SOIL IS SOCIAL: INVESTIGATING MAYA SOIL DYNAMICS AND SOCIAL STRATIFICATION DURING CLIMATE CHANGE WITH X-RAY FLORESCENCE SPECTROMETRY

A Thesis
Presented
to the Faculty of
California State University, Chico

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Anthropology

by

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Fall 2013
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DEDICATION

To my mother Barbara:
For teaching me to love reading;

To my sister Lacey:
For feeding my imagination;

And to Marisol:
For having faith in me,

And for convincing me to have faith in myself.
ACKNOWLEDGMENTS

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ABSTRACT

SOIL IS SOCIAL: INVESTIGATING MAYA SOIL DYNAMICS AND SOCIAL STRATIFICATION DURING CLIMATE CHANGE WITH X-RAY FLORESCENCE SPECTROMETRY

by

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Using an original method of comparing available soil nutrient levels with X-ray fluorescence (XRF) scans of total elemental concentration at the Dos Hombres to Gran Cacao Archaeology Project (DH2GC) in northwestern Belize, this thesis tested for 1) an anthropogenic implosion of the phosphorus nutrient-cycle, called P-fixation, and 2) differences in soil fertility between elite and commoner sites.

The presence of P-fixation was confirmed by the XRF data and is suggested to be anthropogenic in origin. These results reveal a major limitation of traditional soil methodologies that rely solely on measurements of available phosphorous, as the portion of phosphorus content that is unavailable to plants is unable to be measured.
The data for the second research question was determined to belong to two soil populations. Because it is necessary to view social systems as complex dialectics in order to make meaningful interpretations of the soil data, the data for these samples could not be effectively compared, and the planned methodology for approaching this question was rendered moot.

Additionally, severe salinization problems were diagnosed and statistical methods were applied to XRF nutrient signatures to identify over a dozen anthropogenic samples believed to part of the background grid. These sites may represent the class of “invisible Maya” that lived in perishable structures, which are heavily underrepresented in Maya archaeology. These methods may allow for a more dexterous application of theory for exploring larger themes such as social inequality and identity in future research.
CHAPTER I

INTRODUCTION

Background and Terminology

In this thesis I will examine the study of archaeological soils in the Maya lowlands using accessible language and innovative methodologies for regional and site-specific soils analysis. The first objective of this thesis is to determine if a detrimental soil condition called P-fixation was limiting agriculture at the location of the Dos Hombres to Gran Cacao Settlement Archaeology Project (DH2GC). This project is directed by Dr. Marisol Cortes-Rincon, in the northwestern region of Belize known archaeologically as the Eastern Peten Maya Lowlands. The secondary objective is to investigate the social meaning of soil characteristics that possibly reflect social inequality during Maya Terminal Classic.

P-fixation is a soil condition in which phosphorus is present in the soil in various chemical forms that are unavailable for plants to consume. Essentially, the chemical dynamics of the soil prevent the nutrient cycle from changing the unavailable phosphorus into available phosphorus. The capacity of the soil to make phosphorus available has implications both for the agricultural viability of the soil, and the prevailing archaeological methods of measuring available phosphorus for estimating the intensity of site occupation. The meaning drawn from available phosphorus tests may differ greatly if
P-fixation is a factor. Archaeology has traditionally relied upon the artifacts left behind by ancient people to answer questions about the past. What survives into the archaeological record represents what was lost or not taken with the people at abandonment of specific sites, not looted, and not destroyed by natural processes. Studying soils has granted an additional avenue to record chemical traces of human behavior. When humans gather resources from the landscape and bring them to be processed and discarded in a central location, the chemistry of the soil at such locations is altered. These changes may be slight in the short-term; however, repetitive actions over time can cause significant changes that are intelligible thousands of years later.

Leaf-cutter ants are an excellent example of how this process works. Leaf-cutter ants, the only other agricultural species aside from humans, bring leaves to their nest to cultivate an underground fungus that they eat. This process increases the amount of organic material present in the soil which improves the fertility of the soil. Indigenous farmers in the region highly prize the material pushed out of leaf-cutter ant mounds for use as a fertilizer (Wilken1987:53). The way in which the behavior of leaf-cutter ants contributes to the concentration of chemicals and organic matter near their nests is precisely the principle behind studying soils at archaeology sites.

The spatial patterns that emerge when the soils at archaeology sites are mapped have social meaning. The soil data may reflect the resource input of a site, spatial organization, land management practices, and perhaps social inequality. Elite control over spatial organization could be utilized as a way to manage the means of
production or access to public spaces. If this is the case, the locations of sites primarily occupied by elites may present more fertile soils than those primarily occupied by the commoners in a way that is not explainable by natural processes. This thesis investigates soil at both elite and commoner sites against a backdrop of inherent local soil characteristics.

**Hypotheses and Testing Methods**

The primary hypothesis ($H_1$) is focused on the general fertility of the soil. $H_1$ contends that P-fixation was occurring at the DH2GC project area and is significant enough to have limited agriculture in the region. The null hypothesis ($H_{01}$) is that P-fixation is not significant enough to affect the agricultural viability of the soil at the DH2GC project area. The secondary hypothesis ($H_2$) is focused upon detecting social meaning in the soil. ($H_2$) asserts that elite sites will have significantly more fertile soil relative to commoner sites. The null hypothesis ($H_{02}$) is that the soil fertility will not differ between elite and commoner sites.

The reason for including two hypotheses in this thesis is that they are complimentary lines of inquiry. The outcome of ($H_1$) will have ramifications for ($H_2$). The first question will help to establish local soil characteristics. The results will provide context that will aid in the interpretation of what is significant variation in phosphorus levels and perhaps, if the p-fixation is anthropogenic or natural. If P-fixation is present, it would by definition reduce the usefulness of available phosphorus data as a soil fertility
indicator in the particular soil environment. In such a case XRF data may provide more meaningful results. This will be clarified in the following paragraph.

To investigate the two research hypotheses, this thesis will utilize data from soil sample tests performed with both traditional soil tests and X-ray Fluorescence Spectrometry (XRF). The XRF scans will provide total elemental levels of phosphorus, while the traditional tests will reflect only the available phosphorus levels that are relied on by archaeologists, farmers and their plants. With these two types of data, a ratio of total to available phosphorus can be established and P-fixation estimated.

The pH levels will also be useful in this determination of the availability of phosphorus. A pH of 6.5 would suggest maximum P-availability, while 7.3 and over would suggest strong P-fixation. Soil fertility will be gauged by a soil fertility index that will combine multiple soil nutrient levels and organic matter levels. The factors will be weighted based upon the importance of the particular factor in soil fertility.

The first dataset was collected during a three year period from the first 1.3 km of the DH2GC under the auspices of the Programme for Belize Archaeological project (PfBAP). The project was designed by Dr. Cortes-Rincon to systematically investigate the settlements between two known sites in the Maya Central Lowlands: Dos Hombres, and Gran Cacao (Cortes-Rincon 2011:1). Both of these cities were depopulated around CE 900 during the Late Classic period. Most of the sites in PfBAP are abandoned in Terminal Classic with some Post-Classic visitations which likely represent ancestor veneration.
The second data source comes from the peripheral areas of the neighboring site of Chawak But’o’ob, directed by Stan Walling. The background soil samples were collected at both DH2GC and Chawak But’o’ob by Nick Brokaw and Sheila Ward during a tree survey in which the presence or absence of archaeological sites was recorded.

**Organization of the Document**

This thesis will be organized into the following sections: background, soils, the contemporary Maya intellectual renaissance, theory, methods, results, discussion and the conclusion. The background will include the research history of in the project region, the research history of the DH2GC project, the cultural and environmental chronology, physiography and climate, relative dating from ceramics, project area lithic analysis, population density and spatial organization. Appropriate maps and figures will be included.

The soils chapter will include a section on soil genesis that will include discussion of climate, organisms, relief, parent material and time. Next it will review the basic physical and chemical properties of soil, the use of soils in archaeology, and the soils of the project region, sustainability, the preliminary results of the initial project soil survey, and ethnopedology.

The Maya intellectual renaissance chapter will provide a brief overview the contemporary Maya, Pan-Maya movement. The Maya have been so tragically misrepresented that the public commonly believes them to be extinct. Therefore, it is
important that opportunities are taken to correct misrepresentation and to highlight their accomplishments and goals.

The theory chapter will detail the theoretical perspective that I will employ in both the analysis and interpretation. The theoretical perspective will be a synthesis of soilscape, gender theory, and historical materialism. The inclusion of these three often opposing theoretical perspectives will help to triangulate interpretation and temper it against partisan myopia. I will approach the study of archaeological soils as a continuous dialectic between people and soil.

The methods chapter will outline the procedures and rationale followed to produce the results. A comparison between the soils at Programme for Belize Archaeology Project (PfBAP) and the Maya site of Nacco Valley will be included to illustrate the local characteristics of the soil at DH2GC in the context of what is more representative of the norm at Maya sites. The Results, Discussion, and Conclusion sections will of course provide the results of the analysis, theoretical interpretation of the results, and my conclusion based on the preceding chapters.

Purpose of the Study

I chose this topic for several reasons. First, I believe that utilizing soil science and X-Ray Florescence Spectrometry (XRF) has unrealized potential to answer social questions and revolutionize archaeological methods. It is also the case that studying Maya land management during a period of climate change makes the results of such research relevant today.
The results may have significant implications for the importance of building an intimate understanding of the local soil dynamics including the capacity of the soil phosphorus nutrient cycle to make phosphorus available. This variable must be confronted for each project so that we may contextualize and calibrate the interpretation of soil data. Testing for P-fixation spatially may also help to build a context for the abandonment of the area.

There is much unexplored potential in soils archaeology. For example, it may decrease the amount of site disturbance necessary to gather meaningful data for interpretation if smaller test units are excavated, and soil cores are minimally invasive. Reducing our impact is important for protecting finite resources and respecting the places of cultural significance for descendant communities. Finding less invasive methods to retrieve our data may help establish good faith relationships with descendant communities. In addition to protecting sites, a shift to more reliance upon soil data may also help to alleviate overcrowding of curation facilities as increasingly affordable technology such as XRF reduces the volume of export sample sizes from quarts to tablespoons. Field portable technology can eliminate the need for storage of samples altogether.

It is our ethical responsibility to only collect what we have the time and resources to analyze and to conserve. It was not long ago that the handheld Global Positioning System (GPS) was prohibitively expensive but today this technology is a standard feature of smartphones. Before long, the handheld XRF may become as
ubiquitous with archaeology as the trowel. It behooves us to invest in understanding how to use the most effective technologies available in order to meet our goals.
CHAPTER II

LITERATURE REVIEW: PROJECT AREA

The Program for Belize Archeology Project (PfBAP)

The culture area of the ancient Maya includes parts of southeastern Mexico, Guatemala, Belize, northern El Salvador and western Honduras (Aylesworth 2005:12). The project is located in a 2000 km geographic area within the Maya culture area called the three rivers region (see Figure 1), which is named after three rivers; the Booth's River, Rio Bravo in northwestern Belize, and the Rio Azul in northeastern Guatemala. The Three rivers region boundaries are the Rio Azul in the north and west, the Booth's river to the east of an arbitrary line at the Maya site of Chan Chich (Hyde 2003:6). Extensive archaeological projects have been active in the three river's region since the 1980s (Hyde 2003:9). Before this period, the archaeological attention to the region had been sparse and sporadic.

J.E.S Thompson made the first visit to the area in 1939 when he briefly excavated and named the site of La Milpa (Aylesworth 2005:38). R. E. W. Adams conducted two projects in Guatemala during the 1980s and early 1990s that investigated settlement patterns around the Bajo Azucar. These included the Río Azul Archaeological Project (RAAP), and the Ixcanrio Regional Archaeological Project (IRAP) (Adams 1984, 1986, 1987, 1989, 1999, 2000; Adams and Valdez 2003; Hyde 2003:9). The first Three
Rivers Region research projects in Belize began in 1988 under the direction of Thomas Guderjan (Guderjan 1991), through the Maya Research Project (MRP).

*Figure 1.* The Rio Bravo Management Conservation area in its context in Central America (Lohse 2001; Trachman 2007).
The Programme for Belize Archaeological Project (PfBAP) was initiated by R.E.W. Adams in 1992 and continues to operate today under the leadership of Fred Valdez, Jr., (Adams 1994; Adams and Valdez 1993; 1995; Hyde 2003:10). Ford and Fedick (1988) provided an initial survey of the archaeological potential of the area. The data for this thesis was collected in collaboration with PfBAP in the Rio Bravo Management Conservation Area (RBMCA) which is the largest preserve in Belize.

Three Rivers Region Research History

Most of the research conducted by PfBAP is conducted in the RBMCA, which is held in trust by PfB (Aylesworth 2005:12). The original parcel included 45,000 hectares that were acquired from Gallon Jug Agroindustries during 1989. The PfBAP later expanded through donations and additional purchases. Coca-Cola Foods, Inc., for instance, donated 39,000 hectares. A total of 21,000 hectares were purchased from New River Enterprises, Ltd. Today, the RBMCA consists of 105,000 hectares of land which is roughly 4% of the total land area of Belize (Aylesworth 2005:12).

During the same year that PfBAP began, the La Milpa Archaeological Project (LaMAP) was initiated by Norman Hammond to study political and social organization at the site of La Milpa (Hammond 1991; Hammond and Tourtellot 1993, 1999; Hammond et al. 1996, 1998; Tourtellot et al. 1993, 1996, 1997, 2003; Hyde 2003:10). A year later, The Blue Creek Project began to investigate the site of Blue Creek and its hinterlands (Guderjan and Driver 1995; Guderjan et al. 1993, 1994 Hyde 2003:11)). In 1996 the Chan

The primary goals of the PfBAP are the identification and recording of archaeology sites in the RBMCA, and the investigation of the social, and political organization of the Three Rivers Region (Trachman 2007:11). The project operates in collaboration between researchers from many different universities with diverse interests and methods (Trachman 2007:11). PfBAP has expanded exponentially and it continuous to conduct innovative research.

The collaborative effort over a thirty years at over 60 archaeological sites has provided a wealth of information on the settlement chronology and culture history of the Three Rivers Region (Hyde 2003:11). Within the boundaries of the three rivers there are in fact two related but significantly different culture histories for the Bajo Azucar Zone centered around the powerful city of Río Azul and the Rio Bravo Zone associated with the city center of La Milpa (Hyde 2003:12). This project is associated with the Rio Bravo Zone.

Dos Hombres to Gran Cacao

The Dos Hombres to Gran Cacao Archaeology Project (DH2GC) directed by Dr. Marisol Cortes-Rincon, is an innovative project that utilizes micro-scale and macro-scale analysis through interdisciplinary lines of evidence to better understand political and economic organization in the Maya hinterland (Cortes-Rincon 2011:1). These lines of data include a survey of tree distribution, soil properties, water management and the spatial configuration of archeological settlements (Cortes-Rincon 2011:1).
The 12km survey transect is designed to systematically investigate the settlements between two known sites in the central Maya Lowlands in northwestern Belize: Dos Hombres, and Gran Cacao (Cortes-Rincon 2011:1) which were mostly abandoned around 900 CE during the Terminal Classic period. The project is located in a micro-region, previously unexplored. A wealth of data has been collected during the 2009-2012 field seasons that allow for addressing diverse research questions.

**Dos Hombres.** Dos Hombres (see Figure 2) was occupied between the Middle Preclassic (BCE 800–BCE 600) and the Terminal Classic (CE 800/850–900) with abandonment marked by the ritual termination of the acropolis followed by a period of limited visitation and possible pilgrimage during the Post Classic (Trachman 2007:55-56; Houk 1996:236). The first study conducted at Dos Hombres was a settlement survey conducted by Robichaux (1995), who concluded that the population density was likely 480 persons per km (Trachman 2007:29). The chronology was established by Houk (1996) as well as comparative studies on the site layout which suggested a similar layout as La Milpa and the possibility of cosmological significance (Trachman 2007:29).

Two residential courtyards were excavated, one by Brown (1995) (A-5) and a second by Durst (1998) (B-4) which established evidence for Early Classic (CE 250–600) occupation. Two settlement surveys were conducted at Dos Hombres, the first by Lohse (2001) and the second by Lohse (2003). Aylesworth (2005) excavated group (D) to build greater chronology and to examine architecture.
Figure 2. Dos Hombres (after Houk 1996; Lohse 1999; Trachman 2007).
Trachman (2007) conducted her dissertation research at Dos Hombres using a micro-scale analytical approach to household archaeology. She investigated Late Classic social and economic organization, social reproduction, and social identity construction and is the current director of investigations at Dos Hombres.

**Gran Cacao.** Gran Cacao (see Figure 3) is situated in a transitional scrub swamp the northeaster portion of the Rio Bravo Management Conservation Area (Brokaw and Mallory 1993; Hyde 2003:55). The heavily looted site was identified in 1993, and was subsequently mapped and excavated by Jeffrey Durst (1995) and John Lohse (1995; Hyde 2003:55). The site is difficult to access and the quantity and scale studies have been greatly limited.

The site is ranked as a small major center and suburban sustaining area (see Table 1) (Hyde 2003:33). Small major centers are sites that have political and cultural influence that extends beyond the immediate area, have small scale monumental architecture, large plazas, steleas and ball courts (Hyde 2003:52). Suburban sustaining areas were defined by R.E.W Adams as areas 1 to 4 km from a site core (Hyde 2003:46).
Figure 3. Gran Cacao (after Durst 1996; Hyde 2003).
Table 1. Examples of the site-rank breakdown for PfBAP sites, adapted from (Hyde 2003).

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<td>Small Major Center</td>
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<td>El Pedernal</td>
<td>Suburban Sustaining Area</td>
</tr>
<tr>
<td>Las Abejas</td>
<td>Minimal Ceremonial Center</td>
</tr>
<tr>
<td>Dos Barbaras</td>
<td>Minimal Ceremonial Center</td>
</tr>
<tr>
<td>Guijarral</td>
<td>Minimal Ceremonial Center</td>
</tr>
<tr>
<td>Gateway</td>
<td>Informal Cluster</td>
</tr>
<tr>
<td>El Arroyo</td>
<td>Informal Cluster</td>
</tr>
<tr>
<td>Medicinal</td>
<td>Trail Informal Cluster</td>
</tr>
</tbody>
</table>

Three Rivers Region Cultural History

**The Preclassic period (BCE 3000 – BCE 900)**

The beginning of this period of early occupation was marked by modifications to forests and steady increases in deforestation in northwestern Belize (Buttles 2002; Hester et al. 1996; Iceland 1997; Jones 1994a, 1994b; Pohl et al. 1996; Hyde 2003:12). This period ended upon the adoption of ceramic technology. Lithic technologies, however, remain consistent well into the Middle Preclassic, indicating a single continuous population rather than migration.

