by perennial tree cover (e.g. orchards or tree-dominated gardens) (Scarborough et al., 2012; Tankersley et al., 2011, 2015). This “garden city” model seems to apply to many other Maya cities in the Classic periods as well (Dunning & Beach, 2010; Lentz et al., 2015) and elsewhere, such as the Gulf Lowlands of Veracruz (Stark & Ossa, 2007). Investigations at two sites in the Tuxla Mountains of Veracruz found archaeobotanical evidence for increasing use of tree crops over time.
which would have helped conserve sloping lands (Van-Derwarker, 2005).

Much of Tikal’s staple food production may have taken place on colluvial aprons around localized depressions (“pocket bajos”) and the edges of the sprawling Bajo de Santa Fe on the eastern flank of the city (Balzotti et al., 2013; Dunning et al., 2015; Lentz et al. 2014). An unexpected outcome of Preclassic erosion near many southern Maya Lowlands population centers was the dumping of huge quantities of base-rich eroded soil into the region’s many karst depressions (bajos) which had previously been largely unsuitable for maize agriculture (Beach et al., 2003; Dunning, Beach, & Luzzadder-Beach, 2006; Dunning et al., 2002; Gunn et al., 2002). These areas of new, deep colluvial and alluvial soils became the foci of intensified agricultural production in the ensuing Classic period; at some sites this cultivation is evident in extensive field wall systems, though these are not evident at Tikal.

Another focus of intensive and specialized cultivation in both the southern and northern Maya Lowlands were limestone sinkholes or rejolladas. Deeper, more humid soils in rejolladas allowed these places to be used for dry season cultivation and production of crops with high water demand, most notably cacao (Dunning, Beach, & Rue, 1997; Lentz et al. 2014, 2015; Munro-Strasiuk, Manahan, & Stockton, 2014; Munro-Strasiuk, Manahan, & Stockton, 2014).

Wetlands were a widespread locus of agriculture in Mesoamerica. Wetland agriculture developed early within the Gulf Lowlands of Veracruz, where it may have evolved from cultivation along natural alluvial levées (Arnold III, 2009). Macrobotanical, phytolith, and pollen evidence from this area indicates maize cultivation by 7100 14C yr B.P., the earliest known in Mesoamerica (Pohl et al., 2007). Surprisingly, this area has also produced evidence for the Mesoamerican domestication of sunflowers (Lentz et al., 2008). Investigations in an extensive wetland field complex at Mandinga in central Veracruz indicate that development of the island fields began in the Preclassic and intensive cultivation of the fields continued until the 7th century A.D., when several factors including sea-level rise, aggradation, a volcanic eruption, and regional population decline contributed to abandonment of the system (Heimo, Siemens, & Hebda, 2004). Early agriculture also appears to have been established.
along alluvial levees along the Pacific Coast as well, though this cultivation did not evolve into a system of wetland cultivation (Neff et al., 2006b; Rosenswig, 2006).

Large and small patches of island fields are found in riparian and connected perennial wetlands across northern Belize and contiguous areas of Mexico. Many of these field systems originated in the Preclassic, though use and formation history varies from place to place reflecting both differing and changing environmental and political-economic conditions (Figure 3) (Beach et al., 2009; Pyburn, 1998). One notable finding has been the important though variable role played by the gradual capillary precipitation of gypsum and calcium carbonate in the formation of these field systems (Luzzadder-Beach & Beach, 2009). These systems appear to have given dependent populations greater resilience during the troubling times of the Terminal Classic, but ultimately they too succumbed and the fields were abandoned (Luzzadder-Beach, Beach, & Dunning, 2012). Similar field systems are found along the Candelaria River (Siemens et al., 2002) and wetlands around the Laguna de Terminos in southwestern Campeche, Mexico, but have been subject to relatively little investigation. The true extent of the Campeche fields has only recently become apparent (Figure 7).

The wetlands of the Yalahau Fracture zone in northern Quintana Roo, Mexico were also manipulated by the ancient Maya with a system of dikes and dams, but how this system functioned has not been firmly established (Fedick et al., 2000; Fedick & Morrison, 2004; Sedov et al., 2008). One important use of these wetlands was the harvesting of periphyton that was used to fertilize nearby dryland agricultural fields. Analysis of the agricultural fields in the Yalahau was aided greatly by micromorphological study of soil thin sections (Sedov et al., 2008), a technique that has been little used to date in Mesoamerica (but see Beach et al. 2009; Sánchez-Pérez et al., 2013). Periphyton may also have been harvested from wetlands in northwestern Yucatan to enrich urban garden plots at Chunchucmil, a large urban center located in an agriculturally inhospitable area, though with ready access to groundwater (Beach, 1998; Dahlín et al., 2005; Luzzadder-Beach, 2000).

The best known wetland agriculture system in Mesoamerica is the chinampa or island field system once found over large areas around the margins of lakes within the Basin of Mexico. Unlike other areas of Mesoamerica where wetland agriculture began in Preclassic times, the chinampa system appears to have been developed largely in the Postclassic (Parsons & Morett, 2004). While the chinampa system is known to have been extensive in the Basin of Mexico in the Postclassic, its full extent is not known; analysis of historical documents and remotely sensed imagery is helping to map the former distribution of wetland fields (Morehart, 2012). Chinampa systems are also now known to have extended into lake basins in western Mexico (Fisher, 2005).

Compared to many regions of early civilization, Mesoamerica is not incised with any great river systems. Nevertheless, shorter, less voluminous rivers abound in some areas, but are notably absent in others such as the Yucatan Peninsula. Water management was of critical importance both in areas of abundant surface water as well as those without. The Elevated Interior Region of the Maya Lowlands is an example of the latter, a karst region essentially lacking in perennial surface water and largely inaccessible groundwater (Dunning, Beach, & Luzzadder-Beach, 2012). Yet this region formed the heartland of Maya civilization. Urbanization was achieved by harvesting rainwater during the rainy season, storing it, and metering it out through the dry. Large urban centers required sophisticated hydraulic systems. At Tikal, a multi-tiered system of reservoirs was developed to impound and store rainwater (Scarborough et al., 2012). The majority of harvested water at Tikal was likely used to meet domestic needs, including filtering water entering some reservoirs. A few reservoirs appear to have functioned to protect downstream fields during heavy rains, and may have also provided irrigation water to nearby fields. Given the heavy rains and tropical storms that periodically affect the Maya Lowlands, flood control was an important part of water management systems (Davis-Salazar, 2006). Not surprisingly, sites in the Elevated Interior Region that invested heavily in water management often fared better during times of increased drought frequency (Akpinar-Ferrand et al., 2012; Dunning, Beach, & Luzzadder-Beach 2012; Dunning et al., 2015).

At the large Puuc region site of Xcoch in the northern Maya Lowlands a system of large reservoirs was devised in the Preclassic period (Dunning et al., 2014b). This reservoir system was functionally integrated with the site’s monumental architecture (which funneled water into the reservoirs), systemically linked to the network of household cisterns, symbolically linked to a deep cave underlying the site center (and home to rain god worship), and possibly linked to nearby fields for irrigation. Similar relationships are evident in the hydraulic systems at other regional sites (Isendahl, 2011).

Although irrigation in ancient Mesoamerica was nowhere practiced at the same scale as in parts of the Old World, it was nevertheless of critical importance in some areas. Localized irrigation was a vital part of the agricultural system that supported the huge Classic period city of Teotihuacan (Nichols, Spence, & Berland, 1991; Sánchez-Pérez et al., 2013). With the fall of Teotihuacan, settlement shifted onto the lake plains of the Basin of Mexico.
and irrigation became less important (Parsons & Morett, 2004). Kaminaljuyu, a close political and economic ally of Teotihuacan in highland Guatemala, also adopted an irrigation system (Popenoe de Hatch et al., 2002). Irrigation was also important in other areas including the Pacific piedmont of Guatemala and Chiapas, where it was used to facilitate cacao cultivation (Kaplan, 2008).

**PROSPECTION**

A long-standing problem for archaeologists seeking to understand ancient Maya settlement and land use patterns is the pervasive cover of tropical vegetation over large areas. Aerial surveys have been used since a series of regional overflights by Charles Lindbergh and Alfred Kidder in 1929, but with limited effectiveness except in areas where the forest has been cleared; otherwise only the largest of features are typically detectable under the forest mantle. Recent developments in the use of both satellite and airborne remote sensing techniques offer the promise of revealing the previously invisible ancient landscape at multiple scales. The combined use of several types of multi-spectral satellite imagery and airborne sensors is proving to be of considerable use for locating sites and large landscape features obscured by tropical forest canopy in the southern Maya Lowlands (Sever & Irwin, 2003). Saturno et al. (2007) successfully developed a spectral signature based on IKONOS images to identify Maya sites taking advantage of the differential drainage and nutrient status of vegetation growing on the ruins. However, this signature may be region-specific and needs to be refined, or alternate signatures developed to facilitate site detection in other parts of the southern lowlands (Garrison et al., 2008). Airborne radar has been employed in archaeological survey in the Maya Lowlands since the late 1970s, but system resolution was initially too coarse to be useful—despite errant claims of success. Newer systems such as AIRSAR (Airborne Synthetic Aperture Radar) offer much better resolution and initial experiments have proven successful in site detection (Garrison et al., 2011). Combinations of different imagery can also be used to provide invaluable landscape context data such as topography, physiographic features, drainage, and vegetation (Estrada-Belli & Kock, 2007). However, none of these satellite sensor systems or
Airborne LiDAR (light detection and ranging) was flown over the ancient Maya city of Caracol, Belize in 2009; the results after processing were spectacular in the amount of land surface detail revealed including thousands of house mounds and agricultural terraces (Figure 6) (Chase et al., 2011). While these features were already known to exist at Caracol (existing detailed surface maps allowed for ready ground truthing), the LiDAR survey revealed sprawling, previously unmapped terrace face maps allowed for ready ground truthing), the LiDAR systems and residential areas. Previously unknown physiographic features such as cave openings were also detected (Weishampel et al., 2011).

LiDAR has also been tested on the large Tarascan (Purépuca) site of Anagamuco near Lake Patzcuaro, Michoacan, Mexico (Fish, Leisz & Outlaw, 2011). Though not tropical, heavy forest cover on much of the site made traditional mapping a labor-intensive process, whereas the LiDAR survey revealed many square kilometers of urbanized landscape. High initial costs make LiDAR currently too expensive for most archaeological projects, but its pay off in detailed, digital maps readily incorporated into a Geographic Information System (GIS) makes it a technology of choice for thorough site survey (Carter et al., 2012; Chase et al., 2012). LiDAR has also now been flown over the sites of Uxenka in Belize and Yaxnochac, Campeche and other Maya sites in Mexico with promising results still forthcoming. LiDAR has also been used to good effect at Izapa in Chiapas, Mexico (Rosenswig et al., 2012). The effectiveness of LiDAR suggests it would be a highly useful tool for archaeological survey for other areas in Mesoamerica where ground visibility is very poor (e.g., the tropical lowlands of Veracruz; Stark & Garraty, 2008).

Satellite remote sensing has also been used to good effect in other parts of Mesoamerica, perhaps proving most useful in documenting ancient wetland field systems. Morehart (2012) used analysis of Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) imagery in conjuction with historical maps to reconstruct the extent of chinampa agriculture in the northern Basin of Mexico. Heimo, Siemens, & Heath (2004) document the environmental parameters of wetland field systems in coastal Veracruz. Including digital imagery as part of a research design has the advantage of being readily incorporated into a study GIS (e.g., Estrada-Belli & Kock, 2007; Morehart, 2012).

Subsurface remote sensing techniques are also being effectively employed in some Mesoamerican archaeological projects. Ground Penetrating Radar (GPR) has been used successfully in aggrading landscapes where buried features were constructed at least partially with hard stone like basalt, such as Cotzumalhuapa in the Pacific Piedmo of Guatemala (Safi et al., 2012) and Texcoco in the Basin of Mexico (Arciniega-Ceballos et al., 2009). Magnetic Susceptibility (MS) has also been used successfully in naturally aggrading environments including the Tuxla Mountains of Veracruz (Venter et al., 2006). GPR and MS have also been highly useful in urbanized or urbanizing landscapes, both ancient and modern – essentially anthropogenically aggrading contexts (Arciniega-Ceballos et al., 2009; Chávez et al., 2001, 2005). In environments such as alluvial wetlands of Veracruz where hard stone was infrequently used, gridded augering programs have proven necessary to map subsurface sites (Wendt, 2003). In humid tropical environments it is important to note that low elevation structures can be rendered essentially invisible by bioturbation and organic accumulation, and site surveys should systematically sample open areas (Johnston, 2002, 2004).

Site prospection must also be sensitive to geomorphologically dynamic settings such as within fluvial systems. Given the attraction of riparian environments for settlement, archaeologists should actively look for sites in such settings even though early sites especially might be deeply buried (e.g., Holley et al., 2000). This is especially needed in the search for early, more ephemeral, pre-ceramic sites in fluvial environments that have undergone multiple cut and fill episodes (Figure 8) (Borejsza et al., 2014).

