Aspects Of Ancient Maya Water Management at Minanha (Belize), An Interdisciplinary Approach.

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complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

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The water management approach at the ancient Maya city, Minanha in Belize Central America, was examined through excavation and geomorphological analysis. The results have successfully demonstrated that this natural feature, the Mayo aguada, was altered and used by ancient inhabitants in the region. Analysis of twelve sediment samples collected from the aguada revealed two distinct groupings of sediments indicating the onset of terrace construction and active water resource management. Two very different terraces were excavated, demonstrating the tendency of the ancient Maya to modify natural water management features, only when necessary to improve their effectiveness. Finally, it was determined that the Mayo aguada was not capable of providing a year round water source naturally, but required regular maintenance to improve and maintain its water retaining capacity. Comparisons were drawn between the water management approach exercised at this ancient city, and that of its large and influential neighbor, Caracol.

Emphasizing an interdisciplinary approach, this research was undertaken with the assistance and supervision of a geologist, an archaeologist, a geographer and an anthropologist. Dominant themes relating to ancient water management practices were explored from the perspective of the appropriate field of study. Interpretation of the results was thereby informed by several of the disciplines that have influenced archaeological theory and methodology. The limitations of the archaeological dataset, were examined, exploring the distance between data and interpretation. The data and interpretations have been presented with the goal of providing sufficient information regarding the subject matter and each discipline, such that a variety of readers can understand and apply the content herein to their own research endeavors.

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Archaeological excavations are always a team effort, and this is very true within the Social Archaeology Research Program (SARP). Over many years Dr. Iannone and his collaborative team provided training, funding, and insight that allowed this project to begin and succeed. I am very grateful to all members of the SARP family, with special mention to the entire Martinez family for providing a learning environment, a home away from home, and the benefits of their experience.

Prior to embarking on this research I had the fortune to attend SARP as a student, an assistant, and as a supervisor. Working on various areas of the site in different capacities allowed me to benefit from the perspectives of teachers, staff, and students alike, and to gain a broad perspective of the site dynamics. Finally, during excavations at the Mayo aguada I was the lucky recipient of the knowledge and insight from my excavation team, E. Martinez and E. Ruiz, whose experienced perspectives and extremely hard work have greatly contributed to this project.

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Preface

The ancient Maya site Minanha was initially discovered in 1922 by a chiclero (a person who taps sapodilla trees for the sap used in gum). Investigations at Minanha began in 1927, conducted by a team from the British Museum (Joyce et al. 1927, cited in Iannone 1999:6). Excavations were abandoned after one week, due in part to a lack of water that plagued the excavation team. Investigations did not begin again in earnest until 1999, one year after the site was relocated by Dr. Gyles Ianone, and the Social Archaeology Research Program (Trent University) (Iannone 1999).

Phase I research conducted by SARP focused on the social collapse phenomenon that occurred at Minanha, from the perspective of the royal and elite occupants. Phase I focused excavations upon the city center complexes and served to place the history of Minanha, from genesis to fluorescence and eventual decline, into its geographical and cultural context. SARP built upon this foundation with phase II research. Phase II examined the same time period from the standpoint of the lesser status, support population. By generating a multi faceted dataset, SARP is examining community responses to the political and social changes that occurred at Minanha between its establishment and demise (Iannone, 2006:15).

I joined SARP in 2001 as a field school student through Trent University. During the course of a month I gained hands on experience in field archaeology and laboratory methods. I had the good fortune to return as for three months in the summers of 2002 (junior supervisor) and 2003 (assistant supervisor), and one month in 2005 (assistant supervisor). Throughout these field seasons I excavated many areas of the site, while providing instruction to field school students. In 2002 I had the opportunity to survey and map several caves in the vicinity of Minanha, in conjunction with my colleague J. Birch. This research contributed to a coauthored conference paper at the 68th annual meeting of the Society for American Archaeology (Griffith et al. 2004). During these field seasons I gained excavation experience at various areas of the site including the royal court structures, structures within a restricted access courtyard, a plaza structure in the periphery of the city center, and the terraces. In 2007 and 2008, I returned to Minanha to begin excavations at the Mayo aguada, beginning research project.

Research at the Mayo aguada has been conducted under the auspices of the Social Archaeology Research Program and is intended to contribute to SARP's broad research goals. Water management in this challenging environment impacted both elite and non elite populations, and was likely a point of interaction between the two. By cataloguing and examining the response to water management challenges at Minanha, this project will contribute to the social and historical context being examined at Minanha.

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Chapter 1

1.1 Introduction

As early as 2000 years ago, the ancient Maya began altering their environment (Fagan, 2001). These alterations allowed growing communities to maximize their water use and agricultural efficiency (Fagan, 2001). Such efforts allowed for the development and fluorescence of large urban centers in a very challenging environment. In this region, which is characterized by water scarcity, management of water resources would have played a vital role in community growth and limitations. Gill (2000) suggests that water management success permitted cultural fluorescence and ensuing population growth. This population may have exceeded the environments carrying capacity rendering minor and major droughts unmanageable (Peterson and Haug, 2005:328).

This thesis aims to explore the water management regime at the ancient Maya site of Minanha in Belize, Central America. By examining a potential relic *aguada* located near this site, the ancient city's water management approach is characterized and the social implications of this precious resource explored.

Increasingly introspective approaches to contemporary issues of resource management have resulted in an intensification of attention to ancient methods, with an emphasis upon developing improved levels of sustainability in current culture. The archaeological record has often demonstrated that in antiquity, sustainability was implicit within preferred approaches to resource management. Such a focus on sustainability has resurfaced in recent decades (Angelakis and Koutsoyiannis, 2007:viii). With this renewed interest in sustainability and ancient methods of resource management a large and interdisciplinary corpus of research on the topic has been, and is continuing to be produced. With various academic fields addressing this issue, it is important that the interdisciplinary approach maintains rigorous standards. This project exemplifies the interdisciplinary approach, having been conducted in collaboration with a geologist, a geographer, an anthropologist and an archaeologist.

Chapter 2

2.1 Methodological Considerations.

The first step in the current research is to confirm or deny the use of the Mayo aguada as a water management feature in antiquity. Ascertaining that this feature was utilized is conducted through an inductive approach. Ancient water management features are often opportunistically adopted natural features that are subsequently modified where needed for controlled use and protection of the water resource, and to improve their water retention characteristics (Weiss – Krejci and Sabbas, 2002).

Several variables can be identified that, if satisfied, support the hypothesis that the feature under study was used in antiquity for water management purposes. Variables pertaining to this area include: 1) a topography that promotes the collection of water from surrounding hills; 2) clays that result in better water retention than surrounding areas; 3) an ability to hold moisture throughout the year; 4) evidence of Maya occupation in the surrounding area; 5) evidence of human modification that promotes water retention; 6) ceramic evidence that water collection occurred here; 7) the preserved remnants of a plaster seal.

Correlations must exist between empirical data and the broad theories that are developed from them. For this reason, archaeologists promoting highly scientific approaches to interpreting material culture supported the deductive approach by developing a bridging theory, called Middle Range Theory (Binford 1989), composed of natural laws. This was intended to provide the over arching paradigms that could set the rules for falsification and connect data to broad ideas. Recognizing the limitations of the deductive approach, Middle Range Theory requires an iterative process between inductive and deductive reasoning (Binford 1989). By way of this process, observations could be tested against a consistent set of expectations, and narratives could be built from a corpus of data and interpretations. This represented a compromise between relativism and objectivity, in which an objective world composed of facts is recognized, however the interpretation inherent in the construction of data by adding meaning to facts is acknowledged (Binford1989:67).

Upon completion of confirming or denying the use of the Mayo Aguada as a water management structure, Middle Range Theory will provide the bridge to addressing social questions based upon the results.

2.2 Research Questions

Excavations at the Mayo aguada will be applied to address the following research questions:

1) Can it be confirmed that the Mayo aguada was used in antiquity as a water management feature?
2) How was the natural aguada modified for water management?
3) How effectively could the known water feature have supported Minanha at its peak population?
4) How much labor was required to construct and maintain this system?
5) How did the elite of the city center control access to available water sources?
6) How did water accessibility influence settlement patterns in the area of Minanha?