**Middle Preclassic (BCE 900 – 400)**

Although there is evidence of occupation during this time-period, no associated sites have been excavated. There is evidence for Middle Preclassic occupation at La Milpa, Dos Hombres, Chan Chich, and Punta de Cacao (Hyde 2003:13). Because of this there is little known about the Middle classic in the Three Rivers Region, however
social changes are suggested by the presence of monumental architecture (Hyde 2003:13). The culture histories of neighboring areas are used as proxies for interpolation with what is known about the local occupation during this time. Settlements at this time were clustered around natural sources of water and no evidence exists for water collection systems (Hyde 2003:12).

**Late Preclassic (BCE 400 – CE 250)**

The Late Preclassic is characterized by increases in population, landscape modification, and monumental architecture. The new features suggest major changes in social organization (Hyde 2003:14). During this time, for example, ceramic materials provide the first evidence of trade (Hyde 2003:14). The monumental architecture indicates that the rulers were able to organize specialized labor (Trachman 2007:20). The Terminal Preclassic period (CE 150-250), is marked by slight decline at select sites such as El Mirador and the construction of defensive features (Trachman 2007:22).

**Early Classic (CE 250 – CE 600)**

During the Early classic there were major changes in the balance of power in the region. Some established powers declined and others ascended. Rio Azul, for example, was conquered by a rising Tikal around (CE 400) (Adams 1987; Trachman 2007:23. At this point the Three Rivers Region became more autonomous and less connected to the other powers in the greater Peten region in which the Three Rivers region is situated. Near the end of the Early Classic period the city of Teotihuacan
declined. This gave way to a period of economic and political instability referred to as the Classic Hiatus (500-600 CE) (Trachman 2007:24).

**Late Classic (CE 600- CE 800)**

Following the fall of Tikal the major centers in the Three Rivers region, La Milpa, Río Azul, Dos Hombres, and Chan Chich began to grow and prosper (Lichtenstein 2000; Hyde 2003:18). Although this was a period of decentralization, increases in monumental construction at La Milpa suggest that it became a more important regional center or capital (Lichtenstein 2000; Hyde 2003:18). There is evidence of interaction between Río Azul and La Milpa early on but we are not sure which was dominant and if La Milpa was controlled by Tikal or not (Cortes-Rincon: Personal Communication 2013).

The settlements in the rural areas consisted of perishable structures clustered around smaller elite groups which Adams (1995) describes as an aristocratic feudal system. The land exploitation practices during this period had disastrous effects because of intensive deforestation coupled with increases in population that would have increased the need for intensification of agriculture. These human-made environmental problems were compounded by the onset of major droughts.

**Terminal Classic (CE 800- CE 900)**

The problems that characterized the troubling end to the Late Classic defined the Terminal Classic. This was a period in which the many problems that the Maya were facing lead to the permanent abandonment of many city centers, relocation and a social
transformation. The Maya occupied smaller communities in rural settings, and hierarchies diminished.

**Physiography and Climate**

The area between the Rio Bravo escarpment and the Booths river escarpment (see Figure 4) is flat to gently undulating, with a higher proportion of low and high marsh comparative to the uplands in the PfBAP study area. The parent material is hard Paleocene or Lower Eocene epoch limestone covered by a layer of highly weathered Eocene limestone. The soils are generally workable, shallow (between approximately 20cm to 1.5 m) gravelly clay rich and reasonably fertile but poorly drained (Ford and Feddick 1988:5).

![Figure 4](image-url)

*Figure 4. The east to west topographic cross-section of the Rio Bravo Management Conservation Area. Adapted from (Dunning 2003).*

During the 1970s, resources and the environment became a focus of attention for explaining the Maya transition (eg. Culbert 1973). In the 1990s however, researchers began to consider climate. Ecological studies began establish evidence for
climate change resulting in extreme aridity (Hodell et al., 1995, 2005; Rosenmeier et al., 2002), water scarcity and land resource pressure (Turner 2010; Lucero 2002; Gill 2000).

As indicated by Beach et al., (2005, 2009) erosion caused a major shift in settlement patterns with sedimentation that accumulated during Preclassic times in shallow lakes and marshes caused a later shift to settle near these areas. Soil phosphorus, was identified by Lawrence et al. (2007) as the major limiting factor of agriculture in the region and that the deforestation may have lowered the amount of wind-blown phosphorus that the canopy would capture and integrate into the system (Turner 2010:1). Furthermore, a lack of tree cover can increase wind erosion which would remove additional phosphorus from the soil surface (Turner 2010:1).

Ironically, it was during times of great stress that the Maya first began to flourish and grow to build great city centers and monuments (Turner 2010:1). It is clear that the Maya were aware of conservation needs, and adapted to increase sustainability. Despite evidence of these efforts however, evidence of environmental degradation is clear and raises questions about the point of intersection between sustainability of human practices and natural changes in environmental conditions.

Although the project area was abandoned around 900 CE, the Maya endured to the north and later in the Contact Period battled the Spanish. This indicates that the climate cannot explain depopulation of the south alone. It does however appear to be a factor that combined with deforestation and other anthropogenic forms of
environmental destruction created the conditions of social reorganization (Turner 2010:1).

In the past Maya agriculture was looked at simplistically as a uniform system of swidden agriculture. Research at pulltrouser swamp in northern Belize later identified large raised fields that are similar to the chinampas in Central Mexico (Walling 1991). Today the research focused on Maya Agriculture mainly supports the theory that ancient Maya agricultural strategies were regionally diverse rather than uniform (Turner 2012:13908; Fedick 1996). The prevailing view describes a highly adaptable system that varied based on the particulars of local environmental advantages and challenges.

Multiple lines of evidence indicate that irrigated agriculture was practiced around the lowland karst depressions referred to as “bajos” until after the Terminal Classic period when no further attempts were made to maintain the canals (Luzzadder-Beach 2011:3646). Wetlands were long considered unsuitable for agriculture but after four decades of studies on Maya wetland agriculture it’s clear that it played a much larger role in Maya subsistence strategies than previously realized (Luzzadder-Beach 2011:3646).

These studies have contributed greatly to building evidence for large-scale environmental changes, and behavioral adaptation (Luzzadder-Beach 2011:3646). The topography features rolling hills and karst bajo depressions. Important Maya sites are often found near these depressions which are now believed to have been highly productive (Luzzadder-Beach 2009:1710). Many of the earliest Maya sites built around
bajos were abandoned around CE 100-250, while those that developed water management infrastructure such as water storage basins and terraces survived into the class era CE 250-950, (Dunning et al. 2002:267). Nicolas Dunning (2002:267 argues) that the level of human modifications to the landscape in the bajo agriculture system are the most significant and enduring in the Pre-Columbian new world.

Pollen analysis has indicated increasingly heavy levels of deforestation and increases in the cultivation of maize during the Preclassic period, coinciding with a period of soil loss and sedimentation (Turner 2012:13908; Beach et al. 2010; Beach et al 2007; Jacob 1995). The population rose until stagnation during the Late Pre-classic before pressures mounted again followed by the early classic period adoption of intensive terracing and other soil conservation practices which significantly slowed the rate of soil and nutrient loss (Beach 2006).

An important part of Maya agriculture that has recently been receiving more attention from researchers is the “kitchen gardens” or “solares” which the contemporary Maya still rely on (Flores-Delgadillo 2011:112). These gardens utilize a diverse variety of useful food and medicine plants and for raising domestic animals such as turkey and duck (Flores-Delgadillo 2011:112. These spaces would have created a high level of biodiversity above ground and inside the soil matrix which is an important factor in sustaining soil health. These domestic agricultural areas are the focus area of this thesis.
Ceramics and Relative Dating

A preliminary analysis of ceramic artifacts conducted at the PfBAP laboratory by Sullivan and Boudreaux have suggested the dates of occupation at DH2GC ranged from the Late Preclassic (BCE 400 – CE 100) to the Terminal Classic (CE 800/850 – 900) (Perkins 2013:7). The longest occupational history is found at N150 E75 and spans the Late Preclassic and Terminal Classic (Perkins 2013:7). These dates are consistent with the occupation of Dos Hombres and N150 E75 is the closest in proximity to this center. The evidence for occupation history at the elite site at N950 is limited to the Late Classic (Perkins 2013:7).

The older groups were smaller and constructed proceeding or during the emergence of the Classic period while the larger sites constructed during the Late classic. This corresponds with the steady increase in social stratification during the rise of the Maya before the decentralization transition. The construction of larger sites during a time of increasing resource depression is consistent with this interpretation. For example, in addition to rapid deforestation, analysis of plaster floors in the project has produced evidence to indicated that the Maya stopped burning limestone, possibly due to lack of availability of timber (Brennan 2012:1).

Worthy of note is that the elite site at N950 is built within the vicinity of a cave where ceremonial objects were identified including a fragment of an incense burner (Ports 2013:3). Maya cosmology places great emphasis and power in caves that reinforce the political and spiritual affluence of the elites in controlling access to the entrances to
the underworld. The spatial organization of the settlements at DH2GC reflects the symbolic system of legitimization of community leadership (Ports 2013:9).

The elite site where the cave is located is associated with a series of water catchment features such as small reservoirs, channels and check dams, which including a series of small depressions that descend like steps to what may possibly be a ball court below. The effect would have been a cascade of the symbol of life and power: water. The water may have been stored, managed, and channeled to the community during the dry season granting them the power to bestow the means of production and spiritual life (Ports 2013:9).

The occupation history based upon ceramic dating suggests that the commoner sites were occupied for longer periods, and thus if they received an equal resource input they there would be a bias towards higher fertility at commoner sites. The areas compared in this thesis will be in the layers associated with the Late Classic and Terminal Classis periods, directly before abandonment. If sites that were occupied for a much shorter period of time are measured to have a higher concentration of phosphorus, a difference in input is likely.

Lithics

Adam Forbis and Jeff Bryant conducted the laboratory analysis of the Lithic artifacts from DH2GC utilizing a typology by David Hyde (2011), that was modified from Andrefsky’s (1998) morphology flowchart for use in the Three Rivers Region of Belize (Forbis and Bryant 2013:1-2). The lithic assemblage collected from DH2GC during the
2011 and 2012 seasons include chert and obsidian flakes debitage, chert bifaces (see Figure 5) and fragments of obsidian prismatic blade (see Figure 6) (Forbis and Bryant 2013:1-2). The analysis identified 161 flakes, 337 tools, and 1518 fragments of debitage (Forbis and Bryant 2013:1-2). Out of a total of 2075 lithic artifacts recovered from the DH2GC project, 59 were composed of obsidian (Forbis and Bryant 2013:1-2).

The analysis of the 59 obsidian artifacts including flakes, debitage, prismatic blade fragments and one complete prismatic blade was conducted by Dr. Marisol-Cortes Rincon. Of the 59 obsidian artifacts 23 were recovered from N150, eight at N250, three at N350, 19 at N750, and six at the elite site of N950 (Forbis and Bryant 2013:1-2). The highest concentrations of both chert and obsidian were found at N150 and N750 and are interpreted as lithic production zones (Forbis and Bryant 2013:7-10).

An additional possible production zone was identified at N250 featuring an artifact type that had previous been unrecorded at PFBAP. The artifact appears to be a possible engraver or drill. This type of lithic production has not been identified on any of the other settlement studies within the PfBAP. They are similar to drills associated with the area, however, the drills feature a pressure flaked proximal side while the edges elsewhere appear to have been intentionally broken at an approximate 90 degree angle. The edges of the drills usually recovered are pressure flakes or terminate naturally.

Thus far, the smaller sites appear to have higher concentrations of artifacts indicating that they are possible lithic production or re-touch zones. This may indicate that the larger sites consume the products produced at the smaller sites rather than
Figure 5. General utility biface identified on the DH2GC transect. The figure was illustrated by Adam Forbis (Forbis and Bryant 2013).

Figure 6. Nearly complete obsidian prismatic blade, illustrated by Adam Forbis (Forbis and Bryant 2013).
producing them on site. The spatial organization of small production and larger elite sites suggests a division of labor based upon class, with the elite sites serving as nuclei around which smaller satellite production centers orbit. It is possible perishable structures orbited the smaller production zones.

Population Density and Spatial Organization

It is estimated by the project that the project area supported 700 persons per km$^2$. This number uses architecture rather than the volume of water held by aguadas because water estimates do not account for water diverted for agricultural resources Gustas (2013:11). This is considerably great than the 480 persons per km$^2$ which Robichaux (1995) estimated previously.

Gustas (2013:10) created a Geographic Information Systems (GIS) suitability analysis of the project area that led him to argue that the hinterlands between Dos Hombres and Gran Cacao are of special importance relationally. His results support the assumptions of a GIS model I presented at the 2011 SAAs regarding the prediction of site locations based on landforms that were relatively higher in elevation and in proximity to resources.

Gustas suggests that landforms may be utilized in a linear fashion between settlements. The results of Gustas (2013) presented supports a hypothesis presented with my model that a site exists on a platform which I identified at the approximate center between the two cities (see Figure 7 and Figure 8) (Bryant 2011a; Bryant 2011b). The platform appears large enough to support a city smaller in size to Dos Hombres or
Figure 7. Settlement Viability Model (Bryant and Cortes Rincon 2011).
Gran Cacao and is in proximity to non-stagnant water and fertile gleysol soils that although are acidic and poorly drained may have been important soils for agriculture under increasingly arid conditions.

In Sarah Boudreaux (2013) used spectral analysis from satellite imagery to locate a previously invisible body of water near the platform I identified in 2011. It is possible that it is a reservoir of some kind. Her conclusion was that the body of water was evidence that there is another substantial city center in that vicinity. If the path to this hypothetical site and to Gran Cacao is linear as Gustas (2013) suggests the transitions

*Figure 8. Platform X, halfway between Dos Hombres and Gran Cacao.*
between elite and commoner sites of varying size may be enlightening in terms of understanding the political organization of hinterland communities.
CHAPTER III

LITERATURE REVIEW: SOILS ARCHEOLOGY

This chapter is a literature review of soil science in archaeology and ethnopedology, or the ethnographic study of human and soil relationships. Although the nature of soil science is profoundly complex, I will endeavor to write in simple terms. It is my intention to make this section intelligible to the archaeologist who has interest in soils but finds the unfamiliar vocabulary and short-hand acronyms in soils literature to be daunting and near incomprehensible. The section will be brief rather than exhaustive, providing only the most basic introduction necessary to understand the concepts discussed in this thesis. I will also connect soil archaeology to ethics and the future of the discipline.

Soils and People

It is important as archaeologists, especially those interested in agriculture, to consider the relationships between people and their soil from a holistic standpoint. The human actions that affect soil are not simply confined to cultivation of soil. Simple actions repeated over long periods of time such as cooking meals, making tools, painting crafts, disposing of food, urination, defecation, or even sweeping floors may leave chemical fingerprints detectable thousands of years into the future. This is precisely why
studying soils is valuable in archaeology as a means of quantifying and qualifying human behavior temporally and spatially.

To many cultures, soil is considered to be animated. This means that soil is viewed as containing life, or the spiritual essence of their ancestors. Animism seems strange to a westerner, but functionally it should not. Western soil science reveals that soil is a complex living body. It is alive. It is an ecosystem far more complex than is generally understood, and it exists in constant give and take with the behavior of humans and other organisms.

According to the 2006 edition of the online *Encyclopedia of Soil Science*, a single gram of average soil contains 20,000 species of bacteria alone. For every human action there is a reaction in the lives of billions of bacteria, fungi, protozoa, viruses, nematodes and rotifers. This excludes plant life. A single handful of soil represents an entire world that supports billions of organisms (Brady and Weil 2008:244). Like humans, they change their environment, or rather our shared environment, over time.

When humans plow a field, the landscape changes, the soil temperature rises, and oxygen and water infiltration increase, making certain species thrive while others parish or go dormant (Juo and Franzluebbers 2003: 69; Brady and Weil 2008:58). Excessive tillage or mono-cropping can reduce biodiversity. When a field is over-tilled, the soil may become compact and waterlogged, causing oxygen levels to go down. This results in reverse conditions in which the oxygen-dependent organisms die off and are replaced by those that thrive in low-oxygen environments.
When an organism in the soil eats, whether it is an autotroph creating their own food by breaking down chemical compounds, or heterotrophs that feed upon organic materials, their activities change the chemical environment. Like humans, what these organisms do affects the environment and in a circular way alters the human environment. By in large, our society lives in a state of oblivious reciprocity with an alien world.

This literature review will expand upon the perpetual dialectic between both worlds. The following section will touch on the process of soil genesis or formation, followed by a section on the basic physical and chemical properties of soil. Next, the applications in archaeology will be explored as well as ethnopedology, or the ethnographic study of soils. Last, the characteristics of soils both in the region and the project area will be discussed. With this organization I will cover the physical science of soil, how it is applied in archaeology, and the social, economic and spiritual relationships that different cultures have with their soil.

Soil and Sediment Formation

Soils are both the archaeological site, the matrix of cultural material and the record of site formation processes. The core of archaeology is carefully dissecting sites to preserve spatial relationships and associations with materiel culture and attempting to understand the data in terms of human behavior within the boundary of stratigraphy. The unit of analysis in archaeology is the site and so the processes that create the site are paramount.
A distinction must be drawn between soil sediments. Soil is made of minerals and organic materials developed in place on the earth’s surface, while sediments are weathered or eroded particles of mineral or rock parent material that are transported and deposited by the movement of wind, water or glaciers. Paleosol is a preserved layer of soil that formed under certain conditions that can provide information on climate and environment.

The spatial and temporal variability of fluvial sedimentation rates at archaeology sites are important as they reflect internal external factors including climate and tectonics (Ferring 1986:259). Rates of sedimentation can be estimated through the use of sedimentary, biogenic, pedogenic, and radiometric data (Ferring 1986:259) When geoarchaologists compare sites they must consider the differences in climate, biota, sediment texture, and ground water chemistry (Ferring 1986:265).

The matrix accumulation in archaeological sites is define by the rates of sedimentation(Ferring 1986: 259) Knowing these rates of sedimentation aid in creating better chronostratigraphic site histories (Ferring 1986:265) The rates of sedimentation rates offer controls for the preservation an accumulation of artifacts, and their density patterns and content that allow for better qualitative and quantitative analysis (Ferring 1986:265).

Michael Shiffer (1987:11) defined the tenants of site formation process asserting that: (1) they can alter the archaeological record by changing them numerically, spatially and relationally; (2) they can create patterns that are not reflective of behavior;
(3) and that their regularities can be expressed by statistical laws. Geoarchaeological studies in the Maya lowlands, where the project is located, have provided excellent insight into specific processes, both natural and anthropogenic. To apply the principles that Shiffer proposes, the basic concepts of soils should be understood. Soil is a function of climate (CL), Organisms (O), Relief (R), Parent Material (P), and time (T) (Goldberg and Macphail 2006:52; Jenny 1941).