The study of chemical signatures remaining on residual lime plaster floors in order to identify ancient activity areas has been pioneered in central Mexico, particularly at Teotihuacan, then extended to other sites in Mexico, including an ethnoarchaeological study of traditional homes in Tlaxcala which helped developed activity “signatures” (e.g., Barba & Ortiz, 1992; Manzanilla & Barba, 1990). Over time, the sophistication of these studies has increased from the analysis of a few elements to over 20 elements and compounds such as fatty acids and proteins (Barba, 2007).

Chemical prospection for ancient activity areas has been extended to soil floors. Studies have included a signature-establishing ethnoarchaeological study of contemporary earth-floored homes in Las Pozas, Guatemala (Fernandez et al., 2002). At the rapidly buried site of Ceren, investigators had the advantage of chemically testing for activities areas inside and outside houses with in situ architecture, artifacts, and plant remains (Parnell, Sheets, & Terry, 2002). As expected high phosphorus levels were found in food processing, consumption, and disposal areas; iron with areas of animal butchery; and heavy metals with pigment processing. At the rapidly abandoned site of Aguateca, Guatemala phosphorus was similarly found to closely correlate with artifact assemblages indicative of food processing and...
consumption (Terry et al., 2004). At the ancient site of Cancuen, Guatemala, Cook et al. (2006) used ICP-MS (Inductively Coupled Plasma Mass Spectrometry) analysis to test for 60 major, minor, and rare-earth elements collected from two Late Classic house floors, with 30 elements showing enrichment over controls. The most notable concentrations were mercury (likely from processing Cinnabar as a pigment) and gold (since there is no evidence that the Maya at Cancuen processed gold, this enrichment might reflect micro-debitage from jade processing). Like Ceren, at Piedras Negras, Guatemala, Parnell, Terry and Nelson (2002b) found phosphorus to be the most useful indicator of human activity, especially food processing and disposal, iron as an indicator of animal slaughter, and various metals as indicators of mineral pigments. Testing of newly available portable X-ray fluorescence scanner (pXRF) at the Colonial era Hacienda Telchaquillo in Yucatan indicates that this unit was useful for detecting trace metals, but not for phosphorus (Coronel et al., 2014).

Beyond the immediate vicinity of houses, phosphorus continues to be the most useful chemical prospection tool for identifying middens, however, Eberl et al. (2012) found that not all middens show up as phosphorus hotspots, probably because not all trash disposal involved high concentrations of organic wastes. Phosphorus can also be used to identify agricultural gardens and fields where organic amendments were repeatedly applied as part of intensification of cultivation (Dunning, Beach, & Rue, 1997). Once soil use patterns have been identified, soil mapping can be used to extrapolate probable agricultural potentials around and between sites (e.g., Fernandez et al., 2005). Where available, the folk soil classifications used by local traditional farmers can be used to analyze probable land use patterns in the soilscape (Dunning & Beach, 2003; Jensen et al., 2007).

Analysis of residual carbon isotopes in the humin fraction of soil organic matter (SOM) has proven to be an effective tool for understanding ancient rural land use in parts of Mesoamerica. Research in several parts of the world has shown that $\delta^{13}C$ enrichment occurs when a high percentage of vegetation contributing to the buildup of SOM utilizes the C$_4$ photosynthetic pathway such as many tropical grasses, including maize. Changes down the soil profile in carbon isotope ratios can provide an important line of evidence for vegetation change and erosion over time, especially in well dated aggrading profiles. In the Maya Lowlands, paleosols from known agricultural contexts such as terraces and wetland fields provide the most secure evidence for intensive cultivation of maize.
resulting in significant $\delta^{13}C$ enrichment (Beach et al., 2011; Webb, Schwartz, & Healy, 2004). Studies around several ancient Maya sites including Aguateca (Johnson, Wright, & Terry, 2007; Wright, Terry, & Eberl, 2009), Motul de San Jose (Webb et al., 2007), Piedras Negras (Johnson et al., 2007b), and Ramonal (a satellite center of Tikal; Burnett et al., 2012), have documented distinctive spatial patterns for $\delta^{13}C$ enrichment (greater than the 2.5–3% typical from bacterial fractionation) suggestive of fields kept in maize production for extended periods. Altogether, these studies indicate that C$_4$ plants (presumably mainly maize) made up ~ 25% of the vegetation at these sites in the Maya Classic period, but only a few percent today. At Tikal GIS-based soil maps have been used to extrapolate probable zones of maize production beyond sampled areas (Balzotti et al., 2013). However, such extrapolations must remain tenuous for the time being because data points are quite limited. The identification of $\delta^{13}C$ enrichment with in situ maize production must also remain provisional at present because of degrading factors such as slope transport, burial, and the presence of other vegetation that can cause $\delta^{13}C$ enrichment (other C$_4$ grasses and CAM pathway vegetation, both of which can be expected to increase during periods of drier climate; cf. Soils-Castillo et al., 2013). Ultimately, DNA analysis of soil organic matter may provide more definitive information on ancient cropping practices (Speller, 2013).

PROVENANCE

Many provenance studies in Mesoamerican archaeology have focused on obsidian (Braswell, 2004). Many of these studies have been used to elicit trade relations and resource procurement over time (e.g., Brown, Dreiss, & Hughes, 2004; Knight, 2003; Knight & Glascock, 2009). These assessments have become refined enough that changing obsidian sources evident in the archaeological record can be used to help refine site-specific or regional chronologies (Braswell, 2011). Laboratory techniques such as NAA (neutron activation analysis), XRF (X-ray florescence), and ICP-MS have partially replaced visual inspection by refining the elemental “signatures” of obsidian sources (e.g., Ponomarenko, 2004), differentiate sub-sources (e.g., Argote-Espino et al., 2012), and in the prospection for, and identification of more obscure obsidian sources such as that at San Luis, Honduras (Aoyama, Tashiro, & Glascock, 1999). Nevertheless, because visual inspection is capable of distinguishing many Mesoamerican obsidians at almost no cost this method is still widely employed, often as a compliment to machine-based tests and allowing for much greater numbers of samples to be assessed (e.g., Pool, Knight, & Glascock, 2014).

A variety of laboratory techniques have also been applied to other material in Mesoamerica to identify sources and movement. Material for the manufacture of ground stone tools is a scarce resource in the Maya Lowlands and manos and metates made from hard igneous and metamorphic rocks from the Maya Mountains were a valuable item. Abramiuk and Meurer (2006) used thin section analysis to pinpoint sources for ground stone artifacts in the Bladen District of Belize. Jade is also a scarce resource, with the only known source area in Mesoamerica occurring in the Motagua Valley of Guatemala. However, ICP-MS analysis has been employed to begin to distinguish the homogenous jadesites on the north side of the valley from more chemically heterogeneous sources on the south side (Neff, Kovacevich, & Bishop, 2010). Chert, perhaps the most widely stone used for tools in Mesoamerica, has largely defied attempts to develop elemental signatures tied to specific sources (Bishop, 2014).

Other provenance studies have sought to identify or differentiate important clay sources, largely in an effort to develop and refine trade models. This endeavor has proven most successful in areas with greater geologic diversity which produce distinctive elemental signatures within clay, temper, and pigments used in ceramic manufacture such as in the Mexican and Guatemalan highlands (Alex, Nichols & Glascock, 2012; Charlton et al., 2008; Iñañez et al. 2010; Neff et al., 2000; Reents-Budet et al., 2006). Although in use in archaeology since the 1930s, petrographic analysis continues to be a useful tool for identifying distinctive minerals within ceramics as well as microstructure (e.g., Stoltman, 2011), though often coupled with other techniques such as NAA and ICP-MS (e.g., Cecil, 2007). Despite the increasing precision of data being produced by the application of instrumental techniques to Mesoamerican ceramics, interpretation of these data can still be contentious as seen in the lively debate over directionality of trade among the Olmec and Olmec-linked cultures (cf., Blomster, Neff, & Glascock, 2005; Neff et al. 2006c; Neff et al. 2006d; Sharer et al., 2006; Stoltman et al., 2005).

Attempts to establish clay/ceramic provenance in the Maya Lowlands have met with much more limited success because of more limited geologic diversity (e.g., Bartlett et al., 2000), and seemingly require a multiplicity of techniques to be successful (e.g. Cecil, 2007). However, exceptions occur, including the rare palygorskite that was mixed with indigo to make the unique Maya Blue pigment (Arnold et al., 2007).

One localized provenance study sought the sources for bitumen found in Olmec archaeological sites (Wendt & Lu, 2006). Provenance studies have even helped bring
scientific scrutiny to items of pseudo-scientific interest: a combination of microscopy and mineralogy was used to demonstrate that at least two of the “mysterious” crystal skulls could not be of pre-Columbian manufacture or of Mesoamerican origin as had been purported by some (Sax et al., 2008).

One of the many effects of the Chicxulub meteor impact on the Yucatan Platform was the creation of a distinctive generally north-south differential distribution of strontium isotopes across the landmass (Gilli et al., 2009; Hodell et al., 2004). Strontium isotopes, of course, vary across Mesoamerica along with geologic substrates. Human bones absorb small amounts of Sr during childhood growth years. Hence, both places and the humans who grew up there have distinctive Sr signatures, a fact that has led to what are essentially human provenance studies (Price et al., 2008). One notable study of a large skeleton population from Tikal, Guatemala was able to identify immigrants to the city (Wright, 2005). Skeletal detective work has been used to check hieroglyphic inscriptions, iconography, and artifacts that suggested interrelationships between Tikal, Teotihuacan, Kaminaljuyu, and Copan (Price et al., 2010; Wright, 2005; Wright, 2012; Wright et al., 2010), and movement of population through the port town of Xcambo in northern Yucatan (Cucina et al., 2011). Oxygen isotope ratios have also proven useful for differentiating populations and individuals of different geographic origins, particularly between Teotihuacan and the Maya Lowlands and Highlands (White et al., 2000, 2001).

In a review of the use of instrumental technologies to address provenance and other economic issues in the ancient Mesoamerican economy, Bishop (2014) extols the many advances in precision and variety of techniques available to archaeologists today. However, he also decrees the apparent declining use of these techniques to high costs and the closure of research laboratories by universities and other entities as part of fiscal cutbacks. On the other hand, the incorporation of the growing body of provenance data into centralized geographic information systems is helping create more robust spatial-temporal models of ancient exchange patterns, such as that being developed for Central Mexican ceramics (Nicholas, Stoner, & Crider, 2014).

CONCLUSIONS
Forty years ago, a review of geoarchaeological research in Mesoamerica would have been short, but not sweet. Studies in which paleoenvironmental concerns were given more than passing consideration were just emerging. Today, a review of geoarchaeological research of even a few years finds a large and expanding array of studies that either employ geoarchaeological techniques or are driven by concerns central to geoarchaeology such as those discussed in the preceding pages.

A common element in each of the areas reviewed above is the growing recognition of the importance, and consequent use of convergent approaches in order to create more robust models of ancient environments and economies. These approaches include multi-proxy studies of paleoenvironments, land use, and ancient diet to take advantage the growing array of instrumental techniques available to researchers (e.g., Lentz et al., 2014; Morell-Hart, Joyce, & Henderson, 2014; Wahl, Byrne, & Anderson, 2014). A highly promising new approach involves the analysis of hydrogen and carbon isotopes in plant-wax lipids preserved in sediments, because it potentially provides a direct measurement of climate signals along with land cover/use data (Douglas et al., 2012), though time and costs currently constrain its application. In the area of prospection, the introduction of airborne LiDAR to the archaeological study of heavily forested areas of Mesoamerica has revolutionized the ability of performing complete site surveys, a formerly cost and time prohibitive possibility. In provenance studies, the convergent use of multiple instrumental techniques has allowed for tremendous gains in the accuracy of sourcing ancient materials. However, as Bishop (2014) has cautioned, these advances are threatened by their very complexity and expense in a time of fiscal constraint in many academic and other research institutions.

As information about the ancient cultures and environment of Mesoamerica accumulates at a rapid rate, our models need to reflect the complexity of interactions that took place in the past. Complex systems models can provide a useful means of intertwining cultural and environmental factors and processes (e.g., Turner & Sabloff, 2012). The power and success of these models depends in great part on their ability to synthesize and correlate large quantities of data in effective and meaningful ways. In pursuit of this goal it is imperative that the rapidly growing body of data being produced by geoarchaeological and other types of archaeological investigations be incorporated into databases capable of supporting integrated analyses. Geospatial databases offer one effective way to synthesize and compare data from multiple sources in support of temporally dynamic models (e.g., Chase et al., 2012; Heckbert, 2013; Kennett & Beach, 2013; Nichols, Stoner, & Crider, 2014).

As Sheets (2009) has pointed out, the large majority of investigations in which geoarchaeology plays an important role are based in processual theory. Although this focus has proven highly productive, it has tended to exclude more humanistic perspectives. In issues such...
as the role of drought in the Terminal Classic collapse of Maya Civilization, the dominance of processual studies has led to charges of determinism (Aimers, 2007; McAnany & Gallareta Negrón, 2010; Webster, 2002). As noted by Sheets, cave investigations are one area where processual and humanistic approaches are being wed (e.g., Brady & Prüfer, 2010). Given the symbolic importance attached to caves in Mesoamerican cultures, the convergence of investigations seeking the “meaning” of caves and their uses and those seeking paleoenvironmental proxies is to be expected. For example, speleothems are an archive of paleoclimate information and are also important artifacts used in ancient rain-related rituals (Brady et al., 1997; Moyes et al., 2009).