7) How were the non-elite impacted by the water management regime of Minanha?

8) Did climate changes or drought cycles have an impact on this Maya city?

9) Did a crisis of resilience threaten this community?

10) How did the Maya conception of land, water, and resources influence their choice of water management systems?

11) What is the relationship between water management systems and systems of governance?

2.3 Interdisciplinary Approach

Interdisciplinary approaches to research permit the adoption and incorporation of defined paradigms and social theory to address new challenges presented by diverse fields of study. An Interdisciplinary approach should culminate in the *"integration of disciplinary insights"* (Newell and Green, 1982:24). Interdisciplinary methodology is especially appropriate to conducting research regarding complex systems (Newell, 2001 :1). Studies conducted upon multi-faceted, non – linear, cohesive systems require an interdisciplinary approach to accommodate their complexity (Newell, 2001:2).

The implementation of an interdisciplinary approach can only be successful if the researcher is well versed in the complexities of the theories or the methods being incorporated. A lack of thorough comprehension of each discipline involved can result in the application of a cross-disciplinary approach as opposed to an interdisciplinary method. The fundamental difference is that in the cross-disciplinary approach, one discipline dominates the research, while the other is a passive repository of data to be drawn upon uncritically (Newell and Green, 1982:25). Erroneous applications of theory and methodology from the latter discipline can develop.

Interdisciplinary scholarship broadens research by facilitating the use of datasets from one field of study to address problems with another. Currently, this tendency has changed the unidirectional borrowing from geography to archaeology that characterized archaeology's past. Contemporary issues are increasingly being informed by archaeological investigations. Following World War II, an interest in indigenous and ancient forms of architecture was heightened within urban design as a potential reservoir of innovative solutions to modern cities and their structures (Lawrence and Low, 1990:458). This preoccupation attracted interest from diverse fields, and resulted in collaborative efforts directed towards the improvement of contemporary built environments (Lawrence and Low, 1990:458). The study of water management, in particular, is currently preoccupied with ancient studies on climate change and social reactions to water scarcity. Many water stressed regions must manage their water challenges with minimal access to modern technology, and various groups are redressing issues of indigenous and ancient forms of water management. Furthermore, the association between climate change, water scarcity, and collapse indicates that studies of ancient societies can be applied to studies concerned with current struggles, to provide insight into social and ecological resilience. The time depth afforded by archaeological research is complemented by the rich history of social theory and scientific methods of diverse social and physical sciences, insofar as applied methodologies are understood by the practitioners from each field of study.

2.4 Anthropology in Archaeology

Anthropology is a multi-subfielded (Gillespie et al. 2003:155) social science concerned with the study of humankind. Utilizing a variety of methods and sources anthropologists create generalizations about human behavior and diversity (Haviland, 1997:26). Due to its subject matter of human culture, and approaches emphasizing methodological rigor, anthropology has been described as *"a hybridization of science and history"* (qtd in Gillespie et al. 2003: 157). This combination of science and history has resulted in a diverse discipline able to impact and be impacted by fields of research in the social and biological sciences, and the humanities.

Anthropology can be broken down into subdisciplines including physical anthropology (also known as biological anthropology), cultural anthropology (also known as social anthropology), anthropological linguistics, and archaeology (Renfrew and Bahn, 1996). Physical anthropology studies fossils and close relations to humans, such as contemporary primates, to address the origins, ancestry, and variation of the human species (Haviland, 1997:8). Social anthropology is concerned with social aspects of the human experience and often utilizes the active study of contemporary cultures to collect data (ethnography) (Haviland, 1997:14). The study of languages is historical linguistics (Haviland, 1997:13). Archaeology is concerned with studying human behavior by examining material culture. Archaeological studies are primarily conducted upon ancient societies; however, archaeology of contemporary communities is a growing component of this subfield. Often, elements from each of these approaches are integrated into anthropological research agendas.

Anthropology and archaeology have had an enduring relationship. Functionally, many archaeologists hold anthropology degrees, and many universities situate their archaeological studies within anthropological departments. Further, introductory undergraduate anthropology courses at universities commonly expose students to archaeology as a subfield of the anthropological discipline (Gillespie et al. 2003:155).

In the mid 19^{th} Century close ties between anthropologists and archaeologists were maintained by a strong belief in the continuity of contemporary communities within a landscape. It was believed that any supposedly non-modern groups within a locale were the original inhabitants, and had exhibited little cultural change from their ancient ascendants. This belief justified archaeologists' transferal of methods and data derived from ethnographic research onto prehistoric populations (Trigger, 1989:377). The discipline of archaeology benefitted from borrowing the methodologies of anthropology. Anthropologists adopted archaeological approaches enabling them to extend their reach into the pre-historic past (Orser, 2001:625).

Following WWII, archaeology was influenced by trends in mid twentieth Century philosophy. This impact encouraged archaeology to adopt a positivist approach to theories of human behavior. The scientification of archaeology, known as Processualism (Binford, 1962), asserted that objective theories of human behavior could be developed through the rigorous application of scientific methodologies (Whitley, 1999:6). Environmental pressures were viewed as primary causes of social change. Adaptive behaviors such as technology and subsistence were considered most relevant to social change, whereas social elements such as religion and art were viewed as epiphenomenal and less applicable (Whitley, 1999:9). Processualism distanced archaeology from anthropology by embracing positivism as well as by emphasizing reliance upon physical and environmental sciences (Whitley, 1999). Interestingly, as archaeology was developing the Processual approach, positivist approaches were undergoing heavy critique and abandonment in the other social sciences (Whitley, 1999).

Archaeology became further aligned with trends in anthropology during the 1970’s, as rejection of positivist approaches matured (Whitley, 1999; Shanks and Hodder, 1999). This rejection has been labeled post-processualism and is characterized by a critique of processual and materialist approaches as dehumanizing history (Flannery and Marcus, 1999:35). Drawing upon debates within anthropology and philosophy, post-processual archaeology reintegrated social theory and questioned the ability of researchers to develop objective conceptions of the past (Whitley, 1999).

Contemporary archaeology has a renewed interest in internal debates regarding methodology and theory. Archaeology can and has benefitted from research developed in anthropology by utilizing concepts and acknowledging discourses within anthropological circles. Iterative sharing results in an expansion of each discipline and at times blurs the distinctions between these approaches. The role of the interdisciplinary approach can also serve to balance the limitations of each expertise. Archaeology tends to examine broad themes and long-term histories, while anthropological fieldwork is able to expose personal and at times unique interactions within shorter time scales (Brumfiel, 2003). In this relationship, the generalizing approach of archaeology can be balanced by the ability of anthropology to reveal exceptions and variances in the human condition (Brumfiel, 2003:205).

2.5 Geography in archaeology

Beginning in the nineteenth century a formal education in physical and biological sciences became emphasized within archaeological practice (Trigger, 1989:17). Initially this influence was unidirectional, characterized by archaeologists borrowing methods and basic principles developed within geography (Trigger, 1989:17). The degree of the archaeologists' exposure to and comprehension of the borrowed theories and methods employed was variable, depending upon the nature of their prior education. Eventually, as specialization increased, a more collaborative approach was developed in which archaeologists and geographers worked in tandem on common goals (Trigger, 1989:17). In addition to methodologies and investigative techniques, geography has contributed theoretical concepts that have been incorporated into the process of archaeological interpretation (Trigger, 1989). Proponents of social theories emphasizing geographic approaches also encouraged the use of novel methods of data collection and analysis. Such methods include the use of aerial photography for archaeological investigations, artifact distribution mapping and studies, and ecological studies including soil analysis (Trigger, 1989:249). Many of the archaeological approaches with deep roots in geography demonstrate a preoccupation with the *"relationships between landscapes and culture-history"* (Trigger, 1989:249). Within geography, and consequently archaeology, varying degrees of environmental determinist approaches have developed. These approaches emphasize the role of environmental, geological, and geographic factors in relation to social histories. Extreme forms of environmental determinism are influential in theories of the hydraulic State. The development of Landscape archaeology, on the contrary, has maintained an appreciation of the impact of the natural environment, while defining the spaces of social interaction in much more complex terms, incorporating social and cultural aspects into the formation of the natural landscape.