**Parent Material**

Parent material governs the elemental composition of the soil and sediments. The types of minerals also determine which nutrients are potentially most available, the speed of weathering of materials, and the capacity for both nutrient and water retention. The pH of the soil is dependent largely upon if the parent material is an acidic or alkaline (Goldberg and Macphail 2006:60). The pH level changes the composition of the species of biota as well as plant life (Goldberg and Macphail 2006:60). Fungi for example, will dominate acid soil, and bacteria will dominate alkaline soil. Ph is linked to the effects of human behavior on soil formation, because if a farmer were to add lime to a soil to reduce the acidity, this changes the balance between fungi and bacteria.

The parent material in the DH2GC project area is highly weathered calcium carbonate limestone. The soils are thus expected to be alkaline to neutral rather than acid. The bedrock often starts with a horizon of decomposing bedrock, similar in appearance to an anthropogenic plaster floor.
Climate

Climate plays a central role in the development of soils. In arctic or desert environments, the extreme conditions reduce the activity of soil organisms and slow chemical changes (Goldberg and Macphail 2006:52). Climate may be the single most important factor in soil genesis (Brady and Weil 2008:53). Climate is linked strongly to the factor of parent material, because it influences the speed of the processes of weathering. It also affects temperature and precipitation levels which change the dynamics of soil organisms (Brady and Weil 2008:53).

The soils found in areas affected by significantly inhibiting climactic processes are referred to as zonal soils, and can be useful in spatial reconstruction of paleoenvironments (Goldberg and Macphail 2006:58). Intrazonal soils, in opposition to zonal soils are defined by localized factors such as parent material. Soils are either monogenic, meaning they formed under one set of conditions, or they are polygenic, meaning that the conditions changed during formation (Goldberg and Macphail 2006:58).

As stated in the background chapter, the climate was arid and volatile, with long periodic long term droughts. The interaction of this climate on shrink-swell smectite clays is important to note. These clays would have created hard crusts during the dry season that would have made the soil difficult to till. The excavations at N150 E75 revealed a deeply cracked floor, which provides evidence for rapid burial of a horizon by a layer of sediment.
**Biological Organisms**

The role of organisms in soil formation has been increasingly recognized as a central influence on soil formation. Soil organisms are responsible for the breakdown of organic materials as well as inorganic compounds and are the driving force in nutrient cycling (Brady and Weil 2008:53). Beyond nutrient cycling, their activity enhances weathering processes of the parent material, and their movement through the soil and the deposition of their waste builds the soil structure (Brady and Weil 2008:57). Organisms are also linked to the climate, because they release gasses such as carbon dioxide into the atmosphere. The nature of their populations are linked to the temperature of the planet.

The nutrient cycle is a central concept in my thesis because the P-Fixation, the focus of the first hypothesis, is a condition related to the breakdown of the nutrient cycle. The nutrient cycles that sustain plant populations, and by proxy terrestrial animal populations, are maintained by the organisms in the soil. A particular nutrient may change forms several times before it is available to the plant to consume. The basic cycle is illustrated in Figure 9, in which materials from primary producers are consumed by terrestrial heterotrophs and are then broken down by the soil microbial population, and turned into mineralized forms that enter the soil nutrient pool and become available to plants to consume.

In the case of phosphorus, the organic forms are insoluble, which is a form that cannot be absorbed by plants. It must be mineralized into a soluble form to be
consumed (Brady and Weil 2008:602, 615-19). If the capacity of the soil to make phosphorus available is obstructed, it is called P-fixation. P-fixation is a condition in which the soil phosphorus exists in a non-exchangeable or non-soluble forms that plants cannot consume, and is blocked from being converted into soluble or exchangeable forms that

![Figure 9](image.png)

*Figure 9. A very basic flowchart of the nutrient cycle.*

plants can consume. Similarly, in the nitrogen cycle, the various forms include nitrate, nitrite, nitric, nitrous and ammonium.

Under conditions where the soil chemistry is out of balance, the cycle may be stalled, and certain vital nutrients will be unavailable to plants. The conditions that cause P-fixation are related to pH. P-fixation will occur in environments that are very acidic or very alkaline. It is very common in tropical zones, and is usually associated with acidity;
however, the P-fixation on the DH2GC project area would be the result of alkalinity (pH 7.3 or higher).

This affects humans because if there is reduced yield in crops from P-fixation, famine may reduce our numbers and perhaps change our cultural relationship with soil. Humans, which are of course organisms, are recognized as having huge Impacts on soil formation. The prairie soils in parts of the United States are believed to have been altered through constant controlled burning practices by Native Americans combined with the more recent deforestation and tillage by Euro-American settlers (Brady and Weil 2008:58). Soils heavily influenced by human behavior are generally referred to as anthrosols.

Relief

Relief, or topography, plays a critical role in the formation of soils. The uplands generally develop thin soils that erode down-slope and contribute to the accumulation of relatively deeper soil profiles in the lowlands. From the steeper slopes, nutrients may be leached away through heavy drainage, while in the lowlands, nutrients may accumulate and yet be vulnerable to water-logging (Goldberg and Macphail 2006:59).

Topography interacts with both plants and soil organisms, changing the biomass, and which particular species will succeed or fail. The chemical composition is often higher in salts at lower elevation as a result of evaporation rates, and the directional aspect of the topography also influences solar energy and moisture levels.
(Brady and Weil 2008:60). The topography also interacts with the weathering processes of the parent material (Brady and Weil 2008:61).

This is important to consider because the DH2GC project undulated between raised platforms with thin soils, which were preferable for housing above the flood danger zone, and swampy low-lying areas with deeper soils where sediments have collected. The available cultivation surfaces are the areas adjacent to the floodplains, and on the slopes on anthropogenic terraces. The choice of location for placing structures on the landscape changes the type of soils that will be found at archaeological sites as compared to the background.

**Time**

The last factor, time, is very difficult to assess and is integral to understanding the other processes. If the age of a soil is known, the intensity of the processes that created the current conditions of the soil may be estimated. The level of soil maturity is expressed in the number of well-defined horizons.

The amount of time that soils have been forming is important. There are distinct differences between young and mature soils. The processes of weathering, the effects of climate, and the processes of topography and bio-activity, all exist temporally (Brady and Weil 2008:62). The amount of time that particular processes have been occurring will define how much a process influences soil properties. In archaeology, and paleo-environmental reconstruction, the stratigraphic and chronological sequences are of tremendous value.
Chemical and Physical Properties of Soil

Soils are the product of the weathering of primary material from rocks and minerals such as quartz, feldspar, or biotite, into secondary, or clay minerals (Juo and Franzluebbers 2003:17-18). The chemical properties of the minerals that are broken down and the amount of these secondary minerals in relation to particles of silt, sand, and clay, as well as the content of organic materials, make up the structure and chemical composition of the soil (Juo and Franzluebbers 2003:17-18).

Eight elements make up about 98 percent of the chemical elements in soil. These are, oxygen (47%), silicon (27%), aluminum (7%), carbon (5 %), Iron (5%), calcium (3%), sodium (2%), magnesium (2%), and potassium (1%) (Goffer 2007:221). The additional 90 or so elements in the soil make up about 2 %. What has been described above is also the composition of the earth’s crust.

Soil texture is the ratio of sand to silt to clay in soil (see Figure 10). Clay particles are the smallest (< 0.002 mm), followed by silt (0.002-.02 mm), and sand (.02-.2 mm) (Juo and Franzluebbers 2003:46). A soil with equal parts of silt, sand, and clay is called loam, whereas soils dominated by clay, might be defined as clay, silty clay, or sandy clay depending on the ratio.

Soil nutrients are either positively charged cations or negatively charge anions. The particles of clay, or colloids have charges and so they bond with other particles and nutrients. The bonding of these cations and anions with colloidal surfaces is the basic process that drives the chemical dynamics of the soil.
The electrical charges of the particles and their bonding cause the soil particles to aggregate into clusters called peds. The size and shape of peds are the basis of the soil structure. Having a high level of aggregation is very positive for soil health while if the electrical conductivity of the soil is too high, aggregation will be low. The soil aggregation is also changed by biological processes such as the burrowing of earthworms. The soil structure is important for water, and oxygen absorption and retention in the soil (Juo and Franzluebbers 2003:57-62). There is a high level of variation in the aggregation quality and compaction of soils at the sites on DH2GC. The elite sites, for example, contained well-structured and well drained soils that were easily workable,
while the sites near the flood plains contained highly compacted soils, poorly drained soils.

The pH of the soil is the measure of alkalinity and acidity (see Figure 1). This measure has physical chemical and biological consequences. pH is defined on a scale of 0-12 with 7 being neutral. The higher the number on the scale, the more alkaline it is and the lower the number the more acidic. The pH of the soil plays a great role in if either the pairing of calcium and magnesium are dominant or if iron and aluminum oxides are dominant. With an acidic pH the soil with have a negative charge and retain more cations while if the soil is alkaline the charge will be positive and the soil will retain more anions (Juo and Franzluebbers 2003:46).

The pH also determines the limits for which plants and organisms live on or in the soil, and affecting nutrient cycling and availability of nutrients. When pH is very high or low, it can cause chemical reactions such as ammonium volitalization, which causes the nitrogen in the soil to turn into gas and leave the soil system. Such considerations
make the need for archaeologists to develop a holistic understanding of soil (Personal Communication, Mitchel Johns 2013).

The Use of Soil in Archaeology

The behavioral context for where people lived, cooked, made tools, threw away garbage, and even where paths were regularly swept are preserved in soils and sediments. Too often soil chemistry is only used in archaeology for phosphorus spot tests to figure out where to excavate. An entire world of data potential is ignored.

Every percussion strike upon a piece of obsidian glass releases embedded particles of metals such as magnesium that remain in the soil long after the artifacts are removed from primary deposition. In many cases archaeologists obsess over analyzing the remainder of artifacts that were not moved during routine cleaning, not moved during abandonment, and were not looted, yet they ignore the possibility that the most valuable data may be in the back-fill. Unlike artifacts, people do not often take the soil with them when they move, thus the spatial context remains consistent.

The use of soils in archaeology is well established today, but has much unexplored potential. When humans transport organic resources to central processing or habitation locations they increase soil organic matter and other nutrients. For example, when food is consumed the waste is biodegraded where it is thrown away. This process enriches the soil with nutrients, including phosphorus.

Detecting elevated phosphorus has allowed researchers in the past to identify site boundaries, refuse middens and areas associated with the consumption or
preparation of foods (Terry et al. 2000, Middleton and Price 1996; Parnell et al. 2002; Parnell et al. 2002b; Wells et al. 2000). This is often accomplished by placing a grid over the site and analyzing chemical concentrations. This was done at the site of Guiajarral at the PfBAP.

Phosphorus testing is the dominant soil tool for archaeologists, because it is a relatively simple and useful test that on the surface seems to require little understanding of soil science. Areas where available phosphorus is high reflect areas of human occupation from the deposition of organic materials over time. Although phosphorus testing has shown to be generally reliable in archaeology, studying soil requires a case specific approach to understanding the unique dynamics of local soils.

The soils in my project area, as previously stated, show signs of a soil condition called P-fixation. P-fixation prevents phosphorus, an essential plant nutrient, from being changed into a form that plants can absorb. P-fixation may also prevent traditional phosphorus tests from detecting it. Phosphorus tests performed in soils with P-fixation may drastically change results and interpretation. This has major implications in the dominant soils methodology of today.

Apart from phosphorus, concentrations of select heavy metal elements including zinc (Zn), iron (Fe), copper (Cu), cadmium (Cd), mercury (Hg), manganese (Mn), and strontium (Sr), have been utilized in identifying production spaces for lithics or for the production of other crafts involving mineral-based paints (Parnell et al., 2002). Iron (Fe) is often associated with specific types of sites such as, specialized craft production
and kitchen activities like, butchering and processing (Manzanilla 1996; Pernell et al., 2002).

Today it is a well-known fact, that soils at archaeological sites are more fertile than the surrounding natural soils as the result of human activity (Goffer 2007:226). Using phosphorus tests for detecting this phenomenon is well established as a way to measure the spatial extent of a site and the intensity and duration of site occupation (Goffer 2007:227). In relation to this idea, the intensity of occupation should be different among sites and the levels of intensity are measurable for comparison. This is simply because of the slow build up of chemicals over time. If in my project area, P-fixation was a problem, human-thing-entanglement would have made it difficult for people to leave.

When approached through Hodder's (2011:334) concept of thing-human-entanglement, or the evolutionary critique of David Rindos, the people become co-domesticates with their soil, or their plants. The people are domesticates and domesticates. Hodder suggests that symbiosis changes the way in which the mechanism of evolution selects phenotypes (Hodder 2011:314). Rather than survival of those individuals who reproduce, the success of a trait depends less of the individual, but rather as the way in which the phenotype fits into the dialect between symbiotic partners (Hodder 2011:314).

Woods et al. (2013:5) utilized soils data to make population estimates for Precolumbian occupation. These estimations were made based upon calculations of the
productive capacity of the anthropogenic *Terra pretta* for sustaining human population, and the amount of population density necessary to make the observed changes to soil during the time of occupation. Cook and Heizer’s (1965) concept of the annual deposition of phosphorus was used to estimate the Amazonian population of 8-10 million people during 1492. These numbers can be considered as an alternate line of evidence to triangulate with other traditional estimation markers to produce a more holistic understanding of population dynamics (Woods et al. 2013:13).

In addition to measuring the intensity and duration of site occupation, the challenges and the processes leading to decline may be investigated. David Montgomery (2007) has described the decline of ancient civilizations as the result of agriculture expanding out of flood plains, thereby causing soil loss (Wells et al 2013:23). Christian Wells and colleagues (2013) assert that in modern-day Honduras, where vertisols are common and where the ancient Maya lived, the loss of topsoil was a result of the intensiveness of cultivation and the farming of slopes has degraded the soil, much in the same way as it did leading up to the dust bowl in the United States during the 1930s (Wells et al 2013:21).

**Soils in the Three Rivers Region**

The soils in the Three River Region are dominated by a smectite-based vertisol clay. These clays have a high water retention capacity, and depending on soil structure and climate, can be some of the most productive agricultural soils in the world, especially for rice production (Juo and Franzluebbers 2003:228). Much of rice production in south
East Asia is cultivated in type of soil. Smectite clays are highly suitable for growing cotton as well as rice (Juo and Franzluebbers 2003:224). Hydrologist Sheryl Beach, and geoarchaeologist Tim Beach hypothesize that these soils, in swampy areas, such as those in the project area, may have been utilized for cotton production (Beach, Personal Communication 2012). These qualities give us clues on what types of crops would have been appropriate.

The soil contains a shrink-swell clay in high quantities which expands when wet and constricts when dry. Under the right conditions, this can cause soil to self-churn, reducing the amount of necessary tillage (Juo and Franzluebbers 2003:228). The self-churning quality increases aggregation and promotes good soil structure, however, there are challenges associated with these soils that are important to understanding how these soils may have behaved under cultivation.

As with many things, in the strength the weakness may be found. The shrink-swell quality that contributes to positive soil structure, increases nutrient cycling and contributes to the health of the biotic community, also forms a cement-like crust on the surface during the dry months that can be difficult to work, and may be eroded easily by both water and wind (Juo and Franzluebbers 2003:228).

The crust forms deep cracking on the surface and in times of intense stress may cause a morphology called gilgai relief. Gilgai relief is created when water seeps into the cracks on surface crusts and increases moisture levels below the surface in the shape of the cracks. The water causes the soil to expand under the surface, causing small
mounds to rise that reflect the pattern of the cracks (Personal Communication, Cortes-Rincon:2010). They resemble the underside of an egg carton. Gilgai is an indicator of environmental stress on a vertisol environment, and has been identified in the field on both the surface floodplains, and inside the cultural layer of an excavation unit in the project (Bryant 2011). These features suggest conditions of drought in the past that were extreme and that soils were highly susceptible to erosion.

For comparison, the soil type in the region of Texas and Oklahoma affected by the dust-bowl in the 1930s is a shrink-swell vertisol clay as was found in the DH2GC project region. The potential for a similar agricultural disaster occurring during the time of the ancient Maya is very high as the occupation encompassed a period of natural climate change, which caused the conditions to be far more arid than they are today. It is important to note that the climate became increasingly more arid during the Late or Terminal Classic causing the Maya to endure droughts that would span for centuries (Turner and Sabloff 2012:13908; Hodell et al. 1995).

The ancient Maya lived during a time that was far more arid than today, and spikes of severe droughts have been associated with periods of decline leading up to the Classic Period (Turner 2012:13908; Beach et al. 2009; Medina-Elizalde 2012; Hodell 2006; Webster et al. 2007). Multiple lines of evidence reveal that long term periods of extreme aridity correspond temporally with periods of stagnation or decline, including the Classic Hiatus (Beach T, et al. 2009; Hodell et al. 2006; Medina-Elizalde and Rohling 2012; Webster JW, et al. 2007) The most extreme period of aridity was between (CE 750–1050)
which corresponds with the terminal classic abandonment of many central lowland cities such as Dos Hombres (Turner and Sabloff 2012:13908).

These calamities, which far eclipse the conditions leading to the “dust bowl” of the 1930s, caused major impacts on soil productivity leading to upheavals that would have required adaptation. The paleoenvironmental record indicates that the whole of the Maya world endured hundred year droughts, and these conditions eclipse those that shattered the economy of the United States in the 20th century (Beach 2009:1712). The “dust bowl” was the result of only a decade years of drought rather than a century.

The most extreme conditions occurred between CE 750-1050, during which time Dos Hombres, the closest city center to the project, was abandoned (Turner 2012:13908; Hodell et al. 2001; Hodell et al.:1995). Dos Hombres, was occupied between the Middle Preclassic (BCE 800–600) and the Terminal Classic (CE 800/850–900), with abandonment marked by the ritual termination of the Acropolis followed by a period of limited visitation and possible pilgrimage (Trachman 2007:55-56; Houk 1996:236). This termination corresponds with one of the most devastating droughts on record.

It will be useful now to elaborate upon the paleoenvironmental history of the region. In the Late Classic, Maya settlements expanded exponentially using diverse land management and cultivation practices (Turner 2012:13908; Fedick 1996; Robin 2006; Chase 2008). Pollen analysis in the Maya lowlands has indicated heavy levels of deforestation and increases in the cultivation of maize during the preclassic period, coinciding with a period of soil loss and sedimentation (Turner 2012:13908; Beach et al.
2010; Wahl et al. 2007; Beach et al. 2007; Jacob 1995). The population grew until it declined and stagnated during the Late Preclassic before again returning to a period of rapid growth. Pressures mounted again followed by the Early Classic Period adoption of intensive terracing and other soil conservation practices which significantly slowed the rate of soil and nutrient loss (Beach 2006:173).