Resilience theory (Holmgren & Gunderson, 2002) offers one useful avenue for synthesizing human-environment interactions (Redman, 2005; Scarborough, 2009). This perspective sees human-environment systems as an open set of relationships and interdependencies that either adapt to change and survive, or fragment and collapse; human beliefs and actions are an integral part of the outcomes. An important aspect of coming to understand human-environment systems from this perspective is that not only does it help us understand the success and failure of past societies, but can help predict the sustainability and resilience of these systems and their components in the future (Fisher et al., 2009). The perspective of using information gathered from archaeological investigations of all kinds, especially those that most directly involve human-environment interactions, underlies a growing body of research (for example, that supported by the IHOPE initiative: Costanza, Graumlich, & Steffen 2007; Chase & Scarborough 2014). Ultimately what we can learn about the capacity to adapt to environmental change, including that induced by human activities, may be the most enduring product of geoarchaeological studies of the ancient world.

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A CONSIDERATION OF THE SPATIAL ARRANGEMENT OF SETTLEMENT GROUPS AND TERRACES IN CONTRERAS, MINANHA, BELIZE

Carmen A. McCane, Scott A. Macrae and Gyles Iannone

Even though the extent of “greater Minanha” has not yet been defined, early investigations indicate that many of the surrounding valleys and hilltops were home to the people and communities that helped sustain Minanha’s Late Classic royal court. More specifically, Contreras is a one kilometer square zone located approximately one kilometer southeast of Minanha’s epicenter and is situated a densely terraced valley with an abundance of archaeological remains. In 2006, Phase II investigations began in Contreras which have focused on examining the composition of this peripheral settlement community. As a result, for the past four field seasons, reconnaissance, excavations within the settlement groups, and the mapping of the terraces have been completed in order to examine the organization of these aforementioned anthropogenic features. More specifically, this research is aimed at exploring settlement patterns and terrace construction, both temporally and spatially, of the Contreras inhabitants through excavations and by integrating spatial statistics and GIS. Lastly, these investigations were designed to both complement and expand upon previous investigation in Minanha’s epicenter by examining the collapse sequence from the standpoint of a peripheral support population.

Introduction

Minanha is a medium sized center located within the North Vaca Plateau of west-central Belize, near the Guatemalan border. The center is situated almost equidistant between two of the major power houses in the ancient Maya world, Caracol and Naranjo (Figure 1). Minanha was first documented in 1922 when a chiclero came across the ruins while searching for chicle trees (Iannone 2004:3). Five years later in 1927, the British Museum mounted an expedition to map the site and carry out test excavations (Joyce et al. 1927). In 1997 Trent University’s Social Archaeology Research Program was asked by the Government of Belize to relocate the site, and assess the potential for carrying out an archaeological project there. Unfortunately, it soon became clear that the site was incorrectly marked on the government map; however, in May of 1998, the site was eventually relocated.

Community Archaeology at Minanha

In the summer of 1999 a long-term research project was initiated at Minanha. In 2006, Phase I investigations were completed at Minanha, those focused on extensive excavations within Minanha’s epicenter, the royal court complex. The Phase I investigations provided a view of the rise and fall of the Minanha city-state from the viewpoint of Minanha’s royal court (Figure 2). Phase II
investigations which began in 2006, focused on the composition of two settlement zones, the Site Core and Contreras Zones, which are of varying distances from Minanha’s epicenter (Figure 3). The Phase II investigations in the Site Core Zone and in the Contreras Zone were designed to both complement, and expand upon, the previous investigations in Minanha’s epicenter. Specifically, they were aimed at examining the rise and fall of the Minanha city-state from the perspective of the support population. Archaeologists investigating the ancient Maya cannot rely on interpretations derived only from the epicentral court complexes, nor from the sole examination of the peripheral settlement zones. Rather, as Iannone (2006:18) suggested at the onset of the Phase II investigations, an “archaeology of community,” which combines the two perspectives, must be completed (see also Yaeger and Canuto 2000:10-11). The Phase II investigations had three broad goals: 1) to compare the settlement densities and composition of two settlement zones of varying distance from the Minanha epicenter; 2) to excavate a stratified sample of settlement units in both study zones; and, 3) to map the large-scale ancient Maya terrace agricultural system associated with one of the settlement zones. This paper will discuss the research conducted in association with the Contreras settlement zone, along with its associated terrace agricultural system.

The research design, for the Phase II study at Minanha was formulated so as to emulate the methods employed by the neighboring Xunantunich Archaeological Project (XAP), directed by Richard Leventhal (University of Pennsylvania) and Wendy Ashmore (University of California, Riverside) (Iannone 2006). This was for three primary reasons. First, Xunantunich exhibits a developmental sequence similar to Minanha’s, and it is of comparable size and complexity. Secondly, at both centers a concerted effort was made to conduct detailed investigations were carried out in both the epicenter and in the periphery. Lastly, the researchers involved with XAP have produced a multitude of publications by which comparative examinations can be made. The terrace survey design also followed methods employed at Xunantunich. For example, in the most basic sense, terraces are retaining walls built of stacked stones running perpendicular to the slope of the hillside to retain and increase the depth of soil, regulate and distribute water, and enhance the nutritional value of the soil, they can be classified into several different types that exploit various topographical situations and involve different construction methods. The different construction methods have been noted in the past and used to group terraces into “sets” which have been classified as “individual terraces (that) are roughly parallel and collectively appear to manage the same immediate topographic setting.” (Ashmore et al. 1994:259). At Xunantunich, Neff (2008:63-66) created a classification scheme based on terrace characteristics, association to other terraces and to structures. This classificatory model was followed at Minanha, although it was slightly tailored for the Contreras Valley.
Contreras Valley

The Contreras Valley is located approximately one kilometer south of the Minanha epicenter, and was chosen as one of the two Phase II settlement areas because it was considered to have once been a diverse segment of the greater Minanha community, particularly because it is a densely terraced valley with an abundance of archaeological remains (Figure 4). Contreras is bounded on the north, east and west by sloping hillsides which offered its inhabitants an ideal location for the placement of terraces, which are easily observed throughout the valley. In addition to the terraces, settlement groups of various sizes are distributed across the landscape. Over the past four field seasons, reconnaissance, excavations within the settlement units, and the mapping of the terraces in Contreras have been completed in order to examine the temporal and spatial organization of these anthropogenic features. The settlement in Contreras will be discussed first followed by a discussion of the agricultural terrace system.

Settlement in the Contreras Valley

The settlement units in Contreras range in composition from single, isolated mounds to organized orthogonal units consisting of multiple structures. These settlement groups have been organized into seven types based on the Xunantunich Archaeological Project’s classification scheme (Table 1). The seven different group types are based on number of structures, formal arrangement, and height of structures present in the settlement units. Differences in the characteristics of the aforementioned classification scheme are assumed to have social implications. Originally, a 20% random sample of these units was generated to determine which units would be subject to excavations. The sample was stratified based on the settlement types, so that it would accurately reflect the settlement group frequencies for the population. However, after more reconnaissance in Contreras, and the eventual discovery of more settlement units, it was determined that a 15% stratified random sample of these units would have to be a sufficient in terms of generating a representative sample of the settlement community. There are 98 known settlement units in
<table>
<thead>
<tr>
<th>MINANHA PHASE II SETTLEMENT STUDY: CONTRERAS ZONE</th>
<th>Identified Settlement Units Within the Contreras Zone</th>
<th>Randomly Selected Settlement Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV: 5 or more mounds (informally arranged; all less than 2 m high)</td>
<td>0</td>
<td>none</td>
</tr>
<tr>
<td>VI: 1 or more mounds (at least 1 being higher than 5 m)</td>
<td>2</td>
<td>MR815</td>
</tr>
<tr>
<td>VII: 1 or more mounds (at least 1 being higher than 5 m)</td>
<td>2</td>
<td>MR84</td>
</tr>
</tbody>
</table>

**Table 1:** Minanha Phase II Settlement Study: Contreras Zone.

**COMPARISON OF UNIT-TYPE DISTRIBUTIONS BY ZONE (Count)**

<table>
<thead>
<tr>
<th>Zone</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contreras</td>
<td>47</td>
<td>17</td>
<td>28</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>Epicenter</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Site Core</td>
<td>10</td>
<td>6</td>
<td>18</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>59</td>
<td>23</td>
<td>51</td>
<td>9</td>
<td>7</td>
<td>2</td>
<td>151</td>
<td></td>
</tr>
</tbody>
</table>

**COMPARISON OF UNIT-TYPE DISTRIBUTIONS BY ZONE (Percentage)**

<table>
<thead>
<tr>
<th>Zone</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contreras</td>
<td>48.0%</td>
<td>17.3%</td>
<td>26.8%</td>
<td>4.1%</td>
<td>2.0%</td>
<td>0.0%</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>Epicenter</td>
<td>14.3%</td>
<td>0.0%</td>
<td>36.7%</td>
<td>14.3%</td>
<td>21.4%</td>
<td>14.3%</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>Site Core</td>
<td>25.6%</td>
<td>15.4%</td>
<td>48.2%</td>
<td>7.7%</td>
<td>5.1%</td>
<td>0.0%</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>100.0%</td>
<td>15.3%</td>
<td>38.8%</td>
<td>6.0%</td>
<td>4.6%</td>
<td>1.3%</td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>
Contreras, compared to 14 settlement units in the epicentral zone, and 39 in the site core zone (Table 2). Of the 98 settlement units in Contreras, 64.3% of them are either of the Type I or Type II variety, which indicates that most of the units are made up of a limited number of buildings and are informally arranged. Within the epicentral zone, only 14.3% on the settlement units are of the Type I or Type II variety, and in the site core zone 41% of the settlement units are of the Type I or Type II variety. Additionally, only 35.7% of the settlement units in Contreras are formally arranged, while 85.7% of the settlement units in the epicenter are formally arranged, and 59% of the settlement units in the site core are formally arranged. For the larger and more formal settlement units in the Contreras Valley, Iannone et al. (2006:121) have hypothesized that these units may represent long-standing rural families. They also suggest that many of the solitary mounds represent special function or field buildings. In summation, as you move away from the epicenter, the density of the settlement units increases, but their formal arrangement decreases.

Preliminary ceramic analysis from the excavated settlement units indicates that the Contreras valley was inhabited from at least the Late to Terminal Preclassic all the way through the Terminal Classic. Therefore, there was a population residing in the Contreras Valley settlement zone long before the establishment of the royal court and Minanha and a population was able to keep persist in the valley after the fall of the royal court.

It was initially thought that the hilltops in Contreras were “prime locations” for the more formally arranged settlement units because the inhabitants would have had a commanding view of the Contreras Valley when outside of the buildings. Additionally, it was believed that single isolated mounds and “less organized” groups would be located at lower elevations. Thus, a chi-square goodness of fit test was conducted to test these hypotheses. A chi-square goodness of fit was selected as an appropriate test because the comparison desired examines how two nominal variables are related, in this case testing to see if differences exist between group type (1 through 7) and elevation (low, middle, high). The relationship between group types and elevation was found to be statistically insignificant (calculated chi-square = 6.92; critical chi-square = 15.507, p = 0.05). Therefore, elevation may not have had any impact over where the residents chose to reside, and some other variable (e.g., agricultural potential) may have been the primary determinant. Additionally, Average Nearest Neighbor analysis was conducted in ESRI’s ArcMap as a preliminary investigation of the distribution of settlement groups in Contreras. The results are as follows: the calculated R-statistic was 0.99. Since the R-value is smaller than 1.00 it indicates that the settlement groups in Contreras are dispersed randomly across the one kilometer square survey area. In reality, however, spatial settlement arrangements can rarely be described via the three “traditional” idealized states of point distributions: random, clustered, or dispersed. More specifically, the analysis of spatial settlement patterns should be sympathetic to the fact that several diverse, small-scale patterns may exist within a study area, and that different types of patterning often exist at different scales. In other words, nearest neighbor analysis may overlook more complex spatial patterns because it is sensitive at only one scale (Conolly and Lake 2006:162-164). Further, the underlying spatial process may not be homogenous over the study region in regard to the point distribution being analyzed. Therefore, in the future, a Ripley’s K-statistic will be conducted in ArcMap on the Contreras data to evaluate if clustering is present and, if so, to assess its magnitude; these results will enables us to depict the randomness of the settlement groups over different spatial scales.

Lastly, Iannone et al. (2006) reported that a majority of the settlement groups in Contreras are situated on the terraced hillside as opposed to the valley bottom. This type of settlement patterning may be indicative of a conscious effort on the part of the Contreras residents not to build on the rich soils of the valley bottom because these areas would have been the most fruitful agricultural lands. This
may explain why, while the results are not significant, there is some clustering present on the hillsides.

We have just provided you with a brief overview of what the settlement in the Contreras Valley is like with respect to the spatial distribution and with respect to compositional settlement in the site core and epicentral zones. Now, it is time to examine the Contreras Valley agricultural terrace system in more detail.

**Contreras Agricultural Terrace System**

Examining the relic agricultural terrace systems and the culturalized landscape found in the Contreras Valley has provided us with avenues into understanding both the socio-political and socio-economic organization of the valley. The Contreras valley terrace survey was carried out over the last four years. The survey was oriented towards examining a sample of terraces from the varying topographic situations found throughout the valley. This was accomplished with a small team of surveyors, a GPS, and a theodolite.