2.6 Environmental Determinism

Environmental determinism represented a move within geography towards a scientific approach to social analysis. Analogies and explanations for social behavior were drawn from the field of evolutionary biology (Peet,1985:310). At its extreme, environmental determinism neglects the role of culture and agency as social motivators. Furthermore, overly environmental or ecological deterministic theories for culture have tended to emphasize uniformity, neglecting behavioral diversity (Trigger 1990:119) in favor of simple cause and effect explanations for social outcomes. For these failures, environmental determinism is an over simplification of the human condition. To entirely abandon environmental determinism, however, is to disregard the context of the actions and interactions of human societies. The influence of the environment, much like genes, does not replace free will, however it does provide limiting factors and opportunities. Acknowledging that the environment enables and constrains human activity contributes to rigorous explanations of behavioral motivations.

2.7 Landscape Studies

During the early development of archaeology, geographers developed theories laden with varying degrees of environmental determinism. Adopted by archaeology, these paradigms include what is now referred to as Landscape Archaeology. Landscape studies recognize environmental, geographical, and geological variables as important agents in social change, without isolating them from social phenomenon. Historical and modern examples are found throughout social studies. In the nineteenth century Edwin Guest examined English history in relation to British natural geography. H.J. Mackinder associated political and economic history with geographic national boundaries, and F.J. Haverfield associated Roman settlement with geographical terrain (Trigger 1989:249). Such theoretical underpinnings were by no means fully accepted. Prominent theorists such as Durkheim viewed the relationship between habitat and humanity as only an indirect factor to social change (Anschuetz et al. 2001:158). Integral to Landscape approaches is the premise that landscapes are not direct correlates of the pristine natural environment, but are *"worlds of cultural product"* (Anschuetz et al. 2001:160). Landscapes are produced via the process of developing spaces into meaningful places through actions, be they mundane or ritual. This does not make landscapes built spaces, but the result of an iterative process between culture and nature (Anschuetz et al. 2001). This process between the environment and its occupants make landscapes an excellent scale at which to examine the adaptation of populations to environmental factors, as well as symbolic concepts of their natural environments (Scarborough 2003).

Interpretations based on varying degrees of environmental determinism inform the analysis of built environments as well as landscapes. For instance, rectangular shaped structures are often associated with sedentary lifestyles while round structures are more often found in nomadic communities. These correlations are attributed to the more permanent materials required to construct rectangular buildings, and their increased ability to have structural attachments added on. Round structures, alternatively, tend to be more amenable in form and materials to short duration habitation and mobility (Lawrence and Low, 1990). Such associations implicitly presuppose a methodological reliance upon deterministic theory, and are supported by their ability to have predictive success. Recognition of resource and environmental limitations, and their inclusion into theory development is integral to determining the real life necessities of humans. Regardless of cultural or symbolic content, landscapes and associated built structures must ultimately fulfill their utilitarian functions with the technological and environmental means available.

2.8 Built Forms

Built forms are inevitably shaped by the availability of materials, technology, and the limits of climatic conditions. However, they are also designed to accommodate social and kinship groups (Lawrence and Low 1990:462), thereby mirroring social complexity and relationships. Finally some researchers present multi-causal explanations, such as Rapoport, for whom built forms result from *"sociocultural factors modified by architectural responses both to climatic conditions and to limitations of materials and methods"* (Lawrence and Low 1990: 458). Such a diversity of interpretations demonstrates that geographers tend to agree that the landscape and associated built environs contain messages and meanings of its creator culture, as a *"complex repository of society"* (Knox 1991:240), and that both vernacular and symbolic landscapes shape and are shaped by the communities acting within the spaces.

Lawrence (1993) correlates social phenomena with changes in built forms when analyzing the development of residential squares in London throughout political and economic changes. Garden plots and private parks are taken directly as symbolic statements of values. Lawrence is especially interested in their developments during times of great social changes such as transitions from feudal to capitalist modes of production. Of particular interest is the influence of the Aristocracy and the Middle Class in the form of the city, the oft changing relationship between the city and nature, the ability of the city to symbolically represent social values, and the interplay between outside influence and internal traditions in the use of urban spaces (Lawrence, 1993). Such approaches to examining urban environments presuppose the legibility of built forms, and the encoding of social values into built environs.

Labor intensive built environments, such as monumental architecture, is a feature associated with complex societies, and is defined by its excessive scale and elaboration that surpasses practical functionality (Trigger 1990). Maya urban centers are characterized by diverse and intense monumental architecture projects. Cultural tendencies associated with societies manifesting such monumental architecture are: endogamy, social stratification, and decreased reliance upon kinship as an organizing principle of society. Monumental architecture is seen to proliferate in relation to increases in social complexity. (Trigger 1990:122). Furthermore, the degree of centralization and developmental stage of a city can be interpreted by the amount and scale of monumental architecture present. Monumental architecture and urban planning increase in correlation to increasing political centralization which is often associated with early State development, presumably as the need to express and reinforce power relations, (Trigger 1990:125) and the ability to coerce or purchase labor increases.

2.9 Material Culture as a Dataset.

Interpretation of the material culture and built forms of ancient communities is implicit to archaeological research. Archaeologists rely upon methodologies developed in other disciplines, such as geography, anthropology, and sociology, applying these theories to the study of ancient remains.

The interpretive practice is problematic due to a cognitive and perceptual distance between the researcher and the subject, and between the subject and their own subconscious reactions. Furthermore, this challenge is exacerbated when studying the behavior and interpretations of agents within another culture. Members of different cultures live in "*different sensory worlds*" (Hall 1966: 84), in which perceptions and distinct Weltanschauung result in variable filtering out of sensory input through cultural screens. For the archaeologist, this perceptual distance is amplified. A temporal divide is added to the cultural distances that archaeology has in common with anthropologists. When attempting to interpret the mentalities of ancient peoples, archaeologists use various methodologies adapting them to examinations of prehistoric peoples, however their primary source of data remains material culture. Working without native informants, archaeologists attempt to extract meaning from various types and patterns of materials in order to address questions of social structure, belief, daily habits, and any other aspects of life ways from which generalizations can be developed.

Meaning can be embedded in material culture accidently in the patterns of detritus left behind by behavior, or both accidentally and purposefully in built environments. Ian Hodder (1999) demonstrated that cultural meanings, and the relationships between individuals and their environment influence the distributions and morphologies of material items. Social aspects such as ethnic groups, interaction spheres, and symbolic meanings are reflected in the resultant dispersion of materials (Watson 1995). This indicates that it should be possible to hypothesize such cultural and mental symbolisms from indications in material dispersion patterns. Patterns recognized in built environments and in accidental detritus differ in respect to the degree of intentionality in their structure, and their likelihood of being preserved in the archaeological record. Historically, a great deal of data has been collected regarding ancient Maya cities, due in part to their well preserved monumental structures as opposed to rural detritus that suffers more thoroughly from site formation processes. Nonetheless, both archaeological contexts require methodologies directed towards the development of broad theories and interpretations from the data collected.