It appears that the Maya became keenly aware of the importance of soil health after a Preclassic soil erosion event that interrupted growth until soil conservation was taken seriously and conservation infrastructure was built and maintained. The record at Dos Hombres is consistent with this chronology. There was a Late Preclassic population decline that stagnated until the Early Classic before returning to growth and an eventual Terminal Classic abandonment (Trachman 2007:55; Houk 1996:235).

The end of the Terminal Classic period in which Dos Hombres was abandoned is marked by the depopulation of the southern lowlands over a century long period often referred to problematically as the collapse. Lizzie Votruba asserts that the collapse myth is “. . . the quintessential example of an inadequate awareness and subsequent inaccurate representation by Western intellectuals and mainstream media” (Votruba 2012). The traditional scholarship projected western ideals on the Maya and created shallow decontextualized narratives (Aimers 2007; Joyce 1999; McAnany and Negron 2009; Votruba 2012). In northeastern Belize and in the Yucatán, the Maya endured for centuries after the initial decline and abandonment of the major population centers.
The end of the Classic Maya civilization is instead marked by the Contact Period. The difficulties of working these soils, among many other factors and changes that will be discussed in detail, were likely a profound challenge to sustainability of Maya agriculture. The chemical composition of the soils in the region are, of course, defined by the genesis from a parent material of geologically young calcium carbonate limestone. The weathering of the limestone makes the soils generally dominated by calcium, and magnesium. High levels of sulfur are also very common in the soils. The levels of calcium, magnesium and sulfur are the most striking chemical features and play a huge role in every part of soil dynamics.

In a recent paper given at the SAAs, Sheryl Luzzadder Beach explained that sulfur is naturally high in the soils and that rising sea levels and a high level of sulfate and calcium cations in the local water caused calcium and sulfate precipitation. She agreed to the plausibility of my hypothesis that the sulfur was likely retained in the system, despite being water soluble and usually easy to leach, as it bonded with calcium cations and formed gypsum, which is present in regions the soils, often in considerable quantities (Luzzadder Beach: personal communication, 2013).

The pH levels in the study area are uncommonly alkaline for a tropical environment. Tropical areas are usually quite acidic, however a typical pH level in the area neutral to alkaline. The pH levels are not surprising, however, considering the high levels of calcium. The alkaline calcium carbonate of the parent material dominates the
environment, and sulfur, which is an acid and present in high quantities, is not present in the volume needed to render the soils acidic.

**Preliminary Soil Survey of the Project Area**

The initial data from the 2011 season was analyzed, revealing that these common conditions of high calcium and high magnesium levels as well as high sulfur, characterize the project soils. The specific local calibrations of these chemicals in the local anthropogenic soils, however, appear to be problematic for cultivation (Bryant 2011:47-48). Available phosphorus was extremely low; however, organic matter was generally adequate for the nutrient cycling needed to make the total soil phosphorus available to plants. The tests that were run were for available phosphorus, so the total phosphorus was unknown.

P-fixation is a condition in which the soil may contain plenty of phosphorus, however, it is neither available to plants nor detectible by the available phosphorus tests used (Bryant 2011:47-48). The phosphorus cycle becomes blocked. Upon analyzing the base saturation percentages it was recognized that P-fixation may be limiting agriculture on the study transect. The base saturation percentage measures the ration of the bonding surfaces needed for nutrient cycling covered by specific nutrients.

The initial soil tests, sampled from excavation units at archaeological, sites revealed that the calcium was heavily dominate to a degree that was likely preventing the phosphorus from changing forms. The base saturation percentages indicated that calcium was heavily dominant in the soil system. A year after phosphorus fixation was identified on the DH2GC transect, Poot-pool (et al. 2012:112), in a study of modern Maya
agriculture fields in nearby southern Mexico, suggested that P-fixation capacity may be the most limiting agricultural factor in the region. This supports my hypothesis of P-fixation.

**Ethnopedology**

The study of “ethnopedology” or the ethnography of soils, has been pioneered in Central America by Barbara Williams through the study of the contemporary Aztec soil classification system (Dunning 1990; Williams 1982; Williams and Harvey 1988; Williams and Ortiz-Solorio 1981). Dunning (1992) recorded the soil classification system used by modern Yucatec Maya in detail and connected the classification system and the organization of subsistence systems (Jensen 2007:338). The Modern Itzá Maya soil classification, for example, is central to their agricultural system (e.g., Reina, 1967; Atran, 1993). The Yucatec Maya taxonomy contains more than 80 concepts for describing soil dynamics (Wells and Mihok 2010:323).

Some of the most important studies on ancient Maya agriculture and the study of the cultural soilscape have come from collaborations between soil scientists, anthropologists and the modern Maya (Jensen 2007: 340). When partially relying on ethnographic sources, however, it is important to acknowledge that cultures and traditions do not necessarily remain static over time. Ethnopedology will be considered in my thesis for both the way interpretations are made, but also in the way that includes the way the Maya may have accessed the fertility of the soil into the methodology for accessing soil health.
CHAPTER IV

THE CONTEMPORARY MAYA

INTELLECTUAL RENAISSANCE

The Yucatec of Corozal in Orange Walk district, where the project where I collect data is located, came to the region as refugees from the War of the Castes in the middle of the 19th century (Bary 1992:75). The region was originally populated by Mopan Maya, largely driven to the southern region of Belize by the British to avoid forced labor and brutal taxation (Bary 1992:75). The Ketchi Maya, the poorest ethic group in Belize, immigrated to the country in the 1880s to escape near-slavery at German coffee plantations. A century later, another wave of thousands of Maya came from Guatemala as refugees during the genocide of the 1980s (Bary 1992:75). Of the 200,000 people killed in a 36 year conflict, 83.3 percent were indigenous (Montejo 2005:192).

Although the Maya are a diverse grouping of 29 linguistic groups, as the result of revivalism movements, the Maya have come together to form the concept of “Pan-Mayanism” which serves to unify the various May groups under the acknowledgment of shared history and the similarities in their cultural practices (Montejo 2005:16). Pan-Mayanism is expressed through self-representation, revitalization of language, traditional knowledge, spirituality and religion, political awareness, activism, and the establishment of Maya schools to educate Maya youth.
The Pan-Mayan movement has been guided by Maya scholars, the first large wave of which graduate in the 1950s and began the slow process of fighting for a more equitable future for their people (Montejo 2005:74). The continual focus on education is a integral part of the success of the movement and has resulted in an intellectual Renaissance in the Maya community. The result of the Pan-Mayan movement has strengthened Maya identity and has aided in protecting cultural continuity. The revival movements amidst violence and discrimination are evidence of the resilience of the Maya people in their desire to maintain connections to their heritage (Montejo 2005:16). The continual existence of the 29 languages indicates a long standing tenacity for resistance (Montejo 2005:44). In this way, the Maya may be following closely in the footsteps of their ancestors.

Maya scholar Victor Montejo (2005:34) summarizes the tenants and goals that make up Pan-Mayanism in the following way: (1) reaffirming a continuity with ancestors, (2) rejection of the reductionist view of Maya culture, (3) reaffirm presence and visibility, (4) recognizing diversity, (5) considering an attack on one linguistic group and attack on all, (6) understanding that stereotypes result from discriminatory isolation, and recognize “different ways to be Maya,” (7) mutual defense of cultural patrimony, (8) keeping leadership decentralized, (9) unified defense of pluralistic rights and patrimonies, (10) legitimizing revitalization projects, (11) and overcoming the restrictive colonial system.
Montejo contends that the representations that anthropologists in the past created, have been reproduced in textbooks in the region, and have cemented negative stereotypes and misconceptions, and rendering the Maya voiceless and invisible. These misconceptions have consequences in preventing self-determination and in allowing the government to dismiss rights to self-determination and deny land claims. He cites that in Guatemalan textbooks they ignore the factor of disease during discussion of the Spanish conquest. They instead glorify the conquistadors and insist upon the prowess and advanced military technology as being the primary factor in their victory (Montejo 2005:55-56). These misconceptions reinforce the social attitude that the Maya are an inferior people. In situations in which generations of people are heavily discriminated against, it may psychologically sabotage a people by making them view themselves negatively. The Pan-Mayan movement provides a sense of pride and mutual identity, which combats these often internalized negative stereotypes.

Montejo (2005:49) criticizes older anthropologists for focusing on the ancient Maya and rather than the contemporary Maya and asserts that the ancient and contemporary Maya are “equally relevant” in understanding either period. He notes that the ancient Maya were pluralist at the micro level and united under hegemony at the macro level and that the Pan-Mayan movement mirrors this structure (Montejo 2005:16). He suggests that young anthropologists could play a vital role in efforts to help the Maya gain recognition as descendants of the Maya and help them to gain self-determination (Montejo 2005:68-69) and acknowledges that many anthropologists are
working to help the Maya regain self-representation, highlighting the contributions of Maya scholars. He suggests that the role of the anthropologists should be to “dismantle stereotypes” created in the past to aid them in creating an “auto history” written by Maya scholars (Montejo 2005:61-62).

The perspectives of Maya scholars should be carefully regarded, and the new generation of anthropologists should make a good faith effort to reverse the damage caused by the ghosts of anthropology past. The army of straw-men that have been made to represent those who Dreger often refers to “fluff heads” for asserting that anthropologists can benefit the communities we serve are of little consequence. What matters is individuals holding themselves accountable both to the principles of science and to the principles of our humanity.

The Role of the Archaeologist

This last section will address what an ethical archaeologist should adhere to. Such an archaeologist will need to balance the need for scientific rigor, and responsibility to the descendant communities. Politics should not be allowed to pollute the results of scientific inquiry, however it must be recognized that inherently unequal power structures have in the past focused archaeology to cater to the concerns of western elites. Paying service to indigenous communities does not imply that we will doctor data to fit their political agenda. It simply means including perspectives and following lines of inquiry that are important to their heritage.
Archaeologists need to dismantle the traditional power-structures that determine what knowledge is important, and to make our work relevant. I have contacted Maya scholar Victor Montejo, who introduced me to Dr. Richard Leventhal as an example of an archaeologist doing archaeology that collaborates well with the contemporary Maya. Because the project was offered by an important Maya scholar I hope to use this correspondence to explore contemporary issues in knowledge production. Leventhal describes his project bellow as:

. . . purely focused upon an indigenous perspective of heritage and what is important – even to the point of focusing upon the 19th century Caste War and not the ancient Maya that is often perceived to be the heritage of the modern Maya. The people in this project and region do not agree and feel that clearly heritage is about something very different. (Richard Leventhal: personal communication 2/14/13)

The important element above is that the research questions are formulated to answer questions that are of interest to the Maya in a project that collaborates with the Maya during the planning stages. This requires the dismantling of the asymmetrical power-structures that prevent Maya interests, ideas and perspectives from being incorporated into our work. Currently, if consultation happens with descendant communities, it is after the research project has been planned and the greatest opportunity to build a collaborative effort has passed. At that stage the asymmetrical power relationship has already been perpetuated. Leventhal asserted that it is important not to compromise archaeology, but “to connect the asymmetrical power relations with the ongoing nature of knowledge production within the disciplines” (Leventhal: personal communication 2/14/13).
It would be easy to say that as a graduate student I was totally at the mercy of power structures at play but there were things I could have done differently. During the planning stage for my thesis research I did not consult with the Maya about research questions to find out if what I was studying was of interest to them or if they had any insight. Yes, my intentions were good. From the beginning I wanted to include mention of the present day Maya, however, that it is not enough. I failed before I stepped off the plane.

According to Dr. Cortes-Rincon we do not have a modern day Maya community nearby to consult. “The villages in the vicinity are of such mixed heritage that the majority often do not view themselves as Maya. They often describe themselves as Mestizos” (Cortes-Rincon: Personal Communication, 2013). In this light it is unclear how I would have been able to include the local Maya perspective, however, perhaps I should have been more aware of my cultural surroundings and taken steps to investigate the possibility. Beyond awareness of the local people, being aware of the larger Pan-Maya intellectual tradition and the political ramifications of my research questions would have been a positive step.

Archaeologists are often annoyed when people think that we chase after golden-idles like Indiana Jones because we seek sophisticated data rather than looting artifacts, but the data, and what we do with the data means a lot more than buried relics. The data has the power to perpetuate collective cultural suffering while on the other hand; looters trenches have little to do with the everyday lives of Maya farmers. I can,
however, use this realization of initial failure as a way to learn how to conduct future research in a way that challenges the traditional role of the archaeologist and moves the discipline and the interests of living people forward.
CHAPTER V

THEORY

I intend to triangulate three of the most important processes in shaping society and use them to inform interpretations of the Maya. These are gender, environment, and class. For this thesis I am calling this synthesis *gendered eco-materialism*. A point of intersection between feminism, Marxism and ecology is social stratification, which is central to the second hypothesis. Examination of how inequality is manifest today and historically may help to understand the way such systems may have theoretically operated in ancient Maya society. It is important however to be careful in comparing societies with different social structures and environments.

The earliest archaeological evidence of social stratification in the ancient Maya world is in the Pre-Classic when differential access to food and imported goods and architectural disparity was present at the sites of El Mirador, Kaminaljuyu and Uaxactun (Dornan 2004:462). Power in the Maya region emanated from monarchs and an elite class seated in city centers such as Tikal, Copan and Palenque. In the majority of agrarian societies that are organized within a framework of a central state, the elite classes control the most productive lands, effectively controlling the means of production and regulating societal conditions (Carmean 1991:152).
In Jason Barrett’s recent Dissertation at the site of Blue Creek, Belize, he demonstrated that resource allocation was more equitable during the Preclassic, as compared to the Early Classic period. He described “extravagance among the elites and increasing disenfranchisement throughout the hinterlands” during the Early Classic and continued expansion of elite power during the Classic period (Barrett 2004:iii). Barrett suggests that resource monopolies were formed during the Early Classic and that by the Classic period the elites had fully consolidated these monopolies and had achieved much greater levels of power, wealth and prestige (Barrett 2004:iii). In the Terminal Classic Period Puuc territorial groups appear to be arranged by the productivity of their soils (Carmean 1991:164; Dunning 1990). The idea of ownership centered on the improvements to infrastructure made on lands to increased value for sale (Carmean 1991:151).

At the time of historic contact, documents that the Spanish observers called “titulos” regulated land boundaries for community owned and private land ownership which were parceled out by the Maya elites (Carmean 1991:152; Farriss 1984; Roys 1972). Contact era documentation also indicates that salt and possibly other resources were regulated and taxed by the Maya elites prior to the Spanish arrival (Carmean 1991:152; Roys 1972:36-37). Earle (2000:54) argues that cross cultural work suggests a relationship between agricultural intensification and the level of land ownership regulation (Earle 2000:54; Adler 1996, Collier 1975, Stone 1994, Netting 1993). Carmean (1991:151) argues that the Maya system of allocation was a monopolization of the most
productive lands and labor necessary for cultivation and for structural improvement (Carmean 1991:155). She suggests that architectural expenditures and agricultural infrastructure were measures of social status by these means (Carmean 1991:155).

It is likely that much of the manual labor was often performed by immigrants. In Tikal, strontium isotopes analysis was used to identify immigrant populations (Wright 2005), however, in this particular study there isn’t an effective means for testing the ethnicity. Whether the laborers were migrant workers, or the lower class, studies involving slave plantations may be useful in comparing conditions of work. It must be kept in mind however, that slaves are treated differently depending on culture. The residential, religious and community structures of elites are mostly found on hilltops in the most preferable locations. In addition to selection of hilltops for the pleasant views and fresh breezes, these locations may infer social stratification in that the hilltops would allow the elites to monitor the farmers.

Considering layout of plantations to better understand power relationships is firmly established in archaeological literature (Delle 1998; Higman 1988; Randle 2011; Singleton 2001; Upton 1988; Epperson; 2000; Armstrong 2008; Davis 2013). Panoticon plantation theory contends that the elite structure will be the most prominent feature on the landscape as a means of control over the workers (Davis 2013). The visibility of the house to the workers serves to remind them that they are under surveillance. This theory was successfully applied at the plantation at Betty’s Hope, demonstrating that
slave houses were all in line of site of the overseer’s house (Davis 2013). The Maya elites may have organized their settlements in a similar way.

The control of these locations may have given powerful psychological control to the elites over the lives of the lower classes. The environment however, has huge implications upon how the elites exploited the lower classes. The long dry season and the presence of water catchment systems and reservoirs at elite sites suggest that the environment was a huge part of the control of the means of production and the maintenance of the system (Lucero 2002:1). There is evidence during the Contact Period that there was a permitting process for resource access for Maya citizens including hunting rights, clay, salt and the collection of thatching for roofing material (Carmean 1991:152). The environmental degradation could have been driven by the elites to push yields and spur economic growth and to support conquest.

The only other soil archaeology study I have been able to locate which had a similar goal as mine is from John Wingard (2013:148). He conducted a soil study that used a model to estimate the amount of potential for food to be produced as surmised that the demands of the elites would not have prevented the commoners from meeting their basic needs. He suggested that this was evidence that the elites had very little real power and that the commoners probably leveraged considerable power over the elites. The idea is that the greater the fertility of the land, the less power the elites had, however this seems to ignore the structure of the economy and who has political control over the land, or means of production. All he was able to show was that if resources were
distributed fairly there would be no shortfall. This is true today, however, an epidemic of hunger remains because resources are not distributed fairly.

If the society was organized in something similar to a colonial system or feudal system where the land is inherently owned by the elites and parcelled out, this argument does not hold water. It also ignores the control of water. Without access to water in harsh climates and during droughts, the nutrients in the soil cannot be exploited to produce food. It is a truism in ancient state level societies that water is a means to leverage power.

Wingard’s argument also fails to explain an economy that exists outside of a vacuum. Cash crops such as cacao and cotton and the evidence of extensive trade networks in the Maya world suggests that local production may have little to do with who benefits from the resource base. Even in circumstances where farmers own their own land, the fertility of the soil causing the high levels of production as Wingard measured, could have reduced the value of the commodities such as corn, causing less profit for the farmers, not prosperity. Market forces can be counter-intuitive.

If world systems theory is applied, the relative status of the overall settlement in the political economy may influence the amount of profit that is made from production. The raw materials may be extracted from the more distant and less self-sufficient political settlements refined into products elsewhere and are sold back to the people who provided the resource base. A wealthy class of merchants may emerge as
was the case with the tobacco and sugar booms during the colonial period. Gordon Wiley (1984:367) suggests that Maya society resembled colonialism.

Models such as the EPIC model used by Wingard are useful tools but they may lose some of their utility when they are too broad spatially. Problems should be observed at different scales and attention should be paid to particulars of micro-ecology and variations in local cultures. The use of the model was used to try and answer a social question; however, it seems like the model itself only reflected what past production capacity models have done decades prior.

Bill Loker (1986) created such a model for El Cajon, Honduras, that estimated carrying capacity based on soil characteristics and labor requirements, storage loss, and ethnopedology. In his dissertation, he recognized a high level of micro-environmental diversity and suggests interconnection with external economic forces. Wingard’s study is not dissimilar to the work that was done 30 years ago, but with bolder and more precariously unsupported interpretations of social meaning. From this case study, I take warning not to overreach.