As previously mentioned, the terraces have been classified into sets using the same typology employed by the Xunantunich project (Ashmore et al. 1994:259). Contour terraces are the most common, known to vary in length and follow the topography of the hill slopes (Beach
et al. 2002:386). Within the Contreras Valley, they are found prolifically along the twisting slopes of the interfluvial residual hills and the primary valley (Figure 5). Linear terraces are placed independent of contours, and have been observed to run up and down slopes between terrace systems to create lattice-like patterns, or perpendicular to contour terraces to create vast level fields (Demarest 2004:138; Kunen 2001:326; Treacy and Denevan 1994:98-100) (Figure 6). Box terraces or rectangular terraces are found on moderate flat land, in close association with residential complexes (Beach et al. 2002:386; Dunning and Beach 1994:58; Kunen 2001:326) (Figure 7). These are uncommon or easily hidden in or erased from the landscape, and few examples exist within the Contreras Valley (Beach et al. 2002:386). This set also includes many terraces that are not strictly box terraces, but rather terraces exhibiting extreme complexity in close association with settlement units. Cross-channel terraces, also known as weir or check dams, are usually short and tall, and are found in the smaller subsidiary valleys between the residual hills, running perpendicular to gullies, drainages, and other locations that exhibit constricting topography (Kunen 2001:326; Treacy and Denevan 1994:96) (Figure 8). These are often found running perpendicular to contours (Kunen 2001:326; Treacy and Denevan 1994:96). Footslope terraces are found at the base of steep slopes that exhibit very little to no terraces (Beach et al. 2002:387; Dunning and Beach 1994:59-60; Kunen 2001:327; Treacy and Denevan 1994:100-101) (Figure 9). They are rare within Contreras Valley as hills rarely get steep enough to be suitable for contour terracing. The goals of footslope terraces are to control erosion and collect the runoff thereby creating large, flat, plots of land below the hill slopes (Beach et al. 2002:387; Kunen 2001:327). The aforementioned five terraces types, with their specific topographic locations, provide an empirical way to group them. The issue that arises, however, is whether these sets reflect any degree of differing social organization, or simply the environmental situation?

Terraces are found abundantly throughout the Contreras Valley and they were built in all locations conducive to terrace farming. Within the surveyed area there are a total of 458 terraces covering 36.5 hectares of land. These data are indicative of the high density of terraces in the valley (Figure 10). Several of the terraces span great distances, 10 of which are over 100 m in length and one that is 217 meters long. The terraces also exhibit great uniformity, which is supported by the ability to classify the terraces into clear “sets”. In several cases longer terraces are incorporated into several different “sets”, which effectively changes their classification. It is also apparent that a few areas in close proximity to settlements exhibit a significant increase in the frequency and complexity of terraces. These terraces often transcend both terrace typology and slope characteristics. This has produced an interesting mix, with the construction of some large-scale terrace networks that extend beyond individual households and terrace “sets”, along with others that are likely reflective of more intensive, small-scale household systems.
found within the Contreras Valley were also used. The individuals building the terraces were taking advantage of these formations by either starting or ending on the bedrock outcrops, which incorporated them into the overall design. This further reduced the labor needed for both construction and maintenance. One final observation was noted on the construction of the Contreras Valley terrace system. Throughout the valley there were varying levels of terrace quality. High quality terraces are found in close proximity to certain settlement units, sometimes linking groups and key agricultural plots together (Macrae et al. 2008). In contrast, low quality terraces serve to articulate the high quality terraces in many cases, creating convex platforms (Macrae et al. 2008). Unfortunately, this observation will remain purely speculative unless extensive terrace excavations are undertaken.

Agricultural terraces have been notoriously difficult to date. Within the Contreras Valley we have been lucky in the fact that three of our settlement excavations have uncovered underlying terrace constructions. These underlying terraces have been dated to as early as the Late Preclassic. When combined with our settlement data, we hypothesize that there was a small population of agriculturalists using and constructing these terraces during the Late Preclassic. During the Late Classic, with the establishment of the royal court at Minanha, the Contreras Valley saw a significant settlement increase in conjunction with the development of the vast terrace system. This is substantiated by the degree of incorporation between the visible terraces and the majority of settlement groups dating to this time period. Then, during the Terminal Classic—with the collapse of the royal court and subsequent depopulation in the epicenter—the settlement in Contreras also saw a gradual decline; but, several of the larger settlement groups established during the Early Classic in Contreras continued to be occupied into the Terminal and Early Postclassic periods.

In broader terms, the primary goal of the survey has been to explore the socio-political and socio-economic organization behind the construction and maintenance of the Contreras Valley terrace systems. In the Maya lowlands there is considerable variability in the timing, scale, spatial patterning, and forms of terrace field systems. This is thought to reflect differences in the social-political organization of agricultural production and intensification at different centers. Traditionally, this data has been used to interpret terrace systems as being the result of centralized, decentralized, or more recently, heterarchical socio-political organization.

A centralized development is an intensive, top-down approach to community growth reflecting a hierarchical process, and interpreted as evidence of the direct involvement of political elites in the organization and control of surplus (Demarest 1994:146). Decentralized growth is a bottom-up, non-hierarchal process based on individual farming households, lineages, or communities that involve the local control and development of extensive agricultural systems (Beach et al. 2002:386; Demarest 1994:146). Heterarchical organization exists in the middle ground, incorporating aspects of both hierarchical and non-hierarchical social organizations (Crumley 1995:3; Scarborough et al. 2003:xiv). Social structures defined as heterarchical are more reflective of the complex organization, adaptability, and flexibility of typical human societies (Crumley 1995:3; Scarborough et al. 2003:xiv). This complex management system works on all levels of society, from agricultural production, to
settlement organization, to social structuring, involving both vertical and horizontal power relationships (Crumley 1995:3; Potter and King 1995:17). Horizontal relations include societal elements perceived to be unranked and equivalent to each other (Crumley 1995:3; Potter and King 1995:17). Vertical relations occur on a tiered, ranked organization. Heterarchical social organization networks assume different roles of ranking depending upon their context of use (Crumley 1995:3; Potter and King 1995:17). This flexibility makes elements within society unrankable in comparison to each other, or when ranking is possible; the ability to be ranked in a variety of different ways is retained based on participation in individual systems (Brumfiel 1995:3,15).

The results from the terrace survey in, Contreras Valley, suggests aspects of centralized and decentralized organization. The uniformities found within the terrace construction, organization, and typology is suggestive of a well-founded knowledge of the principles of terrace construction. The interconnectivity with surrounding terrace systems, high number, and the protracted length of several of these terraces, suggests a level of interaction that extends beyond the household, and involves a large-scale construction method. These characteristics point towards a centralized organization of the terrace systems. Evidence for higher terrace densities, complexity, and quality within close proximity to settlement units suggests a piecemeal process of construction, and decentralized development. The practicality exhibited in the labor saving methods, such as incorporating natural features into terrace construction also suggests an intrinsic knowledge of the local topography and the fluvial and sediment deposition processes. These lines of evidence point towards decentralized organization of the construction and maintenance of the intensive agricultural terrace systems. Overall this blending of characteristics suggests a mix of both centralized and decentralized organization. This is why it is important to consider the heterarchical approach. However, one question remains: What does the heterarchical classification of the intensive terrace systems of Minanha mean to the interpretation of the ancient Maya of the Contreras Valley, and Minanha?

Conclusions

Over the past four years of research in the Contreras Valley, we have generated a number of intriguing insights. For one, the Contreras Valley was inhabited much longer than originally anticipated – it was originally occupied as early as the Late to Terminal Preclassic, and continued to be occupied through the Terminal Classic and possibly even into the early Postclassic period. Some of the larger, more complex settlement units in the Contreras Valley were inhabited for the entire time span. The success of these groups is likely tied to the Principle of First Occupancy, their control of improved land, and proximity to perennial springs. In terms of other observations, the settlement in Contreras is “less formal” when compared to what was found in the epicentral and site core survey zones. Nevertheless, the Contreras community itself was still quite diverse – it was clearly home to a vast range of peoples with varying roles and statuses. With respect to preliminary spatial analyses, it appears as if elevation did not have significant impact over where the residents chose to reside, and some other variable, or variables may have been the primary determinants -- such as agricultural potential, proximity to springs, etc. Preliminary global spatial analysis suggests that the settlement units in the Contreras Valley are dispersed randomly across the 1 square kilometer. Still, the settlement will need to be examined on a more localized scale so that any sort of clustering on the hillsides or near the springs can be identified.

From our terrace survey within the Contreras Valley we have learned1) our research has provided independent confirmation that, as has been found elsewhere in the Maya Lowlands, the inhabitants of the Contreras Valley began using agricultural terraces at a very early date, to help support a developing community, likely sometime in the Late to Terminal Preclassic; 2) the inhabitants of the Contreras Valley had a well found knowledge of terrace construction resulting in uniform terrace “sets”; 3) the terrace systems within the Contreras Valley exhibit characteristics of both decentralized and centralized socio-political
organization, which suggests a heterarchical organization.

This paper has outlined the goals and some of the results of the Phase II research in the Contreras Valley. These investigations continue to provide a wealth of evidence concerning the peripheral community of Minanha; however, further analyses will help shed light on our understanding of this community and the issues which affected it during its lifetime.

Acknowledgements

First and foremost, we would like to thank the Institute of Archaeology in Belize for their continued support of our ongoing research at Minanha. Additionally, we would like to thank the following funding agencies for their financial support of this research presented herein: the Social Sciences and Humanities Research Council of Canada, and the University Research Council at the University of Cincinnati. Lastly, we would like to thank all of the students, staff, and Belizean assistants on the North Vaca Archaeology Program along with our greater Belizean family. This paper is dedicated to the late David “Ciego” Valencio, thank you for all your years of commitment to Belizean archaeology and for being a great friend… you are missed.

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what makes a settlement an archaeological site? It could be said that once a settlement is abandoned, it enters the archaeological record. Yet, abandonment is not always the uniform social process it appears to be; it may be gradual, affecting distinct parts of the same site in a differential fashion and at a different pace. In this article, we look at abandonment from a diachronic and social perspective, according to which agricultural commoner households outlasted a political elite and remained living in a progressively depopulated landscape for generations.

Settlement abandonment studies have transformed since their original development in the early 1990s when the first seminal volume on the topic, edited by Cameron and Tomka (1993), was published. Early research on the topic, influenced by Michael Schiffer’s (1972) formation processes theory, focused on artifact assemblages of abandonment. However, in some cases, non-elite populations lived for centuries in and around Classic Maya centers without rulers. Processes of abandonment among Classic Maya commoners are detectable and reflect their own ritual and social practices divorced from the ritual performances undertaken by the ruling elite. We study the abandonment context and chronology of three domestic groups from the Contreras Valley, an agricultural community located on the outskirts of the Classic Maya center of Minanha, Belize. There, several artifact assemblages were deposited at the time of abandonment, representing termination rituals. This study goes beyond the ideological dimension of termination rituals to examine how these ceremonies helped reshape the identity of social groups who were about to abandon their home. We explore how the last inhabitants of a mostly abandoned landscape lived through this process of gradual depopulation. Moreover, we evaluate potential explanations for the archaeological processes behind the occurrence or non-occurrence of termination rituals in different domestic groups.

Maxime Lamoureux-St-Hilaire, Scott Macrae, Carmen A. McCane, Evan A. Parker, and Gyles Iannone

The most archaeologically visible dimension of the Classic Maya Collapse is the abandonment of monumental royal courts. Yet, in some cases, non-elite populations lived for centuries in and around Classic Maya centers without rulers. Processes of abandonment among Classic Maya commoners are detectable and reflect their own ritual and social practices divorced from the ritual performances undertaken by the ruling elite. We study the abandonment context and chronology of three domestic groups from the Contreras Valley, an agricultural community located on the outskirts of the Classic Maya center of Minanha, Belize. There, several artifact assemblages were deposited at the time of abandonment, representing termination rituals. This study goes beyond the ideological dimension of termination rituals to examine how these ceremonies helped reshape the identity of social groups who were about to abandon their home. We explore how the last inhabitants of a mostly abandoned landscape lived through this process of gradual depopulation. Moreover, we evaluate potential explanations for the archaeological processes behind the occurrence or non-occurrence of termination rituals in different domestic groups.

The last groups standing: living abandonment at the ancient Maya center of Minanha, Belize

Maxime Lamoureux-St-Hilaire, Scott Macrae, Carmen A. McCane, Evan A. Parker, and Gyles Iannone

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El aspecto arqueológico más visible del colapso Maya Clásico es el abandono de las cortes reales monumentales. Sin embargo, en algunos casos, poblaciones que no pertenecían a la élite vivieron por siglos en centros Mayas Clásicos sin la presencia de gobernantes. Los procesos de abandono de la gente común durante el periodo Clásico pueden ser discernibles y reflejar sus propias prácticas rituales y sociales, las cuales fueron distintas de la élite. En este artículo estudiamos el contexto de abandono y la cronología de tres grupos domésticos del Valle de Contreras, los cuales formaron parte de una comunidad agrícola ubicada en los alrededores del centro Maya Clásico de Minanha, Belice. Varios conjuntos de artefactos fueron depositados durante el abandono de este valle, los cuales representan rituales de terminación. Este estudio va más allá de las dimensiones ideológicas para examinar cómo estas ceremonias transformaron la identidad de los grupos sociales que estuvieron a punto de abandonar sus casas. Exploramos cómo estos últimos habitantes de un paisaje prácticamente abandonado vivieron este proceso de despoblación gradual. Además, evaluamos explicaciones potenciales para los procesos arqueológicos responsables de la presencia o ausencia de rituales de terminación en diferentes grupos residenciales.