Interpretations of ancient cities have borrowed, piecemeal, from various disciplines, as a means to expand their ability to comment upon ancient urbanites. Maya researchers have focused upon symbolic interpretations of architectural forms, and themes of power, religion, and at times resistance. In her interpretations of symbolic messages of Maya cities, for example, Ashmore characterizes buildings and constructions as *"maps of a cultures worldview"* (Ashmore 1991:199) and lauds the renewed archaeological interest at *"identification of such ideational expressions."* (Ashmore 1991:199). Ashmore (1991) has attributed patterns in building layout and cardinal orientation to ideational concepts, characterizing such groupings of structures as symbolic spaces. Ashmore relates the following structural elements of the built environment to Maya ideational concepts that have been interpreted from a variety of sources:

> "(1) emphatic reference to a north-south axis in site organization; (2) formal and functional complementarity or dualism between north and south; (3) the addition of elements on east and west to form a triangle with the north, and frequent suppression of marking the southern position; (4) the presence in many cases of a ball court as transition between north and south; and (5) the frequent use of causeways to emphasize connections

> among the cited elements, thereby underscoring the symbolic unity of the whole layout." (Ashmore.1991: 200)

These structural patterns are seen as analogues to the following ideational concepts, respectively:

> "(1) a multilayered universe, with a sky of many levels in which the royal ancestors lived, and a watery underworld below the natural world, likewise with multiple layers, where supernaturals lived and which served as the setting for the primordial ordeals of mythological Hero Twins; (2) the unification of these layers in time via the cycles of the sun, moon, Venus, and other celestial bodies; (3) vertical connections in space between the natural world and the supernatural domains – for example, via the four bacabs holding up the corners of the sky, mountains mediating between sky and earth, or caves linking the earth with the underworld; and (4) a division of the world in four parts apparently corresponding to cardinal directions plus a central position, each part with its diagnostic color and distinctive life forms."
>
> (Ashmore 1991: 200)

Ashmore tested her theories based upon their predicting capabilities. For instance, Ashmore tested the association between "north", the celestial world and royalty at the Maya archaeological site, Copan. If this association was a true cultural belief, then royal ancestors and ritual activities should be associated with the large Northern structure of Copan (Ashmore and Sabloff. 2003: 232). This test was satisfied, and although far from conclusive, does lend support to the success of Ashmore's hypothesis.

Alternative theories to explain these urban layout patterns also demonstrate predictability success, showing that Ashmore's conclusions remain an interesting focus of debate, but unsubstantiated. The recognition of a relationship between cosmology and built environments in Maya cities is generally accepted, however, identifying correlations remains problematic.

> “The central challenge is not whether political or cosmological symbolism might be expressed in architecture and space, but whether and how one can recognize when such symbolic communication has taken place.”
>
> (Ashmore and Sabloff 2003:233)

All archaeologists do not accept a comprehensible association between built environments and mental constructs. Instead of thereby determining the past to be a closed system, a further reliance upon interdisciplinary approaches is often applied to increase the efficacy of archaeological research. Field investigations conducted by Smyth et al. (1995) at the Maya site of Sayil in the Puuc region of the Yucatan challenges the over reliance of archaeologists upon built structures and tangible materials in order to make interpretations regarding intangible aspects of sociopolitical life. Asserting that architectural forms and features do not always accurately correlate to past function or use, the focus of archaeologists on these structures is chastised. In Maya studies, reliance on excavation of architecture is especially problematic in that “*60-80% of settlement areas have no architecture”* (Smyth et al.1995: 322). Instead, Smyth et al. (1995) focus their examinations on the spaces too often neglected by archaeologists. Soil sampling and surface survey are used to collect data and to complement past architectural excavations. The built environment is not neglected, but placed within an exceptionally thorough context of soils, patterns and artifact assemblages, essentially filling in the voids left by archaeologists. The authors conclude that archaeology, focused primarily on excavation and architectural features, is unsuccessful as it is traditionally practiced. Meaningful insights into settlement patterns are not thoroughly developed or defensible without the broader context of surface surveys and the incorporation of more diverse classes of information.

The extraction of meaning from material culture in ancient societies is characterized in archaeology by a lack of informants. Ethnographic methodologies are accessible where there is a presupposition of cultural continuity to provide some access to an emic perspective. If, however, cultural continuity and cross temporal generalizations cannot provide access to a form of ethnography, it may be that past landscapes and built environments are a closed system that cannot be accessed by contemporary researchers (Clarkson 1999). Alternatively, diversification of the dataset, where possible, may provide access to the intangible lives of ancient groups.

Considering the tenuous hold that the archaeologist has on the cultures they interpret, is it viable to apply such investigations to archaeological cities? The attempt to conduct ethnography through contemporary peoples or via archives, although problematic, can be conducted in a responsible manner if the models being applied are explicit, and limitations of access to native perspectives documented by the researcher. Such daring interpretations may, in fact, be the only way that archaeologists can explore the 'truly interesting' aspects of archaeology. In the words of Erving Gossman *"I assume that a loose speculative approach to a fundamental area of conduct is better than a rigorous blindness to it" (qtd. in Hall. 1966:95).*

2.10 Resources.

The study of access to and allocation of vital resources is especially influenced by anthropological thought. A thorough understanding of culture and its rules and institutions is necessary, as it is within that context that basic needs are procured and satisfied (Scarborough 2003:10). Nonetheless, the divergent approaches of anthropology and archaeology present a very different trajectory of the human condition and response to resource challenges. The long temporal perspective of archaeology emphasizes the tendency for human agents to deplete and destroy natural habitats in pursuit of resources. The anthropological record, on the other hand, with its more limited but precise time scale is capable of demonstrating exceptions to this behavior by examining contemporary and historic cultures that have exhibited sustainable practices and positive responses to ecological crisis (Brumfiel 2003:205). These divergent narratives enrich studies of resource management by offering a more thorough catalogue of the relationship between humans and their natural resources. Water resource management is often cited as a reliable reflection of greater social structure (Scarborough 1993; Wittfogel 1957a). Ancient and contemporary cultures share the universal need for vital resources such as water and nutrition in similar quantities and quality. Further, the laws of physics and geology are presumed to be identical throughout time, rendering the challenges of resource management across time and space comprehensible regardless of differences in culture or time. These aspects of society and their correlating structures are therefore often considered to be very appropriate for cross cultural/temporal investigation (Ortloff 2009:2).

The development of large-scale water collection by any society is, by virtue of its social and resource demands, often correlated with centralized governance (Scarborough, 1993:11; Wittfogel, 1957a). The construction of large monumental structures for centralized water management, and the need for management and maintenance of such structures is indicative of the organization of a large labor force with a governing body to provide oversight and allocate resources (Ortloff 2009; Scarborough 1993). Water management provides a window into greater social structure by indicating the degree of resources and organization available to the community, and the challenges prioritized and indicated by their technological choices (Ortloff, 2009:9). Furthermore, the location of these water structures indicates the likely degree of access that differing groups within a stratified society would have had to the managed water system.

> The concentration of water within the urban core of these (Maya Lowland) Sites is argued to have provided a centralized source of political authority for Classic Maya elites based on controlled water access and to a lesser degree, high performance of water ritual.
>
> (Salazar 2006:275).

This conclusion is problematic. Although rulers may have wished to express, through architecture and ritual, their centralized control, a decentralized resistance may have existed in the daily life of the Maya. Furthermore, preservation bias may hide non-centralized sources of water that provided this resource as a supplement. Current research is suggesting that the water management of Maya cities and communities may have been much more opportunistic, utilizing small depression in the karstic landscape. Many regions are demonstrating a much more decentralized control of water resources, and potentially, political structure. Determining direct relationships between archaeological remains and the social phenomenon responsible for their forms and patterns is a subjective process capable of creating competing narratives rather than definitive correlations.

Chapter 3

3.1 Water.

Water is intricately tied to the fate of human populations, big and small, rural or urbanized, ancient and contemporary. Water must be managed to meet the requirements of agriculture, civic needs, and sustainability. Farmers must have sufficient quality and quantity of water to provide foodstuffs to cities and urban dwellers must be supplied safe water for drinking and daily needs, as well as any demands dictated by their specialization and activities. Furthermore, the avoidance of, and safe removal of contaminated or excess water is necessary to secure the population against disease and erosion. Successful water management systems are sustainable within their social and ecological contexts.

The minimal water requirement for all people averages at approximately 20 – 50 liters per day, including drinking, bathing, cooking and other water dependent needs (Lucero et al. 2011:480). This estimate does not include the water needed to grow the crops for each person. In antiquity, and throughout most of the world today, satisfying this permeates all aspects of daily life (Fishman 2011:45). This pervasiveness means that diverse issues such as politics, health, technology and spiritualism can all be addressed from the perspective of their iterative role in cultural responses to water requirements.