Another problematic piece of supporting evidence used by Wingard is skeletal evidence from Rebecca Storey (2005) that failed to detect significant differences in pathologies in skeletons on the bases of class as expected. This line of evidence however, concerns me because of the problems with using paleodemography in at the site of Copan where Wingard placed his study. I will now use case studies from this very site to demonstrate my reasoning. One of the case studies will be from Rebecca Story, three
years after Wingard's citation of her work, finding major problems with the use of paleodemography in this setting. First a background must be established.

In 1991 a study was conducted at the Maya site of Copan in Honduras that utilized the Survival Distribution Function (SDF) to correct for the heterogeneity of a “poorly preserved sample” of 160 skeletons of low socioeconomic status (Wittington 1991:167). It is established in both archaeology and in ethnography that the practice of the Maya was to bury their dead below or near their structures (Wittington 1991:171; Haviland 1972a; Ruz 1965; Willey 1965; Wisdom 1940). Whittington utilized a collection from Willey and Leventhal (1979) excavated from structures classified by size and architecture to determine social status under Central Place theory (Wittington 1991:171).

Central place theory, developed by the British ecological school, has heavily influenced archaeology in the Maya world. The theory is designed to analyze relationships between sites, and structures to understand political organization (Higgs and Vita-Finzi 1972; Yesner 2008:42). The spatial relationships in my project area are central factor in my analysis.

The first issue with the study is that the methodology for identifying the social status of the individuals is flawed. In addition to known problems with estimating size and identifying hidden stone structures (Webster and fetter 1990:45), many Maya lived in modest wooden or adobe structures that do not survive well into the archaeological record, especially in tropical environments. These structures, not built upon plaster sealed substructures, may skew population data (Webster and fetter 1990:45). The low
status Maya had a custom of burying the dead under the person’s hut before abandoning or burning it (Thompson 1971:214) and early missionary accounts in the Yucatan contend that the poor were cremated prior to burial (Ricketson 1925; Landa 1864:195). There may have been similar cultural practices throughout the Maya world, including Copan. Even if the author were aware of these issues, a low status sample may not be possible to obtain.

The case study does not make any consideration for the soil dynamics that determine preservation and did not consider differential preservation. The factors that determine if skeletal remains preserve are, pre-internment preparation, the chemical environment, decomposition environment, excavation methods, post-excavation methods, and disturbance from pedoturbation or bioturbation (Littleton 1995:6). It is crucial to consider if soil is high in both oxygen and water or has an imbalance of pH (Pinhansi et al. 2007), as it may increase microbial activity in bone collagen contributing to bone decay (White and Hannus 1983:322).

Each increase in temperature of 10°C doubles the pace of chemical decay (Littleton 1995:6-7), and water which is plentiful in tropical zones seriously weakens bone though leaching. Thus well sealed tombs allow for better preservation (Littleton 1995:6-7) by providing a level of internment stabilization (Wittington 1991:172). Maya stone structures were built on plaster floors consisting of layers on construction fill and capped with plaster which forms a barrier that would protect the remains (Littmann 1967:523). Older populations are associated with decline and younger populations are associated
with growth (Storey 2007:46), so a change in this foundation greatly skews population structure.

By sampling a wealthier population, frequency of pathologies (Wittwer-Backofen and Tomo 2008:506) or the age-at-death may reflect a wealthier people who enjoyed better nutrition and longer life (Darmon and Drewnowski 2008:1007). It may however also reflect the osteological paradox, which is that the reverse may be true as the presence of visible bone damage may reflect a person who was able to survive the longest, while those who were less nourished perished before the evidence of their sickness could be recorded in their bones.

The archaeological evidence available at the time suggested a declining population during the Terminal Classic (CE 800 to 900), and a younger and growing population during the preceding Late Classic period before the collapse (CE 700 to 800). The opposite was the result of the study with the earlier Late Classic period reflecting an older population than the Terminal Classic (CE 800 to 900) (Wittington 1991:171). The population appeared to be declining when Wittington thought it would have been growing, and growing when he expected it to be declining.

This information could have been interpreted in multiple ways. The first is that the “collapse” was a series of peaks and valleys rather than a steady decline suggesting that population dynamics varied geographically. During the 1990s the dominant view had been of a uniform “Maya collapse” but because of a surge of hundreds of studies on the “Maya collapse” (CE 750-1050), there is a consensus that rather than being uniform,
population dynamics were more regionally varied (Aimers 2007:329). According to Dr. Cortes Rincon this is a well-known fact a asserting that the “Central and Southern Maya Lowland sites experienced a decline in population while the Northern Maya Lowlands had an increase of population numbers.” She hypothesizes that there were “a series of migrations from the central and southern to the northern areas (Personal Communication: Cortes-Rincon. 2013).”

A second possibility that Whittington could have chosen was to conclude that the data were unrepresentative and the methods lacking in resolution to accurately depict the true population structure. This is certainly a possibility as demonstrated by the great variations in age-at-death calculations when using different methods on the same population. Story (2007) conducted a paleodemographic study of the same Late Classic period population from the Maya site of Copan using two methods to determine age and compared the results, revealing major discrepancies.

One of the methods in the 2007 study suggested that 69 percent of the population were between 65 and 75, which is a major outlier consistent with some pre-industrial historic populations (Storey 2007:40). Both of the samples do indicate an older population which is associated with a period of decline, however, the discrepancies were gaping and raised issues with the resolution of the results (Storey 2007:46). Both of the results of the 2007 study contrast greatly with the 1991 case study indicating a lingering low level of reliability 16 years later.
A third option which Whittington chose was to suggest that the low number of sub-adults in the Terminal Classic period as compared to the Late Classic, suggests lower fertility in the Terminal Classic, a high rate of immigration and low mortality (Wittington 1991:171). This interpretation is made even though he conceded that such a claim has no statistical significance as there were few sub-adults in either period in the homogenous sample (Wittington 1991:171).

There may also have been different cultural practices for burying sub-adults than elders, which could have produced the heterogeneity of the sample. Walker suggests abnormal samples may reflect “age or sex-specific burial areas” (Walker 1995:44). I have observed this at my hometown cemetery where the sub-adults were buried in a special gated location apart from the adults. Segregated child cemeteries are common in historic and ancient societies (Lewis 2007:32) and child remains preserve poorly in the tropics. This factor could radically alter data on growth and decline. When a sample is heterogeneous differing burial practices should be a serious concern.

Whittington maintained that the fertility was higher in the Late Classic, but considering the lack of statistical significance, the stagnating population during the Late Classic may have just as easily been attributed low fertility, low immigration or high mortality and that the Terminal Classic was a time of high fertility. Without the constraints of a significant sample size, the interchangeability of the processes of fertility, mortality and migration, grant a high level of artistic license for storytelling.
There is zero evidence for in-migration or out-migration in the study yet it was used to plaster shut an interpretive loophole. This unknowable process can be used to explain away undesirable data. These issues make it difficult to trust paleodemography to explain change, because it only takes pixilated snapshots of population structures. It may triangulate with various other lines of evidence in meaningful way but cannot stand alone.

Malthus may have interpreted the data at Copan as change in carrying capacity or that the populations were at different stages of oscillation between growth and decline. Boserup may have viewed the Terminal Classic growth as moving towards the season of innovation. Binford may have seen a break in environmental equilibrium, and that adaptation caused subsequent growth. Flannery might have explained the change, assuming a prior increase and broadening of subsistence technology. Rindos might have linked change to the selection of sometimes illogical random cultural traits for people and co-domesticates. Without the constraining effect of ample data from multiple lines of evidence there may be meaningless interpretive chaos.

In cases of extraordinary preservation such as found in sealed tombs and crypts, paleodemography is useful; however, the difficulties remain for prehistoric archaeology especially in an area such as Copan. Paleodemography is not my area of expertise, however, there are decade’s worth of paleodemography literature that recognizes that the discipline is in an ongoing crisis. Milner and Boldsen (2012) remark that despite the sheer volume of studies on age estimation over the last several decades
progress has been “agonizingly slow” (Milner and Boldsen 2012:233). After a century of refinement of age estimation, the methods are “far from ideal” (Milner and Boldsen 2012:224). Some factors may refine, but others such as sample size may be inherent limitations in most cases, the solutions for which are presently confounding.

Marxism

Marxist theory is imminently useful for analyzing social status and economics, which is the focus of the second hypothesis. The labor theory of value is the basic measure of the labor that creates commodities from natural resources and in class based societies these value of labor is socially constructed. For instance, a Maya farmer may have less labor value than a scribe or a shaman. Extended to archaeology it suggests that material culture is constructed in socially structured labor, and that the finished product becomes the means of maintaining the class based structure of labor (McQuire 2007:74).

Vere Gordon Childe suggested that studying the material culture at archaeology sites can be studied as reflections of this social system (Childe 1951:1). This can be applied to Maya social stratification. Elite Maya control of infrastructure such as water catchment systems, or spaces for religious activity and other social functions required the mobilization of labor. The product of the relatively low-value of the labor mobilized for the creation of the spaces and infrastructure would perpetuate the system.

The concept Marx used to describe societies in which elites used cohesion to repress the poor and maintain privilege as Primitive Accumulation, while the social forces of labor are used to maintain control in capitalistic societies (McQuire 2007:74).
pattern of nucleated settlements around small elite centers in the hinterlands in the Maya central Lowlands may suggest a capitalistic system that utilized the social rather than brute force. There is a lack of evidence of defensive features such as forts or defensive walls in the DH2GC project area. The threat of force lingers in the background in capitalistic society; however, the primary means of control could have been access to ritual, and important social functions such as festivals and feasts and the control the means of production through water. The control of water is what Marx and Engels referred to as the control over the base of production, while the control of ritual and social functions represents the domination of the superstructure.

In such a system, the Marxist perspective maintains that a class struggle will exist in which the elite classes try to exploit more and more commodities from the poor while the commoners become increasingly resistant. Elites eventually become too exploitative and political structures are toppled. The abandonment of the DH2GC project area could have in part been the result of political breakdown in which the elites could no longer leverage power over the populace. This could have come from the breakdown of the superstructure from internal culture change and climate change. The climate was much more arid during the time of the ancient Maya and was punctuated by severe droughts (Turner 2012:13908; Hodell et al. 1995). A drought for instance could have prevented the elites from being able to provide the water and fertile lands that formed the base of the means of production as suggested by Lucero (2002). The above statements could be evaluated through material evidence of decentralization of political
power coinciding with changes in internal cultural representation in material culture, paleoclimactic data, agriculture and investigations of water management infrastructure.

Gender

Sarah Nelson argues that the two tenants of feminist archaeology that improve the discipline are that they expose the gender bias among archaeologists today and to illuminate how focus on the powerful has obscured much of the archaeological record (Nelson:2004:1). Gender is extremely relevant to consider in any circumstance in which social status is a research interest. Even if evidence of gender is not anticipated, it should be anticipated so that potential evidence will not be overlooked. Irene Silverblatt (1988: 454-455) wrote that “the study of gender explodes order, restores ambiguity, contradiction, diversity and possibilities to the center of social process.”

Although there is variation in gender roles in activities such as hunting, food processing, and craft production in different cultures, agriculture is an example of an activity that may have very different divisions of labor based upon the culture. The nature of the crops grown and the system of land management may have widespread effects on the way society values the labor of men and women.

In Papua New Guinea the nature of farming does not require tillage because the crops are primarily tubers that need to be buried in individual holes (Denham 2011). In this circumstance there is little difference in the ability of men and women to match productivity. In areas where production mode relies on heavy tillage the physical strength of men may become more valued for increasing yield. If archaeologists can establish
what systems were used, may have implications for gender relations. A system involving clearing forest to create farming plots is a system that may favor male labor.

In the case of the Maya, the kitchen garden upkeep may have been the domain of women. This would have given them control over medicinal and utilitarian qualities of plants. Knowledge of plants and soil may be associated with gender. Studying modern Maya and linkages between gender, plant and soil knowledge may be useful to indicate if this is the case, with care to avoid essentialism. This was explored by Howard (2003) in a paper that discusses contemporary Maya women:

Contrary to previous thinking, it is becoming clear that [indigenous] women know most about these plants because, throughout history, women’s daily work has required more of this knowledge....predominate in plant biodiversity management in their roles as housewives, plant gatherers, homegardeners, herbalists, seed custodians and informal plant breeders....because most plant use, management and conservation occurs within the domestic realm, and because the principal values of plant genetic resources are localized and non-monetary, they are largely invisible to outsiders and are easily undervalued. (Howard 2004:2).

Gender norms prevent us from being free to move into areas in which we are excluded and knowledge is often a way in which access to opportunity and status is manifested (Thomas 2002:38). Level of knowledge and competency may but do not necessarily reflect the level of female social status in ancient Maya society but it is certainly an important factor. Small freedoms created by traditionally female knowledge may be a resource for forms of resistance. Paleopedology and ethnobotany however, may help infer if the soil immediately surrounding the structures were managed by females. Using middle range theory however, must be done without assuming or
perpetuating the ideas of uniform gender roles, or that gender is biological (Nelson 2002:37).

The elite sites contain water catchment systems with large basins connected to what appear to be check dams regulating water leading to systems of sophisticated canals that demonstrate understanding of the necessity of soil conservation. The construction of land of stone land management features such as the stone terraces and the water catchment systems found on the DH2GC transect may represent male labor, but female labor cannot be precluded. The management of these spaces once in place however would not have required as much physical strength, but rather knowledge and attention to detail. The management of household resources in the kitchen gardens, and the quality of drinking water was may have been controlled by women as part of the domestic sphere. It is easy to forget the amount of labor needed to maintain things. It is also important to consider the activities of women as a source of social change rather than only looking solely at men as responsible for the trajectory of humanity (Bertelsen et al. 1987:9

Environmental and Soilscape Theory

The inhabited areas in ancient times compose the “cultural soilscape” which is defined by Wells (2006) as an area of the earth’s surface that is the result of spatial, and “temporally variable geomorphic, pedogenic and cultural processes” (Wells 2006: 125). Wells views the cultural soilscape as an invaluable “analytical domain” and argues that it reveals the “the complex and multilayered dialectic between human behavior and soil
bodies over long periods” (Wells 2006: 125). This way of viewing the environment is an
excellent fit for Marxist and feminist theory. All three are highly compatible with a
dialectical approach.

The investigations upon the cultural soilscape use traditional archaeological
markers and try to correlate them with land use patterns such as cultivation zones and
inhabitation zones. These efforts have identified patterns in major elements, trace
metals and rare earth metals that have not traditionally been checked for correlations in
the archaeological record because no relevance was immediately apparent (Wells
2007:128). In investigations in Scotland in which historic records were used to track land
use, it was found that cultivation areas were depleted in zinc, nickel magnesium and
copper, while habitation zones contain increases of potassium, rubidium, cesium, and

In pre-Hispanic Guatemala and El Salvador, phosphorus, copper iron,
manganese, zinc, lead and mercury have been used to investigate architecture with
different patterns immersing for cooking spaces, and evidence of phosphorus
depressions in patterns that suggest the dripping of rainwater from roofs of structures

Soilscape theory nimbly avoids determinism but rather acknowledges the
complexity of human environmental relationships. It is an acknowledgment of reciprocity
between soil and culture and society. Soil conditions alter society and culture and the
actions of people alter the soil. Over time the natural and anthropogenic engage in
conversation, and this dialogue may be recoverable. This process is surely informed
greatly upon the particulars of gender roles and class interactions. If feminism and
Marxism have power to explain the human side of this exchange, the soil may hold the
evidence as well as the environmental response.
CHAPTER VI

METHODS

Hypothesis One

The first hypothesis (H1) is that P-fixation was occurring at the DH2GC project area and is significant enough to have limited agriculture in the region. The null hypothesis (H0) is that P-fixation is not significant enough to affect the agricultural viability of the soil at the DH2GC project area.

There will be multiple lines of data to draw upon for determining P-fixation from samples taken at Chawak But’o’ob and DH2GC. The first indicator is soil pH. Soils at or above 7.3 on the pH scale have high capacities for fixing phosphorus. Measuring pH will allow for the spatial identification of zones of P-fixation. The second line of inquiry will use the comparison of total phosphorus as measured with the XRF and available phosphorus to detect if there are significant concentrations of unavailable phosphorus where available phosphorus is suppressed and pH is high. If P-fixation is isolated, the unaffected areas can be compared to the potentially affected areas using independent sample T-tests.

The results of the hypothesis are significant because it will help establish the level of agricultural potential of the soil. If agriculture was limited by P-fixation and it can be established as being an anthropogenic pattern it may give insight into the conditions...
of abandonment. It will also inform interpretation of phosphorus levels in relation to intensity of occupation and the ability to know if we can compare phosphorus levels between sites. This last point will be important to the second hypothesis.

Hypotheses Two

The secondary hypothesis (H$_2$) asserts that elite sites will have significantly more fertile soil relative to commoner sites. The null hypothesis (H$_{02}$) is that the soil fertility will not differ between elite and commoner sites.

Before answering the second hypothesis, the first hypothesis will need to be addressed to establish if phosphorus is a viable fertility indicator in this setting. The general soil system will be analyzed with statistical methods to determine if they can be treated as a single population for the purpose of analysis. This process will involve exhaustive testing for significant differences in each nutrient or variable. It will also involve exploring the data with linear regression and correlation models, to detect any issues with unaccounted for variables or patterns that have bearing on the analysis.

Answering the first hypothesis may set the stage for the second hypothesis, or it may prevent it from being a viable question. For example, if the P-fixation does not affect Chawak But’o’ob but P-fixation is heavily affecting those of DH2GC, the comparison would not be valid. If the populations are found to be compatible through the comparison of soil nutrient distributions and pH, a soil quality index will be used to compare soil fertility between elite and commoner sites. The designation of site rank is determined by project director Dr. Marisol Cortes-Rincon. Given that the populations are
compatible, I will estimate the function of nutrient cycling using available P, K, and SOM utilizing a soil quality index (SQI) equation from Brady and Weil (2008).

\[
SQI_w = \frac{1}{n} \times \sum_{t=1}^{n} w_t \times 10
\]

The equation weighs factors based on how important each is in accessing the SQI. Soil organic matter is the most important factor, followed by phosphorus and potassium. The weighted population would be (P) x 3, (K) x 2, and (SOM) x 5. The result will be an ordinal SQI number that can be compared between sites. By using variable indices, the most important nutrients will be more heavily weighted. To assure that the phenomena measured is statistically significant, independent sample t-tests will be used to confirm if each of the variables, P, K, and soil organic matter are significantly different than the levels at the comparisons sites before being turned into an ordinal number.

The results of this hypothesis will have value in that it may suggest that elite sites had a higher resource input. If a fertility index does successfully correlate with site social status it could be utilized to better understand settlement patterns over a landscape. The results would open new avenues of using soil science as part of an inquiry into social questions.