What makes a settlement an archaeological site? It could be said that once a settlement is abandoned, it enters the archaeological record. Yet, abandonment is not always the uniform social process it appears to be; it may be gradual, affecting distinct parts of the same site in a differential fashion and at a different pace. In this article, we look at abandonment from a diachronic and social perspective, according to which agricultural commoner households outlasted a political elite and remained living in a progressively depopulated landscape for generations.

Settlement abandonment studies have transformed since their original development in the early 1990s when the first seminal volume on the topic, edited by Cameron and Tomka (1993), was published. Early research on the topic, influenced by Michael Schiffer’s (1972) formation processes theory, focused on artifact assemblages...
and on recognizing various types of abandonment (Cameron and Tomka 1993). Recent abandonment studies have tended to shift away from low-level inquiry to study broader social phenomena such as resilience or migration among both small-scale and complex societies (Cameron 2013; Glowacki 2015; McAnany et al. 2015). Settlement abandonment has garnered particular interest in several archaeological regions, including the lowland Maya area, where exceptional finds from rapidly abandoned sites such as Aguateca, Guatemala, and Cerén, El Salvador, have attracted particular attention (Inomata and Triadan 2010; McKee and Sheets 2003). Beyond these two rapidly abandoned sites, settlement abandonment studies have focused on the elite segment of society (Aimers 2003; Chase and Chase 2000; Inomata and Triadan 2010; Pagliaro et al. 2003; Stanton et al. 2008; Suhler and Freidel 2003). Lowland Maya abandonment research has tended to focus on abandonment ceremonies (i.e., termination rituals), on the squatting and reuse of elite architecture, and on post-abandonment veneration and pilgrimages to monumental buildings (Inomata and Webb 2003; Mock 1998a; Navarro-Farr et al. 2008; Stanton and Magnoni, eds. 2008).

The topics of intrasite differential abandonment, gradual abandonment by commoners, and social transformations during abandonment have rarely been discussed (Palka 2003:123). Processes of abandonment among ancient Maya commoners are generally assumed to be directly related to the fate of elite groups. In other words, the collapse of the Classic Maya royal courts has overshadowed the dynamics of abandonment among ancient Maya commoners.

In this article, we argue that the processes of abandonment among Classic Maya commoners reflected their own ritual practices divorced from the civic-ceremonial performances undertaken by the ruling elite. Further, we also address the question of why certain domestic groups and structures were ritually terminated while others were not. We explore these questions through the study of the ancient Maya center of Minanha, Belize (Figure 1), which underwent differential and gradual abandonment of its elite and non-elite components over a period of a few centuries (ca. A.D. 810–1200).

We first review the concepts of on-floor assemblages and ritual termination, which have been critical components of Maya abandonment studies. We then summarize the research led by the Social Archaeology Research Program (SARP) at Minanha, focusing on its settlement sampling strategy and the broader chronology of the site. During this process, we examine the Contreras Valley—a peripheral agricultural community—where six termination offerings were recovered from three commoner domestic groups. We then interpret these assemblages and explore the implications for the social groups that lived through most of the abandonment of the Contreras Valley before finally departing themselves. Finally, we examine three potential explanations for the occurrence and non-occurrence of termination offerings among the households of the Contreras Valley.

**Background: Abandonment-Related On-Floor Assemblages**

The abandonment of settlements can leave several different types of artifactual assemblages on the floor of architectural structures. The last inhabitants of these structures and their behaviors are responsible for the deposition of these on-floor assemblages and directly influence these assemblage types (Schiffer 1972). While thinking about on-floor assemblages, we must also consider the processes that affected them after they reached the archaeological record—processes such as bioturbation, erosion, and scavenging (Schiffer 1972, 1985).

What probably constitutes the most common abandonment-related on-floor assemblage is primary or secondary refuse left in unexpected or peripheral sections of buildings (Cameron 1993:3; LaMotta and Schiffer 1999:21; Pagliaro et al. 2003:79; Palka 2003:126–127; Schiffer 1975:56, 1976:33–34; Stanton et al. 2008; Suhler and Freidel 2003:137). These artifacts typically consist of discarded items or small amounts of material not worth bringing away. In other instances, abandoned structures may have been reoccupied by so-called “squatters,” who discarded a considerable amount of trash in post-abandonment context inside or around buildings (Aimers 2003:157; Chase and Chase 2000:69; Child and Golden 2008:82; Schiffer 1985:211; Stanton and Magnoni 2008:14). Some usable items might be left behind in a storage context (see discussion below) or, in
the case of rapid abandonment, many artifacts might be left in situ; in both cases, the items consist of de facto material (Chase and Chase 2000:69; Joyce and Johannessen 1993:138, 151; Inomata 2008:288–89; McKee and Sheets 2003; LaMotta and Schiffer 1999:22; Schiffer 1985:201; Stanton et al. 2008:231–238). As is well-documented in the Maya area, in some cases, artifacts might be deposited or smashed in a ritual fashion on certain structures, as part of abandonment-re-

**Termination Rituals as Exposed Offerings**

It has been over 30 years since abandonment-related termination rituals were defined for the ancient Maya (Garber 1983:117), and they have since been related to the “Maya philosophy of the regeneration of life,” also referred to as *jaloj-k’exoj* (Carlsen 1997:56–58; Carlsen and Prechtel 1991; McAnany 2014; Mock 1998b). This ritual system, associated with ancestor veneration and architecture, involves dedication and rededication rituals that preclude the placement of ancestral burials and caches within buildings (Freidel et al. 1998:135; Garber 1983; Mock 1998b).

According to the *jaloj-k’exoj*, dedication and rededication rituals occurring inside the buildings during their different construction phases conferred *ch’ulel*, or life energy, to the newly constructed building (Mock 1998b:10; Stuart 1998:395–396). Termination rituals, upon abandonment, served to release the *ch’ulel* accumulated by architectural structures, for the purpose of either symbolically killing the buildings (decretory termination rituals) or appeasing the ancestors (reverential termination rituals) (Chase and Chase 1998:301; Lamoureux-St-Hilaire 2011; Mock 1998a; Stanton et al. 2008:237).

We do not adopt the concept of termination ritual uncritically. Instead, we propose a behavioral-contextual approach that prescribes a series of factors for recognizing abandonment-related on-floor assemblages as exposed reverential offerings (Iannone 2000; Lamoureux-St-Hilaire 2011). An exposed reverential offering corresponds to a ritual-oriented artifactual assemblage found on the floor of a structure in a ceremonial context dissociated from any violent episode. By “ritual-oriented,” we mean that an exposed offering consists of an accumulation of broken ceramic vessels comprising a high proportion of serving vessels and censers, as well as other fine artifacts (Lamoureux-St-Hilaire 2011). By “dissociated,” we mean that the assemblage was placed along the central axis of an abandoned domestic structure and was not associated with acts of destruction or scattered human remains (Lamoureux-St-Hilaire 2011). This central placement inside or in front of doorways symbolically hindered access to the terminated structure (Lamoureux-St-Hilaire 2011:34–38). In contrast, scattered human remains appear to be a marker of desecratory termination rituals, a type of ritual associated with military conquest recognized at several Lowland Maya sites (Harrison-Buck et al. 2007; Inomata and Ponciano 2010; Mock 1998a; Palka 2003; Suhler and Freidel 2003; Yaeger 2010). Finally, we argue that exposed reverential offerings should be associated with structural votive features (i.e., dedication and rededication caches or burials), thus associating them with a broader architectural ritual program pertaining to the *jaloj-k’exoj*.

These offerings are understood to be the result of abandonment-related ceremonies that would have taken place in the structures and adjoining patios and that would have ended with the deposition or breaking of vessels in these contexts. We believe that, beyond playing a religious role, these ceremonies were related to the social effects of detachment from place during abandonment (Lamoureux-St-Hilaire and Iannone 2012:216; McAnany and Lamoureux-St-Hilaire 2013).

**The Social Role of Termination Rituals**

Ancient Maya elite and commoners were economically and ideologically attached to their constructed landscape. Commoners and agriculturalists were tied to their homeland, including their houses, surrounding fields, and orchards, which represented their belongings and sources of sustenance. Detachment from these resources during abandonment would have dramatically impacted the lives of commoners. Additionally, the ancient Maya buried their ancestors within this constructed landscape (Knapp and Ashmore 1999). According to the *jaloj-kexoj*, these interred ancestors ensouled houses and shrines and conferred ideological importance to the architecture. This ideational landscape (Knapp and Ashmore 1999) was erected over ancestral living spaces and enlarged with every new construction episode, building on their ancestors’ legacy and creating a “genealogy of space” (McAnany 2014:100). This detachment of social groups from their economic, prestigious, and ancestral heritage must...
have represented a critical process in reshaping their identity (Lamoureux-St-Hilaire and Iannone 2012:216-217).

We suggest that termination rituals served as easing mechanisms for abandoning groups, marking the passage of this social landscape from its systemic context into social memory. The serving and ceremonial vessels found in the exposed offerings discussed below suggest that incense burning and food consumption were at the center of these ceremonies (Lamoureux-St-Hilaire 2011). These communal events, along with the symbolic closure of buildings, may have helped inhabitants to cope with the grief associated with abandonment and to reshape their new social identity as abandoners, or migrants (Palmer and Jankowiak 1996:240-244, 252). Taking place in a period of liminality, such a rite of passage signified a transitory, defining moment for the abandoning social groups who were about to begin a new cycle of occupation elsewhere (Bloch and Parry 1982; Mock 1998b:9–11; Van Gennep 1909). This ritual process redefined houses by removing them from the living world and abolishing their raison d’être: “a house without people in it is not a proper house” (Carsten and Hugh-Jones 1995:44). This animistic concept is particularly compelling given the aforementioned ritual program aimed at ensouling Maya architecture with ch’ulel and then releasing it through termination, thus providing a parallel between mortuary and termination rituals (Mock 1998b:9–11).

Our approach to termination rituals is an attempt to model them in light of their social and historical context. We recognize the limits of our inferences, which are clearly rooted in our own modern understanding of religion and therefore inherently biased (Asad 1993). This is reflected, for example, in our adoption of the distinction between categories of termination rituals (reverential vs. desecratory). We realize that for the ancient Maya the concept of religion was likely malleable and tolerant of a variety of attitudes towards spirituality (Asad 1993; Turner 1995). Hence, we understand that different participants must have had their own interpretation of the values and symbols brought forth during the ceremonies that led to the deposition of exposed offerings (Humphrey and Laidlaw 1994; Turner 1995). In other words, while our interpretations of the exposed offerings presented in this paper attempt to leave room for nuances and contingencies, they remain interpretations.

In summary, we suggest that the performance of termination rituals not only symbolized the releasing of ch’ulel from architecture in a moment of transition, but also played an important role in fashioning the social fabric of abandoning groups, thus easing detachment from place. After the performance of these liminal rituals, the identity of social groups probably shifted from inhabitants to abandoners. This, in turn, entailed the physical and symbolic detachment from both the constructed and ideational landscape. These ceremonies were not necessarily dogmatic, and both their performance and interpretation may have yielded various interpretations on the part of its participants (Turner 1995). We argue that the exposed offerings found at Minanha and discussed in this article were deposited during such transformational ceremonies.

Background: Minanha and the Social Archaeology Research Program

Investigations at the Lowland Maya site of Minanha were conducted by SARP under the direction of Iannone from 1999 to 2010. Research was designed to address the structure, development, apogee, and abandonment of this ancient community (Iannone 2009). Minanha is situated in the North Vaca Plateau of west-central Belize, between the two major sites of Caracol to the south and Naranjo to the northwest (Figure 1). After initial occupation in the Late Preclassic period (400 B.C.–A.D. 250), the Minanha community became a medium-sized polity during the Classic period (A.D. 250–810) and was progressively depopulated during the Terminal Classic and Early Postclassic periods (two periods spanning A.D. 810–1200; Iannone 2005).

The research program was designed to investigate Minanha in three phases (Iannone 2009). The first phase of the program focused its excavations on key groups of the monumental epicenter of the site (Iannone 2009). The second phase, through a 20 percent (Site-Core) and 15 percent (Contreras Valley) random stratified sampling strategy adopted from the Xunantunich Archaeological Project, excavated eight architec-
tural groups out of 39 in the Site-Core Zone (Figure 2), as well as 15 groups out of 98 in the 1 km² Contreras Valley zone (Figure 3; Iannone 2006:2). This random stratified excavation strategy crosscut all settlement types, from small isolated mounds to larger groups exhibiting multiple structures (Iannone 2006). The goal of this reflexive sampling method was to develop a representative dataset of the whole ancient community, allowing for a fuller understanding of its developmental history and its social processes, including its abandonment. The most notable advantage of this method is the possibility of extending conclusions from the excavated sample to the wider Minanha community. Finally, the third phase of the research program focused on the broader political integration and paleo-environmental dynamics of the North Vaca Plateau (Iannone 2009).