The organization required to build and manage large water structures may only be possible in populations whose governance is strong and centralized, capable of mobilizing large numbers of people within necessary time frames (Dunning et al. 1999; Scarborough, 1998). Furthermore, centralized elite power structures are more capable of global perspectives and have the power to strategize and organize structures and building plans on a larger, more integrated scale (Ortloff 2009:7). In accretive development, however, an iterative process between social needs and ecological changes informs each new progression resulting in a cohesive, responsive, adaptable, and seemingly organic development of water management.

Successful water management regimes can improve quality of life and health with the effect of altering demographics by increasing life spans, decreasing infant mortality and attracting large populations into dense communities. During the twentieth century water revolution in the United State, chlorination and filtration alone accounted for a thirteen percent reduction in total mortality, and a fifty percent decrease in child mortality (Fishman 2011:47). This increase in the quality and duration of life promoted the expansion of American cities (Fishman 2011:49).

Technological development and science can be spurred by the development of water management regimes. Although it begins as a trial and error process, experimentation in the engineering principles that underlay the management and allocation of bodies of water may have led to the development of laws of nature and the scientific process (Ortloff 2009:2).

The collection of water, in much of the world, is a part of the daily routine, attaining influence over the mundane movements that define the motivations of daily life. This weaving of water into all aspects of life often includes spiritual elements. In the Quran, man is created from water, and in the Old Testament, water is used to destroy all of man except for the lucky passengers on Noah's ark (Fishman 2011:127).

Due to its ubiquitous nature, water issues can be examined from many perspectives, and have influence over every aspect of the human experience. In antiquity, the predominance of water over all rhythms of daily life was acutely experienced. The detachment of human experience from water that can be experienced in some parts of the world today is an illusion that has held sway only since the twentieth century. The ability to provide water that is *"abundant, safe, and cheap*" (Fishman 2011:31), has created an illusion of water security that has never attained reality in many parts of the world, and that is quickly fading in even the most modern cities. As water management regimes prove unsustainable, it will be increasingly necessary for the relationship between communities and water to be managed in a holistic and viable manner.

3.2 Drought and Resilience.

Drought comes in two forms, manageable and meteorological. The former can be mitigated through behavioral, technological or social changes such as soil management, water management or land use practices. The latter refers to the absolute point at which water scarcity takes the resource below the threshold of necessity such that social mechanisms cannot manage the system (Rockstrom 2003). Social responses that make droughts manageable are "resilience parachutes" (Rockstrom 2003:871). Droughts do not necessarily cause famines, except in the absence of resilience parachutes or other socio-economic factors (Rockstrom 2003:871). The capacity of an ecosystem, or society to absorb change and shock is the measure of its resiliency (Rockstrom 2003:870). Currently, a varied range of options such as social networking, food banks, food relief, and international organizations provide resilience parachutes to communities.

Maya communities endured seasonal as well as protracted droughts. The landscape in antiquity may have exacerbated water management challenges. In antiquity the landscape was not comprised of the lush jungle found in much of the Maya region today. Deforestation, paving, and agriculture would have altered and further challenged ecological resilience in the region (NASA 2012).

3.3 The Hydraulic State.

Much of the foundation of water management theory refers to the processes posited by Karl Wittfogel (1957a; 1957b) in his highly deterministic approach regarding the hydraulic theory of State development. Wittfogel (1957a;1957b) identifies the need for large water management regimes in water scarce regions as a prime mover of social change. Although his treatise, Oriental Despotism (Wittfogel 1957a) has been heavily critiqued and overtly dismissed in the social sciences, his theories implicitly inform a variety of studies regarding State development, and water management (Scarborough, 1993;2003).

Wittfogel defines societies based on agricultural techniques and environments that necessitate massive waterworks as 'hydraulic societies', run by hydraulic governments (Wittfogel 1957a). This nomenclature implies that the very governance that develops is primarily defined by their relationship to hydraulic technologies. Although his primary case study was focused in China, Wittfogel identified hydraulic societies in Egypt, Mesopotamia, India, Persia, Central and Southeast Asia, as well as the Andes, the southwestern United States, New Mexico, and finally, in Mesoamerica (Wittfogel 1957b). Wittfogel based his theories on studies of arid regions, or environments that rendered water management difficult, necessary, and labor intensive. This theory of State development attributes the occurrence of aristocracies and despotic governments to the need to manage irrigation and major water management infrastructure in water challenged zones (Midlarsky 1995; Wittfogel 1957b). That the difficulties posed by water scarcity influence communities is apparent. The nomadic movements of populations in arid countries is highly correlated with the presence of access to water holes, and early settlements throughout water scarce regions tend to be located near natural water features (Scarborough 2003:9). Further, settlement patterns in areas characterized by distribution systems as opposed to point resource systems demonstrate predictable differences in landscape use based on the needs of these different management systems (Scarborough 1993). Although it is apparent that water management options, and choices, influence society in myriad ways, the ability for water scarcity issues to influence the socio-political directions of populations in a deterministic fashion is less clear.

Wittfogel strongly indicates that water limiting factors directly lead to *"A hydraulic revolution – initiating the rise of a hydraulic society. Such a development is strongly indicated by considerations of geography and climate;"* (Wittfogel 1957b: 346). By this logic, examinations of geography and climate should have diagnostic possibilities for determining likely governance structures developing within identified natural phenomena. Further, the identification of ancient landscapes should be diagnostic of whether or not a 'hydraulic society' manifested.

Of particular interest to Mayanists is Wittfogels' assertion that the early rise of a ruling class began first with the development of large ceremonial centers, prior to urbanism and towns (Wittfogel 1957b). Writing in 1957, this appeared to fit well with prevailing theories of Maya history. At the time, popular thought in archaeology was that the vast monumental temples of the Maya were palaces and ceremonial centers for a ruling priestly elite (Fash 1994). Urbanization was considered unlikely in this challenging environment with a characteristically dispersed population (Scarborough, 1993). As more current research has shown, major Maya archaeological sites were often densely populated by a complex urban society (Chase et al. 1990), not complying with Wittfogel's characterization of the development of the early hydraulic state.

In the hydraulic society the need to organize a labor force for the purpose of developing large hydraulic structures leads to the need for a leader, and eventual submission to total authority (Wittfogel 1957b). The resulting governing principles are then applied to other social institutions, such as communications and the military, giving the ruler total control over all social institutions (Wittfogel 1957b). The development and maintenance of water management structures thereby has a predictable, deterministic, influence upon the development, organization, and structure of institutional aspects of society (Eisenstadt 1958). The hydraulic society also leads to the acceptance of the State's need to commandeer large portions of their subjects' labor and goods in order to build or maintain structures (Wittfogel 1957b). The final result is *"a state stronger than society."* (Wittfogel 1960:29). In the complex hydraulic society, all other social institutions, be they market forces or religious institutions, are fully under control of the despotic ruler, and material wealth cannot be accumulated for the purpose of political power which is determined only by proximity to the ruler (Eisenstadt, 1958). In many ways, this developmental trajectory can appear contradictory. Although the development of the hydraulic society is directed by the geological and geographical realities of the environment, the society that develops is one in which the relation of the individual to their environment and the products it can produce are secondary to the resulting political superstructure (Shabad 1959).

A form of geographic materialism underlying the hydraulic theory of State development has maintained its relevance in current water management studies by recognizing the importance of environmental factors in social change. It is the deterministic assertion that a specific relationship to water management will result in the abandonment of free will and the submission to an all-powerful governance that comprises the main corpus of his theory and remains undemonstrated (Shabad 1959). The impact of the development of complex water management is highly complex, with success often relying upon the ability of stakeholders to cooperate with one another. The need to manage water in challenging environments is as likely to develop cooperation between different groups, as it is to foster a dominating relationship and despotic governance over populations (Scarborough 2003).

Wittfogel's final characterization of hydraulic societies is highly insufficient when applied to the Mayan world. *"countries of the hydraulic world were underdeveloped not only in terms of technology, but also, and even more crucially, in terms of the theory and practice of societal freedom"* (Wittfogel 1957b:358). The technologies developed in the Mayan world to address water management issues were intricate and complex, often demonstrating a multi tasking approach with deep understanding of the natural world and high efficiency. Furthermore, it is likely that small-scale water management structures, and seasonal changes were taken advantage of by rural Maya who would exercise greater societal freedom when water was plentiful, and depend upon larger managed cities during dryer periods (Scarborough 1993; Johnston 2004).