Soil Data Collection and Processing

The soil samples for this project were collected over the 2011 and 2012 field seasons at the DH2GC transect and the Chawak But’o’ob site. A total of 12 anthropogenic samples were taken in 2011 and 46 anthropogenic samples were taken in 2012. In addition to the anthropogenic samples a baseline of 92 background samples
were taken at both Chawak But’o’ob and DH2GC. I used software developed by Cornell University, called the *Soil Test Conversion Tool for New York: Version 7*, to convert the data from DH2GC to be comparable to the data collected by Brokaw and processed at Cornell. The software allows for conversions between methods calibrated against bias at the laboratory specific level.

The following section will detail how the data was collected during the two seasons and how it was processed for traditional chemical analysis and X-RAY fluorescence spectrometry (XRF) analysis. It will begin with the traditional methods and end with the XRF protocols. During the 2011 DH2GC field season soil samples were collected by two methods: from the lot floor surface for floatation and from the profiles of excavation units for chemical analysis. Floatation samples consisting of one gallon of soil were taken evenly with a clean trowel from the total surface of the collection area of a unit at a recorded depth. These were usually taken in association with floor surfaces. The samples were placed in a sealed one gallon plastic container and taken back to the laboratory. One cup of soil from the floatation sample were then removed and placed in a plastic zip-lock bag for chemical testing.

The second method of collecting soil samples was from the profiles of excavation units corresponding with different soil horizons. Measurements and pictures were taken to document where the samples were collected. The collection tools were cleaned in the field using water and bio-degradable soaps between each use. Profile soil samples were taken during the final photographs upon reaching bedrock. Munsell color
codes and soil texture were recorded on the lot forms for each change in soil that was
observed by excavators.

In 2011 an initial 12 samples were exported the United States for analysis of
basic nutrients. These samples were analyzed for basic nutrients. The chemical analysis of
the samples for this project were processed at the UMass Laboratory using the guidelines
set by the Northeast Region Coordinating Committee on Soil Testing, NEC-67 in the 3rd
dition of Recommended Soil Testing Procedures for the Northeastern United States.

The samples were air dried upon arrival at Humboldt State University
Archaeological Research Laboratory by Alexandra Cox. Once the samples were dry, they
were shipped to the UMass Laboratory for the testing of basic nutrients using the
modified Morgan extraction method. The samples were tested for pH, Buffer pH,
Extractable Nutrients (P, K, Ca, Mg, Fe, Mn, Zn, Cu, B), Extractable Heavy Metals (Pb, Cd,
Ni, Cr), and Extractable Aluminum, Cation Exchange Capacity, and Percent Base
Saturation.

During the initial inductive phase of analysis I became familiar with the local
soil dynamics, and formulated questions about what was observed and collected
additional data the following 2012 season to answer these questions. During the 2012
season on the Dos Hombres to Gran Cacao settlement survey, soil samples were taken to
detect localized behavior, to better understand the attributes of the soils and to attempt
to isolate anthropogenic processes related to this thesis including P-fixation. Soil samples
were taken from both the profiles of planned excavation units and in strategic shovel test
pits. A total of 10 shovel test pits were excavated for a total of 19 soil samples at 5 loci. A total of 27 samples were taken from 7 select one by one meter excavation units.

The samples were exported to Humboldt State University where they received the same treatment as the previous year. They were subsequently analyzed by the University of Massachusetts at Amherst Soil and Plant Tissue Testing Laboratory to receive the same analysis as the previous season. The samples from the two seasons will provide the anthropogenic soil data for this thesis.

Unfortunately, when it rains hard in Guatemala the Rio Bravo quickly becomes dangerous to cross. The project area is remote, and the risk of dehydration is high. During the 2012 season Dr. Cortes-Rincon made the executive decision to cut short the season for the safety of her field crew. Thankfully, I was granted access the data collected a tree ecology project by Drs. Nick Brokaw and Sheila Ward on both the DH2GC transect by permission of Dr. Cortes-Rincon and the Chawak But’o’ob project directed by Dr. Stan Walling. These data have provided a baseline of soil dynamics that will help ground the anthropogenic data in this thesis and have augmented the anthropogenic data as well.

It is difficult to definitively call the baseline natural because of the amount of land modifications made by the Maya, and that we cannot account for locations of perishable structures. The presence or absence of cultural material however, is a good gauge of occupation. If P-fixation is present, the total phosphorus levels may be a better measure of anthropogenic phenomena in this environment.
The samples taken by Drs. Brokaw and Ward were taken at a consistent depth of 10 centimeters, which means that the soil samples are a mix of soils between 10 and 20 cm. The amount of accumulation of soil and sediments since abandonment varies at different areas in the topography so it is difficult to establish perfect sample chronology across the landscape. The anthropogenic samples were selected from lots that were just below the modern accumulation of soils.

**X-Ray Fluorescence Spectrometry**

The history of X-Ray fluorescence spectrometry (XRF) technology began in 1995 at the advent of X-rays which would be first utilized for XRF medical devices in the 1960s (Arai 2006:4). It is a form of non-destructive analysis. XRF works by ionizing atoms by exposing them to short-wavelength X-rays or Gamma rays. This ionization removes a number of electrons from the atom, and the resulting destabilization of the atom causes other electrons from within the atom to attempt to fill the holes that are left by the missing electrons. This process causes the emission of radiation signatures that are unique to each type of atomic structure. The XRF can interpret the radiation signatures to measure the elemental composition of the specimen.

XRF has been very successful in archaeological applications archaeology including ceramic analysis (Papadopoulou 2004:1877), pigment and ink analysis in historic documents and paintings (Klockenkamper et al. 2000:119), and obsidian sourcing (Davis et al. 2011:45). Stephen Shackly (2010) argues, protocol and calibrations are extremely important. The following section will provide information on the protocol used
and the rational. It will include product specifications procedures and the calibrations used for the instrument.

**X-Ray Fluorescence Spectrometry Protocol**

In this section I will explain the process of sub-sampling and the reasons for the chosen protocol. The subsamples were taken from all of the soil sample locations taken by myself and by Drs. Brokaw and Ward. XRF devices are very reliable; however, human error in lab procedure is a factor in accuracy. To reduce error, however slight, requires a protocol that ensures uniform treatment. Care should be taken to keep the positioning of the samples on the XRF consistent (EPA 1998:4). The protocol for this thesis will adhere to these precautions.

1. Each 5ml sub-sample is dried at 93 degrees C for 60 minutes. Moisture level differences may also cause error, and so each sample was baked in a toaster oven to remove all significant amounts of water (EPA 1998:4). The difference in water content prior to baking presents the possibility that a uniform treatment alone may not produce the desired reduction in error. To account for this, samples were placed inside sealed plastic containers immediately after heating to detect condensation. When condensation was observed, samples were returned to the oven for an additional 15 minutes and retested.

2. After the samples were dry, they were pulverized using a glass mortar and pestle. Before pulverization, small limestone and other pebbles were removed to prevent
them from chemically altering the sample. Pieces of vegetation were also removed. The mortar and pestle were washed in-between each sample.

3. Upon pulverization, the samples were run through a 12 mesh screen. The mesh was washed after each sample to prevent contamination. Samples must be homogenized in granular size by running the samples through a sieve to prevent the fine particles from being disproportionately settling at the bottom of the sample (EPA 1998:4).

4. The dried pulverized and sieved samples are placed in 31. mm diameter by 23.1 mm double open-ended micro-porous sample cups and sealed with 0.24 mill gauge Mylar polyester film. Both products were produced for use specifically with XRF analysis by Chemplex Industries, INC. The result is a cylinder the size of a soda bottle cap filled with soil and sealed on the top and the bottom with a clear film.

5. Each sample is scanned with the XRF with consistent placement of the sample cups and with a vacuum pump to gently pull the film to the XRF scanner to create a slight vacuum inside the sample cup and improve the resolution of the results. The sample cups were gently turned over several times to mix the samples and counteract natural separation by size. The amount of time that the sample will be scanned was uniform. The files were saved and will be included in the appendices of this thesis along with the raw XRF and available nutrient tests recorded in ppm.

The resulting XRF data is an accurate measure of the elemental composition of the soil. The steps outlined above minimize interference from moisture, granule size
error, and placement error. As previously stated, all of the equipment that made contact with the samples was thoroughly washed in between samples to prevent contamination. Each sample was retained inside of a zip-lock bag with provenance information preserved for future analysis.

The following data was collected using the Bruker Tracer III field portable XRF: P, Mg, Al, S, Mn, Co, Ni, Cr, Fe, B, Ti, Na, Si, K, Ca, V, Cu, Zn. The scans were conducted with consistent 90 second timed assays. The statistical analysis was conducted using SPSS software.

Although the most important data used for this thesis is of phosphorus, potassium, pH, and organic matter, I am going to use the full range of indicators to help strengthen my ability to differentiate between soil populations and detect any patterns that may suggest my methods need adjustment. I advocate for looking at as many soil factors as possible to avoid myopia and to build a strong context for the particulars of the soil system. This approach also allows for a transparent display of alternate factors so that reviewers may notice patterns that I am unable to see and perhaps refute any erroneous assumptions I have made. Because nutrients in the soil are so interrelated, neglecting to show relationships that I detect may limit the usefulness of my analysis.
CHAPTER VII

RESULTS

The results section will first address the population issues because they were necessary to resolve before either hypothesis can be validly tested. It was determined through the reorganization of nutrient level patterns in the XRF data that many samples in the baselines were anthropogenic. Having samples in the wrong category would affect the overall outcome of the study, so an intensive effort was made to identify anthropogenic sites and remove them from the baseline. The first section will share detailed results in the comparison of the means between projected and known anthropogenic sites. Following the analysis of the identification and re-categorization of anthropogenic samples the results of both research hypotheses will be reported.

The following section will demonstrate the results of this process by presenting a comparison of the data from the sites that are known to be anthropogenic and those projected to be anthropogenic in the context of the background. For each nutrient the descriptive statistics will be provided with t-test results will be provided to report if there is statistical significance. A box-plot will be included for each to provide visual representation of the distributions in relation to each other.

It is important to take note that the XRF data appears to detect anthropogenic relationship with nutrient levels in a different way than traditional tests. Although the
nutrient indicators that are generally found to be elevated in available forms at archaeology sites appear to remain relevant, instead of being elevated, some are depressed. This suggests that archaeology sites will have high available forms of available nutrients, but lower total levels. Elements that are not essential to plant growth such as sodium appear not to share this dynamic.

Data Comparisons

**Total Sodium Comparison of Projected and Known Anthropogenic Sites**

The box-plot (see Figure 12) illustrates that at both the sites that are known to be anthropogenic and those projected to be anthropogenic, the total sodium levels taken by the XRF are consistent with each other. The differences in sodium levels between known and projected sites are not significant ($t=-1.7; \text{ def}=52.43, \text{ sig}=.09$) (see Table 2), however, the non-anthropogenic sites contain zero sodium. The presence of sodium likely indicates potentially anthropogenic salinization associated with irrigation.

The projected sites and known sites are significantly different ($t= 2.27 \text{ df}=51; 0.007$) (see Table 3) and have differently shaped distributions but appear anthropogenic. As the box-plot (see Figure 13) demonstrates, the non-anthropogenic levels are clearly much higher, and are distributed in a much greater range that never overlaps with either projected or known sites. The differences between projected and known sites likely indicate differences in site use.
Figure 10. Total sodium comparison of projected and known anthropogenic sites.

Table 2. Descriptive statistics for total sodium comparison

<table>
<thead>
<tr>
<th>Total Sodium</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>5383.65</td>
<td>1636.76</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>5906.93</td>
<td>682.09</td>
</tr>
</tbody>
</table>
The plot of total magnesium (see Figure 14) shows once again that the baseline is far higher and a much greater range of distribution than projected and known sites. The total magnesium levels at sites projected to be anthropogenic fall within the same range as known anthropogenic sites with no significant differences (t=1.04; df=57; sig= 0.30).
(see Table 4). The shapes of the distributions also share a downward skew while the baseline looks closer to a normal distribution.

Figure 14. Total magnesium comparison of projected and known anthropogenic sites.

Table 4. Descriptive statistics for total magnesium comparison.

<table>
<thead>
<tr>
<th>Total Magnesium</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>6285.57</td>
<td>10112.5</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>3902.91</td>
<td>4471.55</td>
</tr>
</tbody>
</table>

The aluminum distributions (see Figure 15) for known and projected anthropogenic sites are very similar and are both disparate from the baseline. The there
is no significant difference in aluminum between projected sites and known sites ($t=.739; df=57; \text{sig}=0.463$) (see Table 5). Aluminum is an important nutrient to consider because of its important role in the soil system especially in the context of its interactions with magnesium, calcium, and iron and influence on pH levels.

![Figure 15 Total aluminum comparison of projected and known anthropogenic sites.](image)

**Table 5.** Descriptive statistics for total aluminum comparison.

<table>
<thead>
<tr>
<th>Total Aluminum</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>1765.64</td>
<td>2749.28</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>1272.94</td>
<td>1924.69</td>
</tr>
</tbody>
</table>
The box-plot (see Figure 16) shows that the calcium levels are higher at both the anthropogenic and projected anthropogenic sites, however, the differences between the background and the anthropogenic sites are not as dramatic as shown in other nutrient comparisons. There is no significant difference between anthropogenic and projected anthropogenic sites (t=.389; df =57; sig= 0.69) (see Table 6), although distributions are different in shape. Higher calcium at anthropogenic zones is likely due to the heavy use of limestone plaster as a construction material for houses, floors, and plazas and as a means to make water management features such as aguadas water-tight.

Figure 16. Total calcium comparison of projected and known anthropogenic sites.
Table 6. Descriptive statistics for total calcium comparison.

<table>
<thead>
<tr>
<th>Total Calcium</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>145323.36</td>
<td>84569.62</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>136824.26</td>
<td>74704.93</td>
</tr>
</tbody>
</table>

The box-plot (see Figure 17) shows that the barium levels are lower at both the anthropogenic and projected anthropogenic sites. The mean barium levels are significantly higher at known anthropogenic sites (t= 2.06; df= 56.19; sig= 0.040) (see Table 7). Barium levels have recently been identified in Amazonian archaeology sites as being associated with middens and other anthropogenic areas (Schmidt 2013:5).

Figure 17. Total barium comparison of projected and known anthropogenic sites.
Table 7. Descriptive statistics for total Barium comparison.

<table>
<thead>
<tr>
<th>Total Barium</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>946.91</td>
<td>787.66</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>593.69</td>
<td>523.59</td>
</tr>
</tbody>
</table>

The slight differences in total sulfur (see Figure 18) in the projected and anthropogenic samples are not statistically significant (t=.042; df=56.32; Sig= 0.96) (see Table 8). There is minimal variation in sulfur between background, anthropogenic, and projected sites.

Figure 18. Total sulfur comparison of projected and known anthropogenic sites.
Table 8. Descriptive statistics for total sulfur comparison.

<table>
<thead>
<tr>
<th>Total Sulfur</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>1895.57</td>
<td>935.47</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>1887.05</td>
<td>615.48</td>
</tr>
</tbody>
</table>

There is no significant difference in manganese between projected and known anthropogenic sites (t= -0.5; df=57; sig= .61) (see Table 9). The manganese distributions shapes for projected and known anthropogenic sites are dramatically different from the baseline (see Figure 19). They share a much smaller range and lower means.

Table 9. Descriptive statistics for total manganese comparison.

<table>
<thead>
<tr>
<th>Total Manganese</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>959.77</td>
<td>618.89</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>1082.12</td>
<td>1231.93</td>
</tr>
</tbody>
</table>

The difference in iron concentration means between the projected and known anthropogenic sites are not statistically different (t= -0.91; df= 57; sig= 0.36) (see Table 10). The projected and known anthropogenic sites share similar means, and are both lower than the baseline, however, the range is much greater in the projected sites (see Figure 20). Iron is relevant as an indicator of anthropogenic activity and interacts with aluminum, calcium and magnesium, affecting pH.
Figure 19. Total manganese comparison of projected and known anthropogenic sites.

Table 10. Descriptive statistics for total iron comparison.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropic</td>
<td>37</td>
<td>15445.63</td>
<td>9486.87</td>
</tr>
<tr>
<td>Anthropic</td>
<td>22</td>
<td>18055.66</td>
<td>12175.12</td>
</tr>
</tbody>
</table>

Copper levels are not significantly different within anthropogenic and projected samples (t= -1.16; df= 57; sig= 0.249) (see Table 11). Projected and known anthropogenic sites contain less total copper than the baseline (see Figure 21). Copper is associated with anthropogenic areas (Schmidt 2013:5).
Figure 11. Total iron comparison of projected and known anthropogenic sites.

Table 11. Descriptive statistics for total copper comparison.

<table>
<thead>
<tr>
<th>Total Copper</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>55.91</td>
<td>27.47</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>63.71</td>
<td>19.57</td>
</tr>
</tbody>
</table>
The box plot (see Figure 22) shows that both of the anthropogenic and projected anthropogenic distributions and means are significantly lower than the baseline levels of zinc. The differences within projected and known anthropogenic samples are not significant ($t=-1.08; df= 57; sig= 0.28$) (see Table 12). Zinc is associated with anthropogenic areas (Schmidt 2013:5).

Table 12. Descriptive statistics for total zinc comparison.

<table>
<thead>
<tr>
<th>Total Zinc</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>111.74</td>
<td>44.92</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>124.43</td>
<td>40.49</td>
</tr>
</tbody>
</table>
Figure 22. Total zinc comparison of projected and known anthropogenic sites.

The differences are highly significant between potassium levels between the anthropogenic and projected sites (t=-5.36; df=49.1; sig=.000) (see Table 13). The baseline is normally distributed with a higher range and mean, while the anthropogenic levels have skewed distributions (Figure 27). All the distributions have dissimilar means but both the projected and anthropogenic means are lower than the baseline. Despite the differences the projected sites appear anthropogenic.
Figure 13. Total potassium comparison of projected and known anthropogenic sites.

Table 1. Descriptive statistics for total potassium comparison.

<table>
<thead>
<tr>
<th>Total Potassium</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Anthropogenic</td>
<td>37</td>
<td>529.876</td>
<td>422.06</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>22</td>
<td>1092.5</td>
<td>368.56</td>
</tr>
</tbody>
</table>
Conclusion of the Discrimination of Anthropogenic Samples

After a thorough analysis of the data, the evidence is overwhelming that the samples that were projected to be anthropogenic are indeed so. In most of the cases, there was no statistically significant difference between the concentrations of elements.

There were no significant differences in sodium, magnesium, manganese, calcium, sulfur, copper, iron, aluminum, or zinc in the projected and known anthropogenic samples. In the case of phosphorus, potassium and barium, the differences were statistically significant; however the baseline levels were extremely different from both projected and known sites. The shapes of the distributions usually mirrored each other, and the deviation from the levels of the baseline was in the same direction.