Figure 2. The 1-km² Site-Core Zone and Epicenter of Minanha; groups or structures that revealed on-floor assemblages are indicated (map by SARP).
The first and second phases uncovered 12 on-floor assemblages associated with the abandonment of six architectural groups from the Epicenter, Site-Core, and Contreras Valley. The contextual-behavioral analytical framework that we adopted allowed for the identification of distinct settlement abandonment scenarios in a systematic, replicable fashion, while using a specific contextual terminology. Following this process (detailed below), it was concluded that 11 of the 12 on-floor assemblages resulted from reverential termination rituals, six of which were found in the Contreras Valley (Lamoureux-St-Hilaire 2011).

This research examined a variety of abandonment behaviors and gathered considerable information about commoner abandonment practices (Lamoureux-St-Hilaire 2011). One of its key findings was that the first inhabitants to abandon Mi-
nanha were those of the royal court complex and those of the most recently settled commoner residential groups. These two groups—representing the top and bottom of the socio-political hierarchy—abandoned the site at the onset of the Terminal Classic period (ca. A.D. 810–900). Other groups—especially the first occupants of the Contreras Valley—continued living in the region for centuries after the polity had collapsed.

The Abandonment of the Epicenter and Site-Core of Minanha

The royal court of Minanha, centered at Group J, was built during the Late Classic period (A.D. 675–810; Iannone 2005:29). The royal acropolis was constructed north of Plaza A and consisted of a succession of courtyards, including Group J and functionally related groups (such as Group L; Iannone 2005:29). Plaza A, the main public space of the site, included a ball court to the east, a few temples to the south, and a large range structure to the west, Structure 12A, which led into an elite courtyard, Group F (Iannone 2005:29).

At the onset of the ninth century, the vaulted structures of Group J were in-filled with stones, the frieze of the temple-pyramid was defaced, and the whole courtyard was buried under 5 m of carefully laid construction material, thus terminating its royal-administrative functions (Iannone 2005:34; 2010:363). Soon after, two architectural groups placed in close relation with the royal court, Groups L and F, were terminated. First, three buildings from Group L were filled with a sizable amount of artifacts, including many chipped stone tools, whole and partial ceramic vessels of all kinds, and apparently random sherds, and then purposefully collapsed (Lamoureux-St-Hilaire 2011:82–89). Meanwhile, the Passage-Structure 12A leading to Group F was symbolically blocked with partial ceramic vessels, including eight jars, three bowls, a dish, and a ground stone disc, and then collapsed (Lamoureux-St-Hilaire 2011:55–61). These epicentral termination rituals were apparently aimed at deactivating the royal-related functions of those prominent buildings and are dated to the beginning of the Terminal Classic on the basis of diagnostic ceramics, such as Platon Punctated-Incised dishes (Lamoureux-St-Hilaire 2011:89–90). Following the abandonment of the Epicenter, the surrounding areas of the site remained occupied, with their population living without the governance of a royal court (Lamoureux-St-Hilaire and Iannone 2012).

During the Terminal Classic, Groups R and S, located in the Site-Core Zone, were abandoned in a manner that left on-floor assemblages in one structure. Group R, located a few hundred meters east of the epicenter, consisted of a large raised platform that supported four buildings (Prince 2000). Structure 91R, the smallest of the group, revealed a small ceramic on-floor assemblage dated to the Terminal Classic (Prince 2000:58). This on-floor assemblage, consisting of four partial vessels—a bowl, a dish, and two jars—was not centrally aligned, was devoid of ritual paraphernalia, and thus does not appear to have been deposited during a termination ritual (Lamoureux-St-Hilaire 2011:62–64). This assemblage likely represents refuse left behind at the time of abandonment (Lamoureux-St-Hilaire 2011:95).

Group S (Figure 4), located roughly 100 m south of Group R, consisted of a large raised courtyard that supported nine residential structures and a tripartite eastern temple (Schwake 2008; Zehrt 2006). At some point during the Terminal Classic, a large amount of refuse was dumped inside the northern wing of the temple, Structure 76S, including thousands of ceramic sherds and many other artifacts, such as faunal and lithic materials (Lamoureux-St-Hilaire 2011:98). Some of the ceramic material was dated to the Middle Classic, thus suggesting that the refuse was gathered from a nearby deep midden (Lamoureux-St-Hilaire 2011:98). A masonry cache was then built inside the doorway of the room, thus physically blocking access to that room (Zehrt 2006). The cache was devoid of any non-perishable material except for a greenstone adze (Zehrt 2006). The ceramic data from this assemblage may be combined with a set of radiocarbon dates (Table 1) associated with an intrusive burial from the adjacent Structure 77S, which indicates a Terminal Classic date: [1200 ± 40 B.P. (Beta-254851; Bone collagen; δ13C = 10.8‰) 770 to cal A.D. 890 (p = .68) (calibrated...
at 1σ with the program INTCAL04) cal A.D. 690–900 and 920–950 (p = 95) (calibrated at 2σ with the program INTCAL04) and [1170 ± 40 B.P. (Beta-281098; Bone collagen; δ13C = 12.8‰) 780 to cal A.D. 900 (p = .68) (calibrated at 1σ with the program INTCAL04) cal A.D. 770–980 (p = 95) (calibrated at 2σ with the program INT- CAL04)]. This termination event and the deposition of the associated burial were likely a communal termination ritual that signified detachment from this important residential group on the part of its former inhabitants (Lamoureux-St-Hilaire 2011:95–97).

The Abandonment of the Contreras Valley

The abandonment of the Contreras Valley occurred more gradually than was the case for the Epicenter and Site-Core, spanning both the Terminal Classic and Early Postclassic periods (from A.D. 810–1200). Six on-floor assemblages were found on the domestic structures of Groups MRS4, MRS15, and MRS89. Two of the earlier on-floor assemblages were located in Group MRS89, situated on a hilltop, and contained ceramics dated to the Terminal Classic (McCormick 2007, 2008). These two ceramic on-floor assemblages were found in domestic structures, with the larger of the two placed in a centrally aligned position on Structure MRS89-M1 and comprising seven partial vessels (three bowls, two jars, one dish, and one Chiquibul Scored-Incised censer; Lamoureux-St-Hilaire 2011:109–111). A second, smaller on-floor assemblage was found on Structure MRS89-M4. This assemblage was not centrally aligned and included only a partial jar, but was located directly next to Structure MRS89-M1.

Group MRS15, located at the edge of the valley bottom, revealed an on-floor assemblage on

<table>
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<th>Kernel #, Reference, Lab #</th>
<th>14C ± σ Yrs.</th>
<th>Sample</th>
<th>δ13C</th>
<th>Cal A.D. Yrs. ± 2σ</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Bone Collagen</td>
<td>10.8</td>
<td>690–900, 920–950</td>
</tr>
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<td>Beta-281098</td>
<td>1170 ± 40</td>
<td>Bone Collagen</td>
<td>12.8</td>
<td>770–980</td>
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<tr>
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<td>1050 ± 40</td>
<td>Bone Collagen</td>
<td>-12.4</td>
<td>900–1030</td>
</tr>
<tr>
<td>Beta-254850</td>
<td>1770 ± 50</td>
<td>Charred Material</td>
<td>25.1</td>
<td>130–390</td>
</tr>
</tbody>
</table>

Note: All radiocarbon dates were processed by Beta Analytic Radiocarbon Dating Laboratory using INTCAL04 database.
each of its three larger domestic structures (MRS15-M2, -M3, and -M5; Figure 5). Those assemblages comprised many serving and ceremonial vessels dating them to the transition from the Terminal Classic to the Early Postclassic period (ca. A.D. 900; Lamoureux-St-Hilaire 2011:99–109; McCane et al. 2009). The assemblages from structures MRS15-M2 and -M5 were substantial and included between one and four Chiquibul Scored-Incised censers, several ash-tempered serving dishes of the Belize Red and Platon Punctated-Incised types, and, in the case of Structure MRS15-M2, an elaborate composite three-prong brazier (Figure 6), a miniature snuff bottle, and a rare ceramic cylindrical seal. The assemblage from Structure MRS15-M3 was smaller, located on the edge of the platform, and not ritual in nature, consisting of a partial bowl and complete metate (Lamoureux-St-Hilaire 2011). Despite this, the assemblage appears to have been deposited at the same time as its ceremonial counterparts (as was the case for Group MRS89), which suggests that they were contextually related.

Finally, the latest abandonment date at the site comes from the largest group excavated in the heart of the valley, Group MRS4. There, a sizable ceramic on-floor assemblage was deposited along the central axis on the various tiers of the largest domestic structure of the group, Structure MRS4-M1 (McCormick 2008). This assemblage comprised four Cayo Unslipped jars, a Yalbac Smudged Brown bowl, and a Chiquibul Scored-Incised censer (McCormick 2008). This exposed offering was dated to the Early Postclassic by its ceramic material and by a radiocarbon date from an associated intrusive burial (Table 1) placed in the pyramidal shrine located across the patio, Structure MRS4-M3:[1050 ± 40 B.P. (Beta-254848; Bone collagen; δ13C = -12.4‰) cal A.D.
Five conclusions from the contextual-behavioral approach used to interpret these on-floor assemblages suggest that they were all the result of termination rituals: (1) each of the six assemblages excavated in the Contreras Valley included fragmentary or complete vessels, thus indicating the breakage of vessels in situ; (2) four of the ceramic assemblages (from Structures MRS4-M1, MRS15-M2, -M5, and MRS89-M1) included serving vessels and censers or braziers, thus indicating that the activity associated with their deposition involved food consumption and incense burning; (3) the same four assemblages were found clustered inside or aligned in front of doorways, thus indicating that they symbolically blocked their access; (4) the two structures that did not exhibit this pattern (MRS15-M3 and MRS89-M4) were directly associated with at least one assemblage that did, thus contextually tying them to these ritual deposits; and (5) the three termination rituals proposed for the three groups were directly associated with structural votive features, thus supporting this choice of location for these transformative ceremonies (Lamoureux-St-Hilaire 2011).

The terminated domestic groups and agricultural landscape of the Contreras Valley represented crucial economic resources for the abandoners, who were also leaving behind their genealogy of space. The combination of the constructed and ideational dimensions of Maya architecture is clearly manifested in the eastern shrines of Group MRS4 and Structure MRS15-M2 (Figure 5), which were both the result of multiple construction episodes and contained the remains of ancestors. This was also the case for Structure MRS89-M1, which contained a dedicatory burial. As discussed above, detachment from these prized resources would have been distressing for the abandoners, whose grief may have been mitigated by the performance of termination rituals.

The Settlement History of the Contreras Valley

In order to better understand the social implications of the abandonment of the Contreras Valley, we must review its full settlement history which was revealed through the random stratified sampling led by SARP. This study of the Contreras settlement reveals that the first groups established were the last to be abandoned.

During its long occupation, the Contreras Valley was densely populated and extensively modified for agricultural purposes by the construction of numerous terrace systems (Macrae 2010). The earliest date from the Contreras settlement comes from the antepenultimate floor of a structure from Group MRS4, which was located below a radiocarbon-dated (Table 1) tamped earth floor [1770 ± 50 B.P. (Beta-25480; charred material; δ13C = 25.1‰) cal A.D. 220 to 330 (p = .68) (calibrated at 1σ with the program INTCAL04) cal. A.D. 130 to 390 (p = .95) (calibrated at 2σ with the program INTCAL04)], and indicates a Terminal Preclassic date (A.D. 100–250) (Macrae 2010:110–113). Moreover, fortuitous excavations under the later architecture of Group MRS15 revealed several Sierra Red ceramic fragments in a terrace planting surface, dating it to the Terminal Preclassic period (Macrae 2010:110–113). All the features dated to this period were found in the valley floor, located in an inter-fluvial valley between residual hills (Macrae 2010:110–113).

In the Early Classic period (A.D. 250–550), construction continued at Group MRS4, but overall occupation remained low. However, the Middle Classic period (A.D. 550–675) witnessed a significant expansion, when Group MRS15 and Group MRS89 were settled (Macrae 2010:110–113). By then, residential groups were located outside the productive valley bottom, sometimes occupying ridge-top loci.

During the Late Classic period, the occupation of the Contreras Valley reached its maximum extent and all the studied groups expanded (Macrae 2010:114). This major expansion was related to the contemporary founding and development of the royal court of the site and expansion of the Site-Core Zone, including Groups R and S (Iannone 2005). This rise in population would have increased the demand for food, thus stimulating the development of the agricultural population of the Contreras Valley.

The Terminal Classic period witnessed both the first phase of depopulation in the Contreras Valley and the demise of the Minanha royal court, two trends that seem related (Iannone 2005;
Figure 6. The portable composite ceramic brazier found as part of the on-floor assemblage of Structure MRS15-M2 (illustration by Lamoureux-St-Hilaire). The bowl sitting atop is of the Yalbac Smudged Brown type, while the lid is of the Chiquibul Scored-Incised type.
Macrae 2010:114). Yet, despite this political and general demographic collapse, several construction projects were undertaken in the groups of interest. The inhabitants of Group MRS4 erected a sizable pyramidal shrine, Structure MRS4-M3 (Schwake 2008:157–163), while Group MRS15 grew significantly (McCane et al. 2009:15–33). Some groups of the Site-Core Zone also expanded during this period, including Group S (Schwake 2008). These divergent trends for the populations of the epicenter and the periphery highlight that the fate of the non-elite was not directly associated to the royal court. Nonetheless, depopulation increased throughout this period, and by the beginning of the Early Postclassic, both Groups S and MRS89 had been abandoned.