The strength of Wittfogel's theory of the hydraulic society is in its acknowledgment of the physical realities of water management requirements. The physical environment strongly determines the required and available technologies that can be applied to water management challenges and opportunities (Scarborough 1993). The failure is in the expansion of this theory to the argument that the type of society to develop is not simply predictable, but consistently actualized (Shabad 1959). The fundamental processes of water, and its importance to human civilization is immutable regardless of the society. How water functions within society, however, is highly variable. Environmental factors can be used to identify predictable challenges that will face populations in relation to their water needs, however, it cannot be used to determine which choices those societies will make.

That environmental fortunes impact the fates of societies is clear. Access to harbors, control over land and sea routes, monopoly over spice and trade routes, and conflicts over shared water sources have influenced degrees of national power and conflict (Midlarsky 1995:225). Environmental factors such as water security and varying degrees of vulnerability to warfare determined by the ratio of sea and land borders is posited by Midlarsky (1995) as predictive of the chances of a society developing democratic governance. In general, however, it is not clear that geographical and climatic factors monopolize such influences. Social epiphenomenon such as conceptions and realities of security may be equally responsible for resulting cultural choices. Social and religious factors that result in a lack of food, water, freedom from war, and invasion could result in similar organizational responses as those environmental and geographical factors identified by Wittfogel (1957a,b) and Midlarsky (1995). Any uni-causal approach towards the development of State systems disregards other important social variables that may inform the development and maintenance of political institutions. Pertinent variables could include demographics, opportunities for violence both inter-polity and domestic, economic opportunities, borders, and trade (Midlarsky 1995). Midlarsky argues for the prominence of geographic and environmental factors as testable and effective symbols for social observation, as compared to social indicators such as military size, which may be influenced by myriad factors such as bureaucratic changes (Midlarsky, 1995). Approaches relying upon environmental, geographic, and climatic data sets are testable and reliable variables for analysis.

In more modern treatment of these themes, the transference of knowledge from water management to society at large has been echoed in modern discussions of water management theory. The development of large water management structures necessitates the use of a form of natural science, which encourages the development of a scientific approach to social and environmental issues (Ortloff 2009). The development of large hydraulic structures is indicative of centralized governance, in that such oversight is integral to adopting and enacting such complex planning and engineering feats (Ortloff 2009). These impacts of water management do not, however, necessarily result in a despotic or a static regime.

3.4 Past Water Management Research

The archaeological record shows a diverse range of technologies and techniques that the ancient Maya developed in response to water challenges. The choice of water management approaches was determined by need, availability, and environmental realities. Some of the technologies and natural features harnessed to secure reliable water sources in the Maya Lowlands include canals, wells, reservoirs, and dams (Healy 1983:147), Many of these technologies served more than one function. For instance, a Classic period dam excavated in the Cayo district of Belize may have served to collect and store water, to protect the source spring from silt infiltration, and as a habitat for freshwater invertebrates (Healy 1983:153).

The ancient site of Tikal (Guatemala) (Figure 1) was a highly populated city that has undergone extensive excavations (Scarborough 1991). Water management was more than a pre occupation, at Tikal the city layout, and demographic shifts were defined by water. The very name, Tikal translates as *"place of the water hole"* (Scarborough 1992: 40). By the Late Classic Period (Table 1) Tikal had one of the most sophisticated water management infrastructures in the New World (Scarborough 1993). In order to maintain a population of approximately 90,000 people (Scarborough 1998:39), Tikal was landscaped as a large water management feature. Aside from a variety of large elevated reservoir structures, the plastered surfaces of the city appear to have been laid out and slanted to passively direct rainfall into channels and storage basins (Scarborough 1998:40). Furthermore, landscaped features were developed to double task urban needs, as demonstrated by the use of *sacbeob* (causeways and roads) for both transportation and dykes (Scarborough 1991).

Figure 1. Map of the Maya Region, showing sites mentioned in the text. The research area, Minanha, is not shown. Minanha is located between Caracol and Naranjo (Henderson 1997:35).

This level of water works likely altered settlement patterns by attracting otherwise rural groups to the city, especially during dry seasons. The centralizing force of these water structures may have been tempered during the wet season when opportunistic use of natural depressions in rural areas could decrease rural reliance upon civic supplies. In this case, the natural and small stature of opportunistic water sources would decrease their chances of preservation and recognition in the archaeological record (Johnston, 2004; Scarborough 1998).

Water management research at the site of Caracol (Belize) (Figure 1) reveals a collection of reservoirs throughout the city landscape. Formally constructed and natural reservoirs have been mapped located away from the city center near terrace systems, or within residential groups, as well as a natural aguada located within the city center. Except for the city center reservoir, the water management system at Caracol is dominated by small reservoirs that could be maintained by household groups (Crandall 2006). This system likely supported a minimum population of 122,700 people (Chase et al. 1990).

This large city appears to have a less centralized approach to water management than that observed at Tikal. As residential reservoirs dried up, it is possible that centralization temporarily increased as rural groups focused their needs upon the large central reservoir. During plentiful rain, however, the majority of the population was capable of maintaining their own water supplies.

The site of Monte Alban (Mexico) developed an integrated system of diversionary conservation structures to mitigate their water supply challenges. These included drains, diversion walls, collection/settling tanks and impoundments (Obrien et al. 1980). Collection and settling tanks served two purposes, they provided water to nearby structures and removed silt from the water. The use of filtering techniques is also demonstrated at the site of La Milpa (Belize) where a large aguada was used to filter agricultural pollutants, protecting the residential supply of a densely populated area (Scarborough, 1993).