The samples determined to be anthropogenic were removed from both baselines and included with the anthropogenic samples. Once the anthropogenic and baseline samples were sorted it was possible to compare the populations of the data-sets and approach the first research hypothesis.

Discrimination of Population

After the baselines were established, the next step was to check the populations against each other to check for statistical differences to see if the background soil environment at Chawak But’o’ob could be treated as part of the same population for analysis. I used Pearson’s T-test for Equality of Means augmented with Levene’s Test for Equality of Variances to determine if the baseline for Chawak But’o’ob
can be treated as the same population as the baseline for Dh2GC. The nutrients P, Mg, Al, S, Mn, Co, Ni, Cr, Fe, B, Ti, Na, did not have statistically significant differences.

The levels that varied to a degree to not likely be due to chance were: Si, K, Ca, V, Cu, Zn. Silicone and vanadium are not essential nutrients and are not of great importance in this context, however, Potassium, calcium, copper and zinc are relevant. The only elements that showed statistically different results which are essential nutrients for plant growth are K, Ca, Cu and Zn. The most immediately important is potassium, which along with phosphorus and nitrogen form the three most important nutrients. Next in importance in nutrition is calcium followed by copper and zinc which are micro-nutrients that are only needed in trace amounts in available forms.

Copper distributions do not match each other (see Figure 2); however the range and spread is a near match. It is also the case that the anthropogenic sites at both the DH2GC and Chawak But’o’ob baselines show a significant difference in copper (t=-1.93; df=44.30; sig=.059). This does not appear to be significant enough to affect the testing of either hypothesis.

The baseline distributions of Zinc share similar ranges and spreads but the distributions are skewed differently (see Figure 25). As with copper, Zinc levels were significant between anthropogenic sites on the Chawak But’o’ob and DH2GC transects (t=-2.46; df= 43.67; sig= 0.018). These discrepancies in Zinc levels do not pose a significant problem for testing either hypothesis.
In the case of Calcium (see Figure 26), the DH2GC baseline distribution is skewed lower than the Chawak But’o’ob baseline and the anthropogenic samples. Calcium levels are very high in both populations and the differences are statistically significant ($t=2.91; df=69; sig= 0.005$). It is not a nutrient that will likely be relevant for gauging fertility. Instead, calcium may affect nutrients through changes in pH.
It is clear that the levels of total potassium are much higher on the Chawak But’o’ob baseline as compared to both anthropogenic sites and Dh2GC (see Figure 27) (t=7.5; df= 57.3; sig=0.00). These phenomena could either be due to a natural difference in potassium over the landscape, or perhaps even the baseline samples in DH2GC are affected by proximity to anthropogenic sites. It appears that potassium would need special treatment for possible skew if it is to be used for analysis, however, other nutrients such as phosphorus may be effectively compared across projects.
It is interesting to note, that in the comparison between anthropogenic sites at both Chawak But’o’ob and DH2GC, the elemental levels were more in sync with each other than the baselines were. This is a testament to how great the anthropogenic transformations were. It is important to consider this when determining if Chawak But’o’ob and DH2GC can be viewed as a single population for the purposes of this study. By population I am referring soil characteristics in the way in lithic or ceramic analysis typologies delineate populations and if they can be compared. The continuity in site level
nutrient comparison however, may indicate that the baseline may have much less of an effect on the nutrients of interest than the site use.

**pH Level Comparisons**

The comparison of the nutrient levels do not indicate that Chawak But’o’ob and DH2GC cannot be treated as a single soil population. The final consideration of pH levels will both conclude the determination of population compatibility and gauge P-fixation. The Chawak But’o’ob and DH2GC baseline pH levels are significantly different from each other (t=4.339; df =36; sig=.000) (see Table 14).
Remarkably the pH levels in the DH2GC baseline are neutral to acidic and yet the anthropogenic sites are strongly alkaline (7.6 pH) to the degree at which P-fixation is virtually certain. The anthropogenic sites in Chawak But’o’ob are slightly more acidic than the Chawak But’o’ob baseline (t= 4.399; df= 21.29; sig= 0.000), but both remain in ideal conditions for plant growth (see Table 15). It appears that P-fixation was a condition that was occurring at anthropogenic areas around the DH2GC transect and is not a natural across the landscape phenomena. The pH levels do not change significantly between the Chawak But’o’ob baseline and anthropogenic sites while at DH2GC the levels move from a baseline that is neutral to alkaline conditions consistent with P-fixation. This suggests a possible difference in behavior between Chawak But’o’ob and DH2GC.

Table 2. pH level comparison at DH2GC and CHawak But’o’ob baselines.

<table>
<thead>
<tr>
<th>pH</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH2GC Baseline</td>
<td>43</td>
<td>7.01</td>
<td>0.31</td>
</tr>
<tr>
<td>Chawok Baseline</td>
<td>22</td>
<td>6.55</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Table 3. pH level comparison at DH2GC and Chawak But’o’ob anthropogenic sites.

<table>
<thead>
<tr>
<th>pH</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH2GC Anthropogenic</td>
<td>17</td>
<td>7.58</td>
<td>0.15</td>
</tr>
<tr>
<td>Chawok Anthropogenic</td>
<td>21</td>
<td>6.64</td>
<td>0.97</td>
</tr>
</tbody>
</table>
Phosphorous Comparisons

No significant differences between either total phosphorus were detected for the two baselines ($t=-1.4$; df= 37.2; sig= 0.145) (see Table 16).

Table 4. Comparison of baseline total phosphorus at DH2GC and Chawok But’o’ob.

<table>
<thead>
<tr>
<th>Total Phosphorus</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH2GC Baseline</td>
<td>45</td>
<td>1547.59</td>
<td>297.1</td>
</tr>
<tr>
<td>Chawok Baseline</td>
<td>23</td>
<td>1678.72</td>
<td>365.58</td>
</tr>
</tbody>
</table>

There is however, a very significant difference in both total and available phosphorus levels between projects at anthropogenic sites ($t= 2.83$; df=20.02; 0.01) (see Table 17). Available phosphorus, is nearly double at the anthropogenic sites on the Chawak But’o’ob transect compared to those on DH2GC ($t= -3.0$; df= 36; sig= 0.005) (See Table 18). Total phosphorus, conversely, is nearly three times higher at DH2GC than at Chawak But’o’ob. Where total phosphorus is high, available phosphorus is low. This deviation is excellent evidence of the higher concentration of unavailable organic phosphorus at the DH2GC archaeology sites relative to Chawak But’o’ob sites. This can be accounted for by the deferential rate at which the phosphorus nutrient cycles at Chawak But’o’ob and DH2GC covert organic phosphorus into available forms.

Table 5. Comparison of anthropogenic total phosphorus at Chawak But’o’ob and DH2GC

<table>
<thead>
<tr>
<th>Total Phosphorus</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH2GC</td>
<td>17</td>
<td>503.1</td>
<td>466.02</td>
</tr>
<tr>
<td>Chawok</td>
<td>21</td>
<td>178.46</td>
<td>150.12</td>
</tr>
</tbody>
</table>
Table 6. Comparison of anthropogenic available phosphorus at Chawak But’o’ob and DH2GC.

<table>
<thead>
<tr>
<th>Available Phosphorus</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH2GC</td>
<td>17</td>
<td>4.58</td>
<td>4.53</td>
</tr>
<tr>
<td>Chawok</td>
<td>21</td>
<td>8.87</td>
<td>4.21</td>
</tr>
</tbody>
</table>

The process of phosphorus and perhaps other nutrients remaining trapped in the organic forms may be made intelligible by examining the relationship between pH and soil organic matter. Potassium, for example, can be fixed by similar conditions as cause P-fixation. As expected, soil organic matter levels are higher where the pH level is higher. There is a moderate positive correlation of .377 significant to the .01 level (see Figure 33). The scatter plot shows a cluster of values around 7.0 pH, or neutral. As pH climbs, organic matter levels increase significantly leaving a trail of dots. These locations are in the zone at which they would be affected by P-fixation.

Hypothesis Conclusions

Hypothesis One

The data on pH, available phosphorus, and total phosphorus data strongly indicate conditions of P-fixation at anthropogenic sites on the DH2GC transect. The average pH level at DH2GC anthropogenic sites is 7.5 which well exceeds the 7.3 pH threshold. The locations where pH is above 7.3 there are concentrations of organic material and total phosphorus and very low available phosphorus. There is no indication of P-fixation on the Chawak But’o’ob project, or in the DH2GC baseline. At all of these
locations, the pH levels are below 7.3, organic matter and total phosphorus levels are significantly lower and the available phosphorus levels are significantly higher. The measures used are statistically significant, and strongly confirm the presence of P-fixation. I can reject the null hypothesis for $H_1$ that P-fixation is not significant enough to affect the agricultural viability of the soil at the DH2GC project area. I can accept $H_1$ that P-fixation was occurring at the DH2GC project area and is significant enough to have limited agriculture in the region.

**Hypothesis Two**

The results of hypothesis one have ramifications for the data that I was intending to use to test for inequality between elite and commoner sites. It is clear that
the methods that I had planned on are problematic in light of these results. First, the two populations were not comparable in fixation capacity for phosphorus. I can only use samples that have similar fixation capacities, so this reduced my sample size to a less than statistically significant size.

Second, the dynamics between organic matter, pH and phosphorus fixation make the planned reliance upon organic matter as the dominant soil health indicator untenable. Variations in organic matter are likely affected by inequality of p-fixation capacity and this could skew the results to make it look like inequality of soil fertility. Where organic matter is high, it may indicate organic matter that has been locked out of the nutrient cycle rather than an indication of site use intensity. Total phosphorus presents a similar problem as it may have built up under p-fixation. Additionally, potassium, the third most important nutrient I had planned to utilize is fixed by the same conditions that cause p-fixation.

It is hard to isolate nutrient cycle gridlock from the input of resources. I cannot test the assumption of \( H_2 \) that elite sites will have significantly more fertile soil relative to commoner sites. Under these circumstances I cannot reject the Null Hypothesis \( H_{02} \) that the soil fertility will not differ between elite and commoner sites.

In the discussion section where it is more appropriate to explore my personal insights, I will dive deeper into possible patterns of economic social behavior that may be testable given the proper data. The sites identified by chemical signatures may potentially represent a lower class of people living in perishable structures that a
pedestrian survey crew would not be able to easily locate. The inability to answer the second hypothesis may testify to the importance of investing ample time in understanding local dynamics and patterns before trying to make site to site or project to project comparisons.
CHAPTER VIII

DISCUSSION AND CONCLUSION

Discussion of Primary Results

In the final days before I received a comparative data-set that was vital to this thesis, I was near resignation that the data would come too late. I had accepted the possibility that it would not come in time and I passed the threshold at which it was necessary to explore the data I had to answer alternative questions. To start my results section sans the results, I wrote:

Often when we set out to learn something about the world, despite our best efforts to direct the process and control for variables, we instead learn humility. Robert Burns (1785) wrote, “The best laid schemes of mice and men go often awry, and leave us nothing but grief and pain, for promised joy!” This is a lesson difficult for academics to learn because we are people who are accustomed harnessing sheer will like a saber to clear a path where there seems none. Acceptance of limitations can be difficult for the tenacious and resilient. Despite hyper-preparation and obsessive resolve, some things are beyond our control.

Thankfully, I would internalize this harsh lesson, find the analysis of the alternative questions fruitful, and then promptly receive the data I yearned for. As a result, I have additional supportive analysis to strengthen the results and put them in a larger context. Although there was a long period of time in which the process was stalled, the end product of this thesis may be better for the barriers.

As such, the discussion will include the results of these sections. I will first present a comparative analysis I performed between the Nacco Valley Project in
Honduras, and the data I collected over the last two years at the DH2GC Archaeology Project. Second, I will discuss the XRF analysis that led the statistical identification of anthropogenic sites, and the implications. This will include the consideration of the concentrations that XRF reads compared to what is detected by traditional testing. Both of the first two seconds were completed with uncertainty of if I would receive the final data.

Third, I will interpret and expand upon the confirmation of the first hypothesis concerning P-fixation using all of the data. Fourth, I will address the inability of the data to facilitate a test of the second hypothesis. I will outline how it demonstrates the necessity of understanding the local soil nutrient conditions to interpret and use soils data.

**DH2GC and Nacco Valley Comparisons**

The soils in the Dos Hombres to Gran Cacao Archaeology Project (DH2GC) in northwestern Belize are atypical of what is normally seen at Maya sites. This section will attempt to demonstrate the abnormal qualities of the soil on the DH2GC project. This analysis will build an infrastructure upon which to build the larger quantitative elements of my thesis. The objective is to address the hypothesis that there was significant P-fixation limiting agriculture in the DH2GC area. P-fixation is a condition where phosphorus, and essential nutrient, is in the soil, but is bound to clay particles in a form that plants can't absorb.
In order to contextualize the nutrient level data at DH2GC I will utilize data from multiple sites located in the Maya lowlands of Honduras, in the Nacco Valley. The data was collected by Wells et al (2013), and includes soil organic matter, phosphorus and pH levels. These are useful indicators and in comparing distributions of the nutrient levels, and running tests for correlations, the DH2GC data may be understood in greater context. One utility of this comparison is that it allows for the exploration of what anthropogenic soil distributions look like.

The Nacco Valley is by no means a perfect comparison as there are differences in the local soil texture and topography; however, the samples were taken from anthropogenic sites and fit into the typical ranges commonly reported by archaeologists. The numbers will reflect what is typical and will illustrate that the data found at DH2GC archaeological sites are atypical by comparison. There are likely variables that will cause skew; however, the level of contrast between the sites will far exceed what could be expected for margin of error.

Wells also used a different chemical extraction method for the nutrient data at Nacco Valley which may alter the results. To ameliorate this problem I used software developed by Cornell University, called the \textit{Soil Test Conversion Tool for New York: Version 7}, to convert the data from DH2GC to be comparable to the data collected by (Wells et al. 2013). The software allows for conversions between methods calibrated against bias at the laboratory specific level.
Another concern is the sample size of each site. At the time of the analysis there were only 18 anthropogenic samples from DH2GC that fit the comparative cafeteria and 21 samples from Nacco Valley. These sample sizes are not ideal, however, the contrasts between the projects are rather dramatic and correlations were found within the .01 alpha level. Although the sample size is an issue the results should warrant attention.

The following section will compare the data-sets using descriptive statistics before performing inferential statistics. The descriptive statistics demonstrate that the distributions are fundamentally different between sites. These sections will include box-plots, scatter-plots, Pearson’s correlation, ANOVA regression and a Levene’s Test for Equality of Variance Independent Sample T-tests.

The Independent Sample T-test will be used to compare the means from the two sample populations to establish if the levels are significantly different across populations. The Pearson’s Correlation test will gauge if there is a significant association between the variables. The ANOVA regression will determine if the dependent variables are predictable based upon the levels of an independent variable.

I hypothesized that the levels of phosphorus and organic matter would be significantly different between DH2GC and Nacco Valley. I will utilize the Independent Sample T-test to test this hypothesis. In addition to the above hypothesis I will use both correlation and regression to test between both organic matter and phosphorus, and organic matter and pH within the two populations. I hypothesized that there would be a
significant correlation between the variables of phosphorus, organic matter, and pH. My expectation is that the relationships will be non-existent at Nacco Valley and present at DH2GC.

The following section will compare the data-sets using descriptive statistics before performing inferential statistics. The descriptive statistics (see Tables 19 and 20) demonstrate that the distributions are fundamentally different between sites. The phosphorus levels at Nacco Valley have a much greater spread, a much greater standard deviation, a heavy negative skew and yet many positive outliers.

**Table 7. Descriptive statistics for DH2GC.**

<table>
<thead>
<tr>
<th>DH2GC</th>
<th>Range</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Matter</td>
<td>11.80</td>
<td>4.30</td>
<td>16.10</td>
<td>7.80</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>8.00</td>
<td>0.00</td>
<td>8.00</td>
<td>2.78</td>
</tr>
<tr>
<td>pH</td>
<td>0.70</td>
<td>7.20</td>
<td>7.90</td>
<td>7.58</td>
</tr>
</tbody>
</table>

**Table 20. Descriptive statistics for Nacco Valley.**

<table>
<thead>
<tr>
<th>Nacco Valley</th>
<th>Range</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Matter</td>
<td>3.30</td>
<td>1.20</td>
<td>4.50</td>
<td>2.53</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>1083.00</td>
<td>85.00</td>
<td>1168.00</td>
<td>342.46</td>
</tr>
<tr>
<td>pH</td>
<td>1.80</td>
<td>6.20</td>
<td>8.00</td>
<td>7.33</td>
</tr>
</tbody>
</table>

**Phosphorous.** The differences in phosphorus levels are significant at the .000 level between sites (t= -2.49, df=37, .000). The null hypothesis can be rejected, and we can accept the hypothesis that the phosphorus levels are significantly different. The
phosphorus levels at Nacco Valley have a much greater spread, a much greater standard deviation, a heavy negative skew and yet many positive outliers.

The differences between the phosphorus distributions are so great that DH2GC phosphorus levels barely register next to the high range of variation in the Nacco Valley (see Figures 29 and 30). Phosphorus is a primary indicator for human occupation over time, and which accumulates in vast quantities at archaeological sites. The high levels of phosphorus at Nacco Valley are much closer to the norm for archaeological sites. The phosphorus levels at Nacco Valley are much more favorable than DH2GC. In this context, the phosphorus levels are indicating much higher levels of anthropogenic resource input.

Figure 29. Comparison of phosphorus levels by site.
Figure 30. Phosphorus levels at DH2GC.

With the scale adjusted to display the DH2GC phosphorus data, the DH2GC distribution also has a negative skew and the shape of the box-plots are very similar with much positive whiskers that are much longer than those which are negative. It appears that DH2GC proportionally vary inside of a much smaller spread. Both of the negative distributions and the presence of outliers may imply anthropogenic activity at different intensities with some areas in Nacco Valley containing far higher levels of variation in phosphorus. A comparison with the non-anthropogenic baseline data, once available, will provide context on if these distribution shapes are indeed anthropogenic signatures.
Organic matter. As expected a Levene’s Test for Equality of Variances indicated that the differences in the organic matter levels between sites are strongly significant ($t= 7.1, 37, .000$). The null hypothesis can be rejected, and we can accept the hypothesis that the organic matter levels are significantly different. In DH2GC the organic matter has a much larger range with negative skew and positive outliers (see Figure 31).

![Figure 31. Comparison of soil organic matter levels by site.](image-url)

This seems to be a complete mirror image of the phosphorus comparison between the Nacco Valley and DH2GC. The Nacco Valley has much higher available phosphorus, and DH2GC has much greater organic matter. This could be an indication that the resource input at the Nacco Valley was converted into various inorganic available forms, while at
DH2GC, the nutrient cycle was impeded and the nutrients remained in unavailable organic forms.