The Early Postclassic period was the last period of occupation at Minanha (Macrae 2010:114). There is no evidence for architectural modifications at this time, save for intrusive features such as the intrusive burial in Structure MRS4-M3. Indications are that Group MRS15 was abandoned at the onset of the Early Postclassic while Group MRS4 was abandoned at some point during this period.

First and Last Occupancy in the Contreras Valley

Established in the agriculturally productive valley bottom, Group MRS4 is the earliest settlement among all excavated Contreras groups. This settlement pattern fulfills the principle of first occupancy, that is, “one could be the initial ‘occupant’ or cultivator of land and thus lay claim to it in that way” and “the best lands are claimed early in the colonization of an area” (McAnany 2014:96–97). Following this, newcomers or descendants wishing to establish new groups had to settle in relatively marginal areas of the valley, where they had to invest more energy in intensive agricultural techniques such as terraces (McAnany 2014:97; Macrae 2010:142). Both Groups MRS89 and MRS15 were among these later settlements, but their settlement patterns are dissimilar. Group MRS89 was built in a marginal location: on a hilltop, remote from water sources, and on land that would have been unproductive to farm. In contrast, Group MRS15 (Figure 7) was constructed over terraced agricultural soils dating to the Terminal Preclassic, only 175 m away from Group MRS4 and oriented directly toward it. This contrast suggests that different social or economic factors characterized the settlers of Groups MRS89 and MRS15 (Macrae 2010:112). Therefore, not only was the location of Group MRS15 more favorable than that of Group MRS89, but it appears that some form of relationship tied it to Group MRS4. Interestingly, by A.D. 900, Groups MRS4 and MRS15 were the only two groups to remain occupied among those we excavated.

We suggest that the apparent resiliency of Group MRS4 and neighboring Group MRS15 may be related to the principle of first occupancy, which prescribed preferential location and access to resources. Consequently, those advantaged commoner groups were either able to remain or simply more interested in remaining in the valley for a longer period than later established groups. This privileged land tenure would have been particularly instrumental given that paleoclimatic
data indicate that this region suffered droughts during the Early Postclassic period and that the soils of the Contreras Valley may have been exhausted during the height of the Minanha polity (Iannone et al. 2014; Kennett et al. 2012). In other words, given the absence of a ruler or an urban population in need of agricultural surpluses, and given probable environmental stress, groups that did not have preferential access to the land migrated. Accordingly, we suggest that the principle of first occupancy may have favored groups that were first settled to endure through last occupancy.

Living Abandonment

According to the random stratified sample, 78 percent of the domestic structures from the Contreras Valley were occupied in the Late Classic and 54 percent were occupied in the Terminal Classic, while only 21 percent remained inhabited by the Early Postclassic period. This gradual depopulation of the Contreras Valley would have significantly transformed the social landscape and affected the identity of its remaining inhabitants. As generations passed, the loss of neighbors may well have become part of the daily life of the remaining population.

The contrastive social landscape of the increasingly abandoned Contreras Valley would have been sharpened only by the then fully abandoned monumental Site-Core. At face value, this situation is somewhat comparable to the occupational level of the Contreras Valley during the Early Classic (18 percent rate of occupation vs. 21 percent). Nonetheless, the last occupants of the valley were surrounded by ruins being overgrown by an encroaching ecosystem, instead of being surrounded by a natural landscape. Whereas these resilient social groups used to live among peers in a densely populated area, they had become the few inhabitants of a sparsely populated area. They were the last groups standing, and the place where they stood had changed dramatically.

These observations highlight how the process of abandonment was lived not only by abandoners, but also by those who remained. How did these social groups perceive this abandoned landscape? From an economic perspective, this may have seemed beneficial, since they could have taken full advantage of the valley without worrying about land tenure by neighbors. Otherwise, the abandoned landscape may have represented a harsh reminder of the failure of the ancient community.

Alternatively, the economic situation of the last inhabitants of the valley might not have been particularly advantageous. Beyond the detrimental ecological context and the lack of clients in the site-core, broader societal factors such as the disintegration of inland trade routes may have contributed to undermine the viability of the Contreras Valley (Turner and Sabloff 2012:13911).

The socially deprived landscape seems fit for framing reverential termination ceremonies as rituals for coping with the reality of abandonment. Yet, if termination rituals played such an important role, why do we find evidence for them only in a fifth of the excavated domestic groups in the Contreras Valley?

Discussion: The Occurrence and Non-Occurrence of Exposed Reverential Offerings

The presence of exposed offerings in just a fifth of the excavated sample challenges the idea that termination rituals played a decisive role in the transformation of the Contreras landscape. Therefore, it is important to reflect on why certain architectural groups were ritually terminated while others were not. More to the point: Why do we find archaeological correlates of termination rituals in only certain architectural groups? Below, we present three potential explanations for the disparity in the archaeological recovery of termination rituals.

Natural and cultural formation processes. A first hypothesis to explain the lack of termination rituals in most excavated structures relates to post-depositional formation processes (Schiffer 1972). These formation processes may have been natural, such as erosion, animal disturbance, or bioturbation, or they may have been cultural, like squatting or artifact scavenging (Lamoureux-St-Hilaire 2011:124). These formation processes would have occurred after the abandonment of the concerned groups, but while inhabitants remained in the valley. Some factors may have prevented the desecration of artifacts, including the fact that most vessels placed on the terminated
structures were probably broken in situ and that termination rituals may have involved the dismantling of structures, thereby covering the offerings (Suhler and Freidel 2003:141). Given the perishable nature of the Contreras buildings, assessing such a dismantling is, unfortunately, impossible.

It is also plausible that the remaining inhabitants avoided disturbing termination offerings out of respect for the departed groups, or due to the religious dimension of the exposed offerings. Nonetheless, some agents lacking inhibition, such as children, may have led activities in and around these buildings, thus disturbing the offerings (Hammond and Hammond 1981). This hypothesis may be supported by the fact that the only remaining on-floor assemblages were found either on a steep hilltop, a location probably rarely visited, or on the last structures to be abandoned. Indeed, data suggest that by the time the occupants of Group MRS15 deposited their termination offerings, the occupants of Group MRS4 were among the very few left living in the valley. It is therefore plausible that the MRS4 occupants, who were related to the former occupants of Group MRS15, did not disturb these nearby termination offerings out of respect for kin.

**Variability in termination rituals.** A second hypothesis for explaining the differential recovery of on-floor offerings relates to variability in the performance of termination rituals. Economically speaking, groups who had invested less effort in the creation of their social landscape, and perhaps did not have preferential access to agricultural land, were probably predisposed to abandon their settlement more easily. This may have resulted in a reduced prestige and attachment to their home, which may account for archaeologically invisible termination rituals, or even their absence altogether.

Alternatively, kinship ties among groups may not have prescribed termination rituals in all contexts. The most important structures within groups often provided the only example of a termination ritual. Similarly, the termination of the principal domestic group for a given lineage may have served as a proxy for the termination of subsidiary groups bound by various social ties.

Another likely explanation for this heterogeneous “ritual” landscape lies in the probable flexibility in religious customs among the ancient inhabitants of the Contreras Valley. Indeed, the performance of rituals within this rural community long-divorced from a royal court was probably not dogmatic, rather being adapted to local economic, social, and ideological contexts (Humphrey and Laidlaw 1994). Thus, some households may have decided to conduct termination rituals while the majority opted not to, or simply carried out different types of ceremonies that did not leave archaeological traces.

**Abandonment with anticipated return.** Another potential factor attributable to the absence of termination offerings in most architectural groups of the Contreras Valley is the possibility that, at the time of abandonment, some social groups believed that they would be returning to their home in the near future. This explanation rests on the condition that social or ecological factors would have pushed the inhabitants of these groups to proceed to what they believed to be an episodic abandonment with anticipated return (Plunket and Uruñuela 2003). This type of abandonment normally results in a considerable amount of material typically placed in the corners of rooms (Simms et al. 2012).

Such a mobility strategy may have been more common than we suspect. Indeed, the return of abandoners and the resumption of daily activities would eliminate the archaeological signatures that are most often associated with abandonment. Over centuries, a household group may experience several such abandonment episodes, yet these would be rendered invisible by the return of the occupants. Evidence of abandonment with anticipated return would surface only if the abandoners never returned and if the material they left behind was never disturbed afterward.

**Counterexample from Escalera al Cielo.** Abandonment with anticipated return is indicated by the presence of de facto refuse such as household goods in storage contexts (Schiffer 1972). The Late and Terminal Classic period Puuc site of Escalera al Cielo offers an excellent example of such behavior (Simms et al. 2012). There, excavations of household groups uncovered ceramic vessels and tools in storage, suggesting that the site was abandoned between A.D. 950–1150, at which time the episodic abandoners anticipated returning to their homes.
Excavations at Escalera al Cielo recovered rich assemblages of pottery and lithic artifacts found around the exteriors of doorways and along back and side walls within structures. This pattern contrasts with the centrally aligned on-floor assemblages of Minanha. Yet the assemblages recovered from Escalera al Cielo most likely do not represent the complete material inventories of the abandoners. As a point of comparison, the site of Cerén, El Salvador, was rapidly abandoned due to catastrophic volcanism, forcing its inhabitants to leave almost all of their possessions behind (McKee and Sheets 2003). There, each household contained between 40 and 100 vessels, which were located practically everywhere in and around structures, save for doorways (Beaudry-Corbett and Bishop 2002). The assemblages from Escalera al Cielo are considerably smaller, with an average of 4.14 vessels per structure, indicating that many items were removed during abandonment (Simms et al. 2012). This average is comparable to the four vessels per on-floor assemblage at Minanha, yet the types of vessels, their completeness, and their context is markedly different.

While some Contreras residential groups were ritually terminated, others may have been abandoned temporarily, rather than permanently, thereby circumventing the actual need for ritual termination. That being said, no evidence for abandonment with anticipated return was found at Minanha.

Summary. It is impossible to explain with certainty the disparities in the abandonment processes documented in the Contreras Valley. Nonetheless, considering abandonment as a social practice, rather than a purely behavioral one, opens new avenues of inquiry for investigating the subtleties of differential and gradual abandonment. These abandonment processes and related social practices highlight the complexity of social organization, or differentiation, characterizing the commoner segment of an ancient Maya community.

Conclusion

The ancient Maya community of Minanha was gradually and differentially abandoned between A.D. 810 and 1200. The top and bottom of the social spectrum were first abandoned. The agriculturalist groups settled on the best land in the Contreras Valley—incidentally the first established there—were the last to be abandoned. This pattern indicates that many household groups remained occupied after most of their neighbors and the royal-administrative core had been vacated. This differential abandonment and the presence of termination offerings in three residential groups allows us to inquire into the transformative aspects of abandonment on the identity of both the abandoners and the remaining inhabitants of the Contreras Valley. Moreover, this study yields interesting findings regarding the nature of commoner-specific abandonment ceremonies.

The behavioral-contextual analysis of six on-floor assemblages from three Contreras domestic groups indicates that a portion of the settlement was reverentially and ritually abandoned. Reverential termination rituals, while anchored in religious precepts, also played a social role in helping abandoners detach from their settlement and redefine themselves as migrants. While leaving Maya cities would have meant a thorough social reordering for the abandoning groups, remaining within a depopulated and transformed settlement also would have induced an adaptation to a transforming landscape. The disparity in abandonment chronology and behaviors among household groups suggests that social ties may have favored differential resilience and affected abandonment behaviors.

Studying households from a diachronic perspective—from founding to abandonment—allows us to inquire into the shaping and transformation of the identity of social groups. This approach may be coupled with a consideration of the multiple dimensions of ancient landscapes, in which social groups anchored their life and identity, and which provide us with an excellent background for framing archaeological social models. This emic-oriented method of inquiry is strengthened by the behavioral-contextual analysis of on-floor assemblages, which provides a systematic and replicable analytical framework.

The approach proposed by Cameron (2013) and other authors inquires into the transformative power that migrant groups had over their new host community by studying the often forced immigration of sedentary populations. On the other
hand, by looking at the differential abandonment of an agricultural population, we have studied the transformative power that abandoners had on their former community. Abandonment and migration are two faces of the same coin, yet they yield very different implications for settlements. The question of migrations during the Classic Maya Collapse remains problematic for scholars because next to no data is available on the topic. Nevertheless, this case study does not suggest a case of rapid mass migration. Instead, this abandonment appears to have played out in a more subtle and gradual fashion that entailed idiosyncratic ritual and social phenomena that deserve to be studied in their own right.

Finally, this study affords us a glimpse into a critical moment of ancient Maya culture-history, where many aspects of the identity and structure of social groups played themselves out. At that time, the ancient Maya social landscape commenced its transformation toward its current archaeological state, thus providing us with such an intellectually compelling object of study.

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Supplemental Materials. Supplemental materials are linked to the online version of this paper, which is accessible via the SAA member login at www.saa.org/members-login.