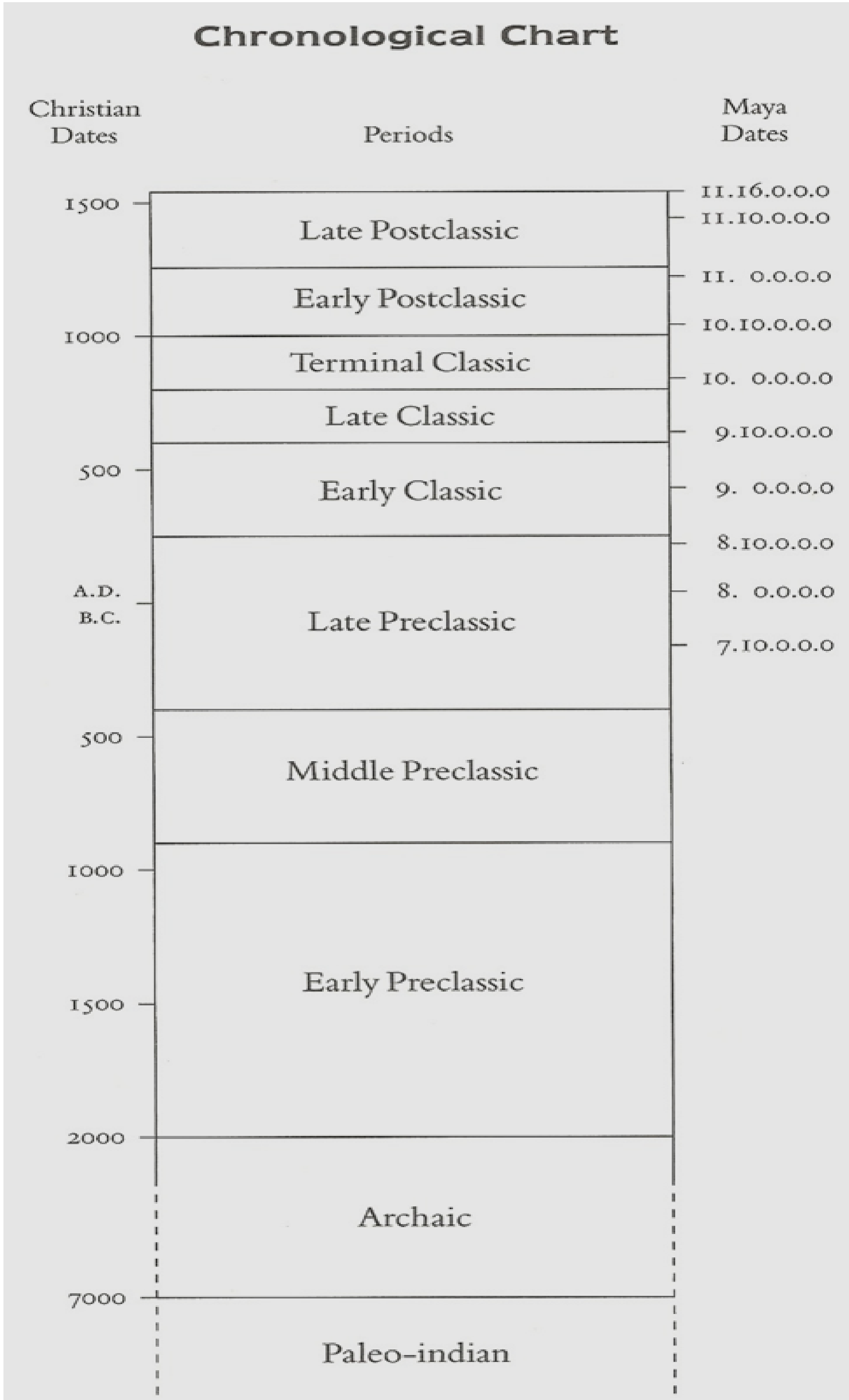

Table 1. Maya time periods (Henderson 1997:xvii)

Archaeological studies in the Maya area have often focused upon large water management features, disregarding the potential for small features. It is likely that small features contributed greatly to Maya communities as they did in many cultures. In Peru, the Inka used small modifications to natural features to decrease their reliance upon surface storage during the dry season. These modifications sequester ground water within its natural watershed, thereby avoiding problems of sedimentation, freezing and evaporation (Fairley 2003). It is likely that similar methods of utilizing natural features on a small and opportunistic scale was common in the Maya area as well. Johnston (2004) addressed small features by examining the role that wells may have played in rural Maya areas. His research indicates that a sample bias favoring large centralized water features may result in an overstatement of elite control over access to water during season droughts. Johnston argues that in the hinterlands supporting populations were able to expose fault springs by digging wells, thereby undermining the coercive and centralizing force of large elite controlled water management installations. Furthermore, Johnston demonstrates that many opportunistic and small water sources found in karstic landscapes leave little or no surface trace for archaeological survey and identification. This likely results in a sampling bias that has serious implications for interpreting the political force of water management features (Johnston, 2004).

The Late Classic site of Copan (Honduras) (Turner and Johnson, 1979) also contains many smaller features that contribute to a broad water management system. At Copan the challenge was not scarcity, but flooding and erosion caused by high precipitation levels, rivers that are prone to overflow, and many paved urban surfaces (Salazar, 2006). Salazar identifies a large selection of small architectural features that serve to drain and channel water, as well as protect civic investments such as architecture as well as domestic homes and patios. This demonstrates that large water management installations are simply one of many aspects of water management in Maya cities. A thorough understanding of water management in the Maya world can only be obtained by locating and describing smaller features in both rural and urban settings.

Chapter 4.

4.1 The Ancient Maya

The ancient Maya are one of many cultural groups that occupied Central America in antiquity. Various groups inhabited the Central American region prior to, contemporaneous with, and following the Maya fluorescence. Occupation of the region by non- Maya and pre-Maya groups is evidenced by obsidian and chert stone fluted points as early as the end of the last glaciation (Henderson 1997; McKillop,2006). The ancient Maya populated the broad geographic region, Mesoamerica (Figure 2). As an identifiable culture group, the Maya inhabited this area from approximately 1800 B.C.E (Mckillop 2006) and their descendants still occupy much of the same lands and beyond. This region is defined as much by cultural traits shared by a various groups in Mesoamerica as it is by its geographical limits, which at times are undefined, with increased ambiguity as one researches further back in time (Henderson 1997). The picture of ancient Maya development and, in particular, demographics, fluctuates not just over time periods, but also in degrees of certainty. The following synopsis will present general trends as they are depicted in archaeological literature, however it must be acknowledged that much more complex narratives continue to be presented and to inform the archaeological database.

Mesoamerican regions were initially occupied by mobile hunter-gatherer groups during the Paleo-Indian period (Gruhn and Bryan, 1977; McKillop, 2006) (Table 1). These Paleo-Indian groups were likely of Asiatic origin, having arrived in the Americas by following Mega fauna across the Beringia land bridge, which formed several times during the late Pleistocene (McKillop 2006). Continuity in the form of an ancestral relationship between Mesoamerica's earliest inhabitants and the ancient Maya is not known (McKillop 2006).

The Maya eventually expanded to occupy those regions currently identified as Guatemala, Belize, El Salvador, the Yucatan Peninsula, and parts of Mexico and the western areas of Honduras (McKillop,2006) (Figure 3). Their many communities developed urban centers well known for impressive monuments, complex calendric and mathematic systems, hieroglyphic writing and large elite dynasties.

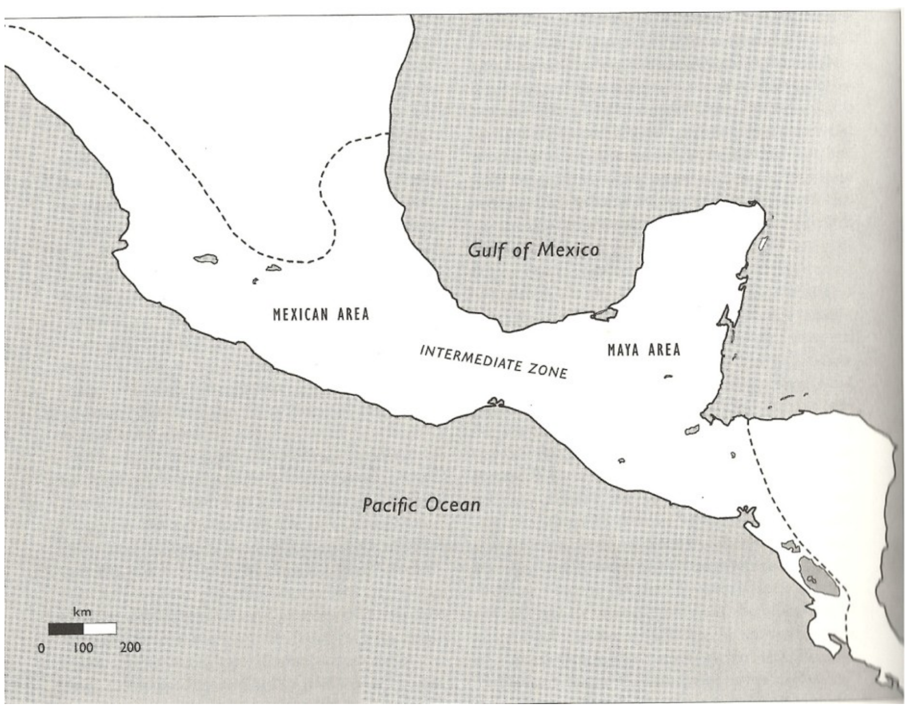

Figure 2. Mesoamerica (Henderson 1997:24)

Figure 3. Map of the Maya Regions showing contemporary borders (Wells and Mihok 2009:314)

The Paleo-Indian period ended with the extinction of Pleistocene mega fauna McKillop, 2006). Mesoamerican groups then entered the Archaic period (Lohse, Jon C. 2010) (Table 1), characterized by adaptation to a diet increasingly focused upon smaller animals and the collection of wild plants (McKillop, 2006). This period culminated in the gradual change from small game hunting and wild plant collection to the domestication of plants and animals. The Archaic period, thereby, appears to have laid the groundwork for the development of permanent crop centered settlements as opposed to reliance upon nomadic behaviors and mobility (Mckillop, 2006). There is little evidence of this time of transition in the Maya area, although evidence has been found in other parts of the Mesoamerican region with a great deal of information coming from sites outside of the Maya region in Mexico (McKillop, 2006). The Archaic period ends with the first evidence of ceramic pottery. The development of a ceramic culture is associated with the adoption of permanent villages as a normal mode of living (McKillop 2006).

The first evidence of distinctly Maya groups date to 1800 B.C.E and 1000 B.C.E along the Guatemalan Coast and Southern Maya lowlands respectively (McKillop 2006). Complex social communities that developed prior to and contemporaneously with early Maya society certainly influenced their initial development and tendencies. This effect is evidenced in Mayan cultural traits that likely began with earlier groups and were passed through communication to the Early Preclassic Maya (Table 1) (Healy, 1997; Healy and Awe, 1995;1996), and through resource trade that occurred between early Maya communities and neighboring Mesoamerican groups.

The Olmec and Izapa cultures are two Mesoamerican groups who interacted with the Maya throughout their early development. The Olmec occupied the Gulf Coast of Mexico and are popularly known for building massive altars and colossal head statues of basalt. Many traditions that eventually spread throughout Mesoamerica are evidenced in the Olmec culture as early as 800 B.C.E. These include a reliance upon maize crop, monumental architecture, and a symbolic artistic expression that continued in much of Mesoamerica (Webster, n.d.). Continuity exists between the Maya and the Olmec languages. The Olmec likely spoke Mixe-Zoque, which is an ancestral Mayan language (McKillop 2006). Furthermore, the Maya appear to have adopted their calendric and number systems from the Olmec (McKillop 2006). The Izapans, another Mesoamerican group, were located on the Pacific coast (McKillop 2006). This culture group temporally developed mid-way between the Olmec and Maya communities, with its peak being during the Maya Late Preclassic (Table 1). Izapan artifacts show artistic similarities to later Maya artwork in the Lowlands, including depictions of gods that later developed and came to epitomize Mayan artistic and spiritual life (McKillop 2006).

Throughout the Middle Preclassic period evidence shows spreading Maya occupation as well as developments and declines of other non-Maya groups that influenced and interacted with the Maya throughout Mesoamerica (McKillop 2006). During the Middle Preclassic period, possibly ca. 700 B.C.E, Maya groups became full players within the Mesoamerican region, creating their own monumental architecture and artistic traditions (Webster, n.d.). Curiously, Early Preclassic developments, such as a sedentary lifestyle, ceramics, and other accouterments of permanent social living occur first on the Pacific Coast, and seem to develop later into the Middle Preclassic in the Maya lowlands, although it is the Maya lowlands which eventually demonstrates the greatest expansion and expression of Classic period Maya urban civilization and its most notable achievements (McKillop 2006).

Evidence of occupation of the Maya Lowlands (Figure 3) is found for the Middle Preclassic period. These early communities were likely small sedentary, egalitarian groups, adept at pottery making and agriculture. These populations traded with neighboring groups for useful and exotic materials (McKillop 2006). The Maya region during the Middle Preclassic was diverse, with several sites demonstrating differing levels of social change and complexity. In particular, evidence of monumental architecture at isolated sites indicates that social stratification may have occurred earlier in some regions, while egalitarian village lifestyles endured longer in other regions (McKillop 2006). During the Late Preclassic, increased social stratification and complexity eventually became common throughout the Maya Lowlands (McKillop 2006).

Although the Late Preclassic is often interpreted as merely a preamble to great Maya achievement, much of the Classic Maya tradition was established at this time, and some of their greatest achievements date to as early as the Late Preclassic. For instance, during the Middle and Late Preclassic, the large centers of El Mirador (Figure 1) and Nakbe undertook construction projects that rival all monumental architectural achievement in Mesoamerica during ancient times (Fash, 1994). Furthermore, craft specialization and occupational diversification are firmly established as cultural norms during the Late Preclassic (Fash 1994). Many Classic period (Table 1) tendencies began during the Late Preclassic, including artistic traditions, writing, and possibly the development of a hereditary noble class and dynastic rule (Webster,n.d.). Research has shown that this time period has much in common with the later Classic era. It is, however, the Classic period sites that much of contemporary culture is most familiar with, and that often serve to define Maya achievement.

The Classic Maya period is a time of expansion and development as well as the beginnings of the eventual decline in the Maya Lowlands that occurred between A.D. 300-900 (Table 1). This period is officially recognized and defined by the use of hieroglyphic inscriptions and Maya long count calendric dates carved onto stelae (carved monuments) (McKillop 2006). These particular monuments are considered diagnostic of this time period of growth as they are considered indicative of the dynastic rule that both created and informed the content carved onto these monuments (McKillop 2006). Other elements that characterize this phase in Maya history include polychrome ceramics, elaborate monumental architecture, political centralization and decentralization, dynastic kingship, an increased use of art to depict historical rulers and their achievements, and the building of stone ballgame courts as a central feature of Mayan urban architecture (McKillop 2006). Finally, it is throughout the Classic period that the Maya reached the height of their population in relation to both absolute numbers and density (McKillop 2006), peaking during the seventh and eighth centuries (Culbert and Rice, 1990; Henderson, 1997). Population estimates of individual cities ranges widely (McKillop, 2006), and with many cities still unexamined and even unidentified, broad population estimates are all the more controversial.

The Classic period expansion first took shape in the Southern Maya lowlands, as evidenced by extensive and rapid construction programs in public space (Henderson 1997). The use of stelae began with large city-states but spread throughout Lowland Maya sites by the end of the early Classic period (Table 1). The Classic Maya era is characterized by a vibrant urbanism often incorporating large populations, top down urban planning, and civic architecture that is distinctive from rural settlements in both size and form (Chase et al. 1990). During this time large powerful cities such as Tikal, Calakmul and Caracol (Figure 1) in the Southern Lowlands dominated the political sphere and maintained a heavy influence of Maya cultural developments (Webster, n.d.).

Increasingly throughout this period, monuments became associated with hieroglyphic inscriptions detailing propaganda, biographical information, and announcements from the dynastic rulers of their cities (Henderson 1997). These elites continued during the Late Classic period to become increasingly distanced economically and in relation to lifestyle, from the greater rural and civic populations within their cities and hinterlands. Their power and demands upon support populations increased. Supporting populations also changed demographically with increasing urbanization and specialization (Henderson, 1997). Craft specialization and organization of the labor force reached high complexity during this time including the development of corporate groups, reminiscent of guilds, with a marked difference in organization between the labor of the urban craftsman and that of the rural farmer (Chase et al. 1990). The majority of the Maya continued to live a farming lifestyle. This rural lifestyle was also affected by large city centers using their influence to extract increasing tributes, and the need to develop increasingly intensive agricultural techniques in order to support the needs of growing urban populations (Henderson, 1997). As cities increased their power and influence, vying with one another for land and prestige, large regional power struggles resulted in a tapestry of changing allegiances and rivalries (Henderson, 1997). Regardless of such shifting social atmospheres, increased metropolitanism resulted in increased homogenization of much of the Maya world-view and belief systems. These cultural traditions seem to have become much more standardized within the Maya region as compared to the greater Mesoamerican cultural sphere, at least at the social level of the aristocrats (Henderson, 1997). Although the process of social change throughout the Classic period is complex and regionally diverse, populations increases during this time were likely unmanageable and unsustainable by the ecological and technological norms of the time by the closing of the Classic period (Fash 1994).

The Northern Lowlands of the Maya region must be considered a distinct region. The populations of this region had much in common with other Maya groups, however, they often expressed their shared history in unique ways. Fundamental Maya attributes such as the calendar and writing systems, and the use of stelae monuments reflect Maya identities and traditions. Furthermore, trade connections are continually evidenced through elite goods derived from southern sites. However, northern sites maintain distinctive styles of art and architecture, as well as the abandonment of pottery traditions found in the southern regions (Henderson 1997).

In the Highland region (Figure 3), settlement and trade patterns were disrupted between A.D. 410 and 535 by the eruption of Ilopango volcano in El Salvador (Dull et al. 2001), resulting in population declines and outright abandonment of some cities. Even those