Phosphorus is used to measure intensity of occupation, which usually indicates the decay of organic materials, so it may be seem intuitive that the levels of organic matter should be higher at the Nacco Valley. The reverse is the case however. At DH2GC, the distribution has a much larger spread, with one major positive outlier, a much longer positive rather than negative whisker length and a slightly negatively skewed distribution. The Nacco Valley distribution is very consistent and follows a standard normal curve without skew.

This data supports the presence of P-fixation in the soils at DH2GC and the absence of such problems at the Nacco Valley. P-fixation prevents phosphorus from mineralizing into soluble forms that plants can absorb. Nacco valley has a normal distribution of organic matter, and high levels of phosphorus, which may reflect a balanced nutrient cycle in which the organic matter is being recycled into phosphors forms that plants can absorb and that available phosphorus tests detect. The baseline may potentially confirm or refute this notion.

**pH Levels.** A Levene’s Test for Equality of Variances indicates that the differences in the pH levels are significant at the .05 level between sites (see Figure 32) \((t=2, \text{df}= 37, p=.05)\). The null hypothesis can be rejected, and we can accept the hypothesis that the pH levels are significantly different. When comparing the pH levels, it is apparent that the majority of values and the median at DH2GC are above 7.5 which is a
threshold of alkalinity over which major soil problems occur.

The distribution is tight, suggesting a uniform pH dynamic at DH2GC. At Nacco Valley there is much more variation and a much larger spread, however, the majority of values at Nacco Valley fall below the 7.5 pH threshold. With pH over 7.5 P-fixation increases dramatically and nitrogen is lost through ammonium volatilization. Potassium availability may also be affected. The pH at Nacco Valley is much more favorable than that at found at DH2GC.

Figure 14. Comparison of pH levels by site.
The tight distributions for both high pH and low phosphorus at DH2GC appear to support the hypothesis of P-fixation on a large scale that would have limited agriculture across the DH2GC transect. In DH2GC the pH is consistently above the 7.5 threshold and has very low levels of phosphorus. DH2GC soils are calcareous; however, the Nacco Valley soils are in the normal range of variation for healthy soil. The phosphorus levels are much higher than those at DH2GC and have much more variation. This is likely due to faster rate of mineralization at Nacco Valley.

The tightness of the distributions of both pH and phosphorus may have been due to a water table rise leading to the precipitation of sulfate and calcium cations into the soil, drastically changing the pH levels and rendering the soil calcareous. The crops that the Maya depended on, such as Maize, would have grown poorly in this environment. There remains the possibility that these indicators may have been changed during modern times, however, the location of the DH2GC project area, unlike Nacco Valley, is remote, and there is no record of occupation since abandonment beyond pilgrimage.

**Correlations.** The next step is to examine correlations between different indicators within the populations. This will further illuminate the anthropogenic patterns. Both a Pearson correlation and an ANOVA test were run for the Phosphorus, pH and soil organic matter at DH2GC. These tests provided interesting insight into the relationships between the variables.
A significant positive relationship was detected between soil organic matter and phosphorus above the .01 level (see Figure 33) \((r = .62, p = .006)\). The Pearson Correlation coefficient indicates that the relationship is strong. No relationship was found for pH and organic matter \((r = -.231, df = 17, p = .356)\). The pH levels are generally homogenous above the threshold at which point become problematic, so it is not surprising that there is no relationship. An ANOVA regression test mirrored these results and established that the phosphorus levels could be predicted by the organic matter levels \((10.1, [df = 1, 17], p = .006)\).

*Figure 33.* Phosphorus and organic matter correlation at DH2GC.
No correlations, however, were detected between any of the variables in the Nacco Valley data (see Figure 34). Similarly the pH is homogenous, except that at Nacco Valley it is in a more beneficial and neutral range. The relationship between phosphorus and soil organic matter, although strongly correlated in DH2GC, was nonexistent at Nacco Valley.

A Pearson’s Correlation test indicated that the there was little or no relationship between phosphorus and organic matter ($r= .06$, df= 20 $p= 0.78$). In addition to the correlation result, the ANOVA regression model did not detect a relationship ($f=.25$ [19, 1] $p= .88$).

![Figure 34. Phosphorus and organic matter correlation at Nacco Valley.](image)
Phosphorus levels are very high, but the levels are arbitrary. This reflects the high level of variation in the intensity of occupation at anthropogenic sites. The outliers are likely the result of human behavioral differences. The scatter-plot shows that the values are mostly clustered in a horizontal line except for some outliers that are much higher. It does not appear that removing these outliers would change outcome to reflect an association.

The strength of association between soil organic matter and phosphorus at DH2GC and the lack of association at Nacco Valley may be revealing. Although the phosphorus levels are low at DH2GC, they are still tied to the levels of organic matter. In normal circumstances, the phosphorus levels should be higher at DH2GC based upon the much higher levels of organic matter relative to Nacco Valley. This is not the case however, because phosphorus levels are very high at Nacco Valley and are uncorrelated with the levels of soil organic matter.

The divorce in the relationship between soil organic matter and phosphorus at Nacco Valley indicates that the values likely reflect anthropogenic phenomena. The levels do not reflect what would be expected naturally. The results at DH2GC reflect a natural correlation between soil organic matter and phosphorus, and very little variation in phosphorus levels, suggesting universal deficiency in phosphorus availability at DH2GC. In my consultations with soils professor Dr. Mitch Johns, he suggested that the correlation was likely a reflection of p-availability. The levels at DH2GC may have once been similar to Nacco valley however, if P-fixation did occur, the anthropogenic
phosphorus that can be seen clearly at Nacco Valley is immobilized at DH2GC, and made invisible to our available phosphorus tests.

Discussion of Secondary Results

X-Ray Florescence Spectrometry
Data Analysis

The XRF data was meant to be used to determine if where pH levels were 7.3 or higher, there were large concentrations of total phosphorus. Upon looking at the results prior to receiving the pH data however, the possibility of another utility became apparent. The data that was created with the XRF scans included several elements that were not originally planned not be part of the study. One of these elements, sodium, appeared to be occurring in a binary pattern. Either the sodium levels were approximately 4000 to 6000 ppm, or they were zero.

I noticed that only under a couple exceptions, all of the known anthropogenic sites had sodium levels in the thousands as mentioned above. In the baseline data, the majority of the samples contained zero, however, those that did have sodium, had levels consistent with the anthropogenic sites. In light of this, each nutrient was scrutinized next to the baseline and the known anthropogenic sites to ascertain if they reflected anthropogenic levels.

As reported in the results section, I was able to show statistically significant evidence that the samples that contained sodium, match the anthropogenic samples. The variation was within the levels that can be reasonably expected for difference of site use.
The result meant that the samples needed to be re-categorized so that the baseline was not polluted by strongly anthropogenic sites.

Although not originally part of the thesis, this line of inquiry became very relevant as it allowed for the detection of anthropogenic sites in the background that would have skewed the results. As I shall explain in the following section, it allowed me to detect sites that may represent the Maya living in perishable dwellings.

**Total Sodium Correlations.** Presence or absence of Sodium proved to be an effective predictor of whether a sample would share statistically significant nutrient signatures. Correlations tests were run between sodium and phosphorus, potassium and calcium to investigate the phenomena.

A Pearson’s correlation test detected a weak negative relation of -.281 between sodium and phosphorus at anthropogenic sites at the .034 significance level (see Figure 35). This may indicate that where most salinization has occurred, the levels of P-fixation are elevated. Salinity and P-fixation may go hand in hand in that sodium raises the pH of the soil, which increases the level of P-fixation.

A very strong negative correlation exists between calcium and XRF sodium (-.91. sig=.005 (see Figure 36). It is unclear what the negative correlation between sodium and calcium infers, however is warrants future attention as it may be related to anthropogenic patterns. There are to be strong to vary strong positive relationships for zinc, iron, chromium, manganese and cobalt, however, this likely only reflects that certain
Figure 35. Correlation between XRF sodium and phosphorus.

elements, such as iron and aluminum are associated with each other. Sodium is the only base cation that can affect soil pH and is not an essential nutrient.

There is a very strong potassium and XRF sodium correlation negative correlation of 0.46 at the .00 significance level (see Figure 37). This may be related to salinization and P-fixation as well. Potassium can be affected by high pH conditions that fix phosphorus. If the pH is becoming more alkaline because of the sodium, it follows that potassium would also be depressed. In addition to phosphorus and potassium being fixed in alkaline soils, the anthropogenic soils at DH2GC were likely experiencing problems with nitrogen
Volatilization as well. This is where the nitrogen is changed into ammonium and is lost into the atmosphere.

The use of XRF sodium as an indicator resulted in a much stronger baseline, and the reorganization of an anthropogenic signature for site use in the area. The dynamics of using XRF soil data for archeological application is different from traditional methods. The lack of literature on the subject allowed little preview into what differences to expect in the levels, or how these data connect to anthropogenic activity.

Figure 36. Correlation between XRF sodium and calcium.
For example, high available phosphorus is a tried and true indicator of an anthropogenic site; however, the reverse was true with total phosphorus and other nutrients because of fixation. At the locations of sites, there was a significantly lower level of phosphorus and other elements that are commonly associated with archaeological behavior. It is hard to interpret what is occurring without intensive study, however, I can speculate that the depressed levels of total phosphorus and other elements may indicate the removal of these elements from the soil over time through erosion and perhaps leaching due to intensive irrigation.
Using total phosphorus and available phosphorus levels in conjunction may allow for more sophisticated models for estimating site use intensity. In conditions where phosphorus is not fixed, available phosphorus may indicate resource input such as fertilizers and food-waste, and total phosphorus may indicate the level of exhaustion of the soil. These measures could be combined with length of occupation estimates to create a potentially high resolution estimate for site use intensity. It may also be the case that combined in an equation with pH, these variables might be used to correct for the phosphorus fixation capacity.

There is still much to be explored in this direction. The differences in what is detected by the XRF and the traditional soil tests present incredibly complex questions that will require consulting soil scientists and physicists. For example, the traditional tests for sodium differed greatly from the levels taken by traditional means. While the XRF recorded either sodium levels by the thousands of ppm and zero sodium in baseline samples, the traditional sodium tests detected sodium in every sample.

It is unclear why the XRF presented a binary like it did, however, whatever the explanation, it has predictive power to locate sites that may otherwise remain invisible and track behavioral patterns. There may be a kind of interference in the XRF readings, perhaps related to particular chemical phenomena in the soil, possibly related to one of the nutrients that were identified as having an association. These include: phosphorus, calcium, potassium or zinc, iron, chromium, manganese and cobalt. It may be that traditional sodium tests may prove complimentary with XRF readings.
Identification of anthropogenic signatures. The realization that the second hypothesis was not testable came about due to the effectiveness of analyzing all of the soil elemental concentrations available for study. Although the social research hypothesis could not be approached as planned, the identification of anthropogenic sites that were not identified during the pedestrian survey may indicate that the sites were either stone structures that had been buried to where they could not be detected, or they were perishable structures. As noted in the literature review, ethnographic accounts at contact indicated that most of the Maya lived in perishable structures that would not survive into the archaeological record.

If this account is accurate, our understanding of settlement is severely impeded by focusing on stone structures. If surveys were modified to catch such structures a whole new avenue of household level archaeology could open up to research. The inclusion of a previously underrepresented for lower class in spatial analysis, and excavation, we may learn a great deal about social stratification in Maya society. Where these sites are in relationship to stone structures of various levels of complexity may illuminate relationships between the laborers with both the elite and middle class sites. If a data-set of stone structures and these invisible sites were compared in an environment in which p-fixation capacity is equal, the question I could not address might be effectively answered. Dr. Stan Walling’s research at Chawok But’ o’ ob is innovative on this front because he focuses on investigating the most humble
identifiable structures. The techniques used in this thesis could compliment such an approach.

I would like to connect the results and discussion to theory as well as can be done under the circumstances. The inclusion of gender theory was largely included under the reorganization of the possibility that the maintenance of water-management and soil conservation infrastructure and the kitchen gardens may have been the domain of women. This would have been a source of empowerment if it entailed a specialized base of knowledge of the management systems and the cultivation and utilization of useful plants. It is difficult to take the application much further given the data.

The results are an excellent fit for soilscape theory as the data revealed that P-fixation was present at anthropogenic sites in one particular project and not in the other. The fact that the P-fixation was isolated to DH2GC anthropogenic sites when the baseline pH is higher at DH2GC than at Chawak But’o’ob indicates separate dialectics. The pH levels reveal that the agricultural land around DH2GC were ideal, and the high levels of sodium indicate irrigated saline soils in the locations where P-fixation is present. These are part of the same dialectical system.

Soluble salts primarily enter the soil through weathering of primary materials, and are transported through water (Brady and Wiel 2008:412). When the water evaporates, the soluble salts are left behind laving concentrations. Salinity may occur naturally because the lack sufficient rain to flush the salts out of the soils. In human agricultural systems salt accumulation usually results from conditions where too much
water is applied for cultivation rather than where not enough water is applied (Brady and Wiel 2008:412). These soils become salt-affected due to human irrigation systems that increase water-logging (Brady and Wiel 2008:412). A change in vegetation from perennial native plants to shallow rooted domestic annuals also has the effect of increasing how much rainwater can percolate the soil into the ground water, thus raising the water table and depositing sodium, and potentially calcium, magnesium and potassium (Brady and Wiel 2008:412).

The salinization of the once fertile land along the Tigris and Euphrates in southeastern Iraq and the San Joaquin Valley in California are classic examples of land exhaustion. The soils in Iraq, for example, were not naturally well drained and so although it was once deserving of its namesake of the “Fertile Crescent,” the conditions were not tolerant of intensive irrigation and cultivation over the long term (Brady and Wiel 2008:415). The accumulation of salts is one the most difficult soil ailments in alkaline soils (Brady and Wiel 2008:411) and is associated with change in climate. A change towards more arid climate may contribute to salinization processes (Williams 1999:85).

The effects of salinization in the project area would have many implications agriculturally. Salinization would affect crop yields, but disproportionately depending on what the local people were growing. Squash and corn are both moderately sensitive to salinity, sorghum is moderately tolerant and cotton is very tolerant of saline conditions (Brady and Wiel 2008:427). In the local context, food crops would be more difficult to
grow in a saline environment, the cash crop of cotton may have remained relatively stable.

The presence of high salinity indicates that there were less salts being flushed out of the soil system than were accumulating. The most likely cause is intensive irrigation and cultivation in an increasingly arid environment. The high levels of sodium at archaeology sites where water catchment systems are present, it is likely that the choice productive areas where the water was diverted were likely affected by salinization as well. Many of the anthropogenic sampling locations at DH2GC were near water catchment systems such as canals and aguadas.

If the local soils were affected by both salinization and P-fixation it would suggest an untenable situation for farmers. The two factors may have been interrelated. If lands were cleared of deep rooted plants and replaced with annual crops, the water table may have risen and the soils may have become infused with water subtle sodium, calcium, and magnesium that in the dry season would become locked into the system. The surplus of calcium over time could have begun to interfere in the nutrient cycle of phosphorus, as well as potassium and nitrogen. P-fixation would stunt nutritional availability and salinity would affect soil structure and the ability of seeds to germinate.

Even with changes to management practices, it would have been hard to reclaim this land. The presence of either salinization, P-fixation or both provides a strong case for anthropogenic exhaustion of the soil. The elaborate nature of the water-management infrastructure would seem to indicate excellent management; however, it
may have been that over time, maintenance of the infrastructure was too costly, especially considering the volatile nature of shrink-swell clays. Perhaps a decline in infrastructure maintenance might have been related to economic conditions and the level of investment by local or state governments. War, for example, often focuses resources away from infrastructure needs. In all likelihood whatever reason led to abandonment was interconnected to many outside forces that we cannot detect.

Marxist theory is useful in terms of the potential hidden sites of a lower-class. These people might represent the base of labor. The elite sites feature elaborate water-catchment features and canals that channel water away from the sites. The water and the land could be viewed as the means of production. If the elites managed these resources, climate change and agricultural problems such as P-fixation and salinization may have caused them to lose credibility and control over the workers. This is argued as a potential reason for the political collapse during this time period by Lucero (2002). If conditions became economically intolerable they may have moved northwards to join more prosperous communities or formed decentralized communities near water sources and away from urban settings.

Concluding Remarks

In conclusion, this thesis successfully used a combination of XRF and traditional soil data to confirm that P-fixation was present and isolated around the household groups and the small elite site at DH2GC. PH levels and the organic matter, total and available phosphorus levels strongly supported the rejection of the first null
hypothesis. Sodium levels from the XRF were also matched with other chemical signatures to identity sites that may have been around perishable structures. The second research question could not be addressed because the samples earmarked for the analysis were revealed to be incompatible without a sophisticated way to account for the differences in P-fixation capacity.

Under P-fixation, fertilizer would be much less effective than before. The organic material would have built up yet would not transform or turn into available nutrients at the rate needed to sustain intensive cultivation. Indicator species that farmers relied on would not help them. A rise in pH and the onset of P-fixation would have drastically reduced the agricultural viability of the area and was likely a contributing factor to abandonment. The low nutrient levels near archaeology sites where high levels should be most expected may indicate erosion as a factor as this is the primary way that phosphorus may be removed from the soil.

It may also suggest that despite exhaustion of the agricultural fields, there may have been a slow decline in population with full abandonment occurring when the concentrations of available nutrients at residential sites were depleted, leaving little choice. The Maya buried their dead below their houses, and considered their soil to be filled with the spiritual essence of their ancestors. There may have been a high level of resistance to leaving.

Despite what the results reveal about the difficulties the Maya in this area were facing, humans are tenaciously resilient. The conditions under which people endure
to maintain their connection to the land they grew up on may defy what immediately
seems rational. As suggested in human-thing entanglement theory, people shape the
environment for their needs, but need to constantly make increasingly expensive
investments to live in the same place (Hodder 2011). Eventually when things become so
broken to where the dialectic between people and their soil is severed, there comes the
tragedy of displacement. There is little more traumatic to a people and to their culture to
live in disarticulated exile, however, people do not just lie down and die.

Such was the burden accounted by those who were forced to leave Oklahoma
during the American “dust bowl.” No other source can provide a more moving
description of that human tragedy than that of John Steinbeck in The Grapes of Wrath:
“They streamed over the mountains, hungry and restless—restless as ants, scurrying to
find work to do—to lift, to push, to pull, to pick, to cut—anything, any burden to bear, for
food. The kids are hungry.”

Structures of the Maya were often ritually terminated upon leaving,
shattering many clay pots and figurines that were made from the soil. In their world, soil
was the primary source material for all things. It was the bases for pottery, religious
objects, and the food that they ate. It was partner in a conversation that lasted for
generations. It was the place of the afterlife, the underworld, and where their ancestors
lived. The sky was not heaven for the Maya. It was the soil.
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