Supplemental Document 1. Excerpts from Maxime Lamoureux-St-Hilaire’s Master’s thesis, including a detailed description and analysis of each on-floor assemblage discussed in this paper, as well as associated top plans and illustrations.

Supplemental Document 2. A summary of the reconstructible ceramic vessels contained in each of the on-floor assemblages discussed in this paper with ceramic types.

Data Availability Statement. This article is based on data excavated by SARP. Excavations in the Contreras Valley were mostly supervised by Carmen A. McCane, whose site report chapters contain raw data and may be emailed by the first author upon request. The analysis and interpretation of the on-floor assemblages relies on the M.A. thesis of Maxime Lamoureux-St-Hilaire, available on Proquest (and partly available as Supplemental Document 1). The organization of the Contreras Settlement data and its interpretation relies on the M.A. thesis of Scott Macrae, available on Proquest. Moreover, several papers presented at the Belizean Archaeology Symposium by the authors contain preliminary interpretations and are available in the conference proceedings.

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Notes

1. The term *jaloj-k’exoj* is used among modern Tzutujil Maya of the Lake Atitlan region of highland Guatemala and refers to a “concentric system of change within change, a single system of transformation and renewal” (Carlsen and Prechtel 1991; McAnany 2014; Mock 1998a).

2. The sampling strategy elaborated by Iannone for the SARP investigations of Minanha emulates the sampling strategy adopted by Ashmore and the other members of the Xunantunich Archaeological Project (Ashmore et al. 1994). It separated all settlement types in six categories along a continuum based on the size and quantity of mounds, from single isolated mound (Type I), five or more mounds of less than 2 m in height (Type IV), to groups with at least on mound of 2–5 m in height (Type VI). It should be noted that no group outside the Epicenter qualified for Type VII, which included a mound of more than 5 m in height.


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Conclusion

Information about the prehistoric past is only available in the archaeological remains left behind in the archaeological record which is dependent upon the environment, time, and substance. Therefore, to be meaningful, these remains must be interpreted under the influence of an always-changing archaeological record (Sullivan 2008; Lucas 2005). More specifically, the archaeological record is ambiguous in the sense that prehistoric phenomena “do not speak for themselves” and are therefore subject to the problem of equifinality (i.e., having the same end result) (Schiffer 1976; Shanks and Tilley 1987). As a result, researchers are forced to make (hopefully) objective conclusions from the data about what these data indicate about the past, and these data can range from individual artifacts, to archaeological sites, to the results of regional surveys, to paleoenvironmental proxy signals. Additionally, archaeology relies on the contemporary character of the archaeological record as a means of mediating between the past and present (Jones 2002:169). More specifically, from the time archaeological and paleoenvironmental phenomena materialized in the past, they have been subjected to a series of cultural and natural formation processes which may have disturbed their original place of deposition during the abandonment process (Schiffer and Rathje 1973; Schiffer 1976:11), and may have affected the ability of researchers to gather these types of data from the archaeological record. Consequently, non-subjective conclusions can only be made about the origins of the archaeological record with an understanding of the cultural and natural processes that could have affected is content and formation. The effects of cultural and natural formation processes must be taken into consideration and corrected for before making inferences so that a more accurate picture of past behavior or environment can be understood.
So, how can researchers become more cognizant of the effects of cultural and natural formation processes?

Multi-disciplinary approaches (e.g., geoarchaeology) to the study of the archaeological record enable archaeologists (and other participating geoscientists) to have a firmer grasp of the ambiguous nature of these archaeological phenomena and be able to interpret them more intelligently. This dissertation demonstrates not only the importance of geoarchaeological research in examining human-environment interactions in antiquity, which can help us to learn about the capacity of humans to adapt to environmental change (discussed in more detail in the concluding paragraph), but each of the three articles also highlight some of the concerns/limitations encountered when interpreting these types of potentially “ambiguous” results. A summary of the (hopefully unambiguous) results and potential future work for each of the three articles is provided below.

**Article 1:**

As Article 1 illustrates, geoarchaeology has rapidly emerged as an important component in the investigations of ancient cultures. This article focused on the expansion of geoarchaeological research since 2000 within Mesoamerican archaeological investigations. It was determined that there were five major themes central to recent studies: 1) the correlation of environmental change and culture history; 2) anthropogenic environmental impacts; 3) ancient land cover, land use, and diet; 4) archaeological prospection; and 5) provenance studies. These five central themes are often times interwoven (the first three are sometimes

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1 The author of this dissertation completed a majority of the survey related to the growth of geoarchaeological research in the southern Maya Lowlands since 2000.
inseparable) and applied under a complex systems approach that allows scientists to more accurately model the intricacies of cultural and natural processes through their use of multiple environmental proxies. These five themes also fit nicely into the ‘blended’ definition of what constitutes geoarchaeological research discussed in the dissertation Introduction.

Not only were examples of the geoarchaeological research being conducted in the different regions of Mesoamerica provided in this article; but, often times, the article also highlighted some of the criticisms/concerns with respect to the philosophies under which the results were being interpreted, a method’s chronological precision, or correlations being made between variables (e.g., drought led to the collapse of the ancient Maya). Due to a growing array of instrumental techniques, information about ancient cultures and environments continues to expand at a rapid rate through the use of multi-proxy studies of paleoenvironments, land use, and diet. As a result, it was proposed that, in the future, the data being produced by geoarchaeological (and other types of archaeological investigations) be incorporated into a database capable of supporting integrated analyses (e.g. a Geographic Information System). This would be an effective way to synthesize and compare data from multiple sources in support of more robust and temporally dynamic models.

**Article 2:**

Early investigations indicated that many of the surrounding valleys and hilltops were home to the people and communities that helped sustain the Late Classic royal court of Minanha, a moderately large Maya center in west-central Belize. In 2006, Phase II investigations began in a terraced valley with an abundance of settlement units located
approximately one kilometer southeast of Minanha’s epicenter, the Contreras Valley. These Phase II investigations were designed to complement and expand upon previous investigations in Minanha’s epicenter by focusing on the examination the composition of this peripheral settlement community (both temporally and spatially), creating an ‘archaeology of community.’ Specifically, these investigations were aimed at examining the rise and fall of the Minanha city-state from the perspective of the support populations.

There are 98 known settlement units in Contreras with a majority of them being made up of a limited number of buildings informally arranged (there are much ‘less formal’ when compared to the epicenter and Site Core); however, larger and more formal groups do exist in the Contreras Valley and it has been proposed that these settlement units may have represented long-standing rural families (i.e., according to the Principle of First Occupancy). Preliminary ceramic analysis from the excavated settlement units indicates that the Contreras Valley was inhabited from at least the Late to Terminal Preclassic all the way through the Terminal Classic. Therefore, there was a population residing in the Contreras Valley long before, during, and after the fall of the royal court. Preliminary spatial analyses indicated that elevation did not have any significant impact over where the residents chose to resides and settlement units in the Contreras Valley are also dispersed randomly across the 1 square kilometer survey area.

With respect to terrace construction, it was determined that the inhabitants of the Contreras Valley: 1) began using agricultural terraces at a very early date to help support a

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2 Phase II investigations also included the examination of the composition of the Site Core zone, but the authors of this article only focused their research on the settlement groups and terrace construction in the Contreras Valley.
developing community (some time during the Late to Terminal Preclassic); 2) the inhabitants had a well founded knowledge of terrace construction resulting in uniform terraces ‘sets;’ and 3) the terrace system within the Contreras Valley exhibit characteristics of having a heterarchical organization.

These investigations provided a wealth of knowledge concerning the peripheral community of Minanha; however, further analyses could continue to help shed light on our understanding of this community and the issues which affected it during its lifetime. In 2010, Phase II research ended at Minanha and Phase III investigations shifted to the examination of the minor centers surrounding Minanha (the Waybil and Martinez sites). However, if research were to ever resume at Minanha again, it could be beneficial to expand on some of the research performed in the Contreras Valley. For example, how would settlement composition and density change if the survey area was expanded to 2 square kilometers? Additionally, what if some of the geoarchaeological methods and techniques described in Article 1 were employed with respect to land cover, land use, and diet? More specifically, carbon isotope and isotope analysis on the faunal (and human remains) could help us to understand the types of foods that were being consumed and from where resources were being procured from. Further, soil chemical analysis could help to shed light on the extent and intensity of domestic and agricultural production. Lastly, pollen records could help to estimate the amount of forest cover and the recovery of macrobotanical remains could be used to reconstruct food preferences beyond the standard models that focus on corn, beans, and squash. All of these aforementioned hypothetical geoarchaeological data could help us to “paint a better picture”
of the life of the Contreras inhabitants. These data could also help us to understand the eventual abandonment of the Contreras Valley described in more detail in Article 3.

**Article 3:**

The ancient Maya community of Minanha was gradually and differentially abandoned between A.D. 810 and 1200. It appears as if the dwellings at the top and bottom of the social spectrum were the first to be abandoned. Interestingly, the agricultural groups settled on the best lands in the Contreras Valley—the first groups established there—were the last to be abandoned (e.g., Principle of First Occupancy). Therefore, some of the Contreras household groups remained occupied after most of their neighbors and the royal court complex had been vacated. Further, the presence of termination offerings in three of the residential groups indicates that a portion of the settlement may have been reverentially and ritually abandoned. These offerings may have played both a religious and social role (i.e., helping abandoners detach from their home). The difference in chronology and behavior among different settlement groups may have favored differential resilience and affected abandonment behaviors.

The authors also explored why certain architectural groups were ritually terminated and others were not. Three potential explanations were offered for the disparity in the archaeological recovery of termination rituals. First, post-depositional natural (e.g., erosion, bioturbation, etc.) and cultural (e.g., squatting, scavenging, etc.) formation processes may help to explain the lack of termination rituals in many excavated structures. Second, variability in termination rituals may help to explain a lack of on-floor offerings relating to termination rituals (i.e., ceremonies that did not leave archaeological traces). Lastly, at the time of abandonment,
some household groups may have believed that they would be returning to their home in the near future. In this portion of the article, the authors emphasize the importance of including the potential effects of natural and cultural formation processes in their interpretations of the termination rituals in the Contreras Valley as highlighted in this chapter’s opening paragraphs.

In the future, again, if research were to be resumed at Minanha it could be beneficial to expand on the research being conducted in the Contreras Valley. Not only should the geoarchaeological techniques mentioned in the “future work” portion of Article 2 (discussed above) be conducted, it might also be interesting to perform residue analysis and/or phytolith analysis on the ceramic vessels and burners left in ritual deposits to help determine potential plant use and ritual behavior. Further, carbon isotope, phosphorous and other trace element analysis could be performed to locate areas of household gardening, food processing, craft production, etc. Lastly, a more in depth examination of the potential effects that drought may have had on the Contreras (and greater Minanha) populations is warranted. This third article provides an excellent overview of the presence (and absence) of the termination rituals and abandonment of the Contreras Valley; however, what this article fails to discuss is why the individuals abandoned this community. Through the use of the aforementioned geoarchaeological techniques discussed in Articles 1, 2, and 3, the “story” of the Contreras inhabitant’s occupation and abandonment of the valley could be strengthened. For example, a few potential questions that could help to explain the gradual and differential abandonment of the Contreras Valley could be investigated with the use of more geoarchaeological techniques: 1) were there any temporal changes in resource exploitation (e.g. clay, obsidian, etc.) and what sorts of implications do such changes have for understanding resource access?; 2) did the soils in
this agricultural valley become depleted?; 3) any evidence of overhunting?; 4) did their diet change and why?; and 5) could the drought(s) have had devastating effects on the population? Answers to these questions, and others like them, not only could help to strengthen our understanding of the abandonment of the Contreras Valley, but the use of these potential paleo-analogs can help us also to learn about the capacity of humans to adapt to environmental (and societal) changes. Understanding the potential success and failure of the Contreras inhabitants (and any other prehistoric/historic communities, civilizations, etc.) can help us to predict the sustainability of and resilience of these systems and their contemporary counterparts.

**Concluding Remarks:**

To reiterate, this dissertation demonstrates that geoarchaeological research that directly examines human-environment interactions can help us to learn about the capacity of humans to adapt to environmental change. More specifically, understanding the success and failure of past societies can help us to predict the sustainability and resilience of these systems. That is, learning about the capacity of humans to adapt to both societal and environmental change is the most important enduring product of geoarchaeological investigations of the ancient world. Geographers such as Carl Sauer, felt a moral responsibility to contemporary society to study the human-environment interactions of prehistoric cultures so that we, as humans, do not make the same mistakes as those that were made in the past (e.g., environmental degradation) (Livingstone 1992). As a result, geoscientists (e.g., paleoecologists, soil scientists, geologists, biologists, and climatologists) are increasingly turning to archaeology because it can provide a long-term view of human-environment interactions that have shaped
both Quaternary and Holocene landscapes (Goldberg and Macphail 2006). Therefore, the past is essential not only to understanding the present, but even more important to evaluate the potential outcomes of modern trends (e.g., regional development, resource management, ecological sustainability, etc.) which have become central concerns in human geography (Butzer 1982:320). As we continue to learn more and more about the past, it becomes more apparent that former generations, civilizations, and ecological history can tell us a lot about the sustainability of our present-day and future strategies.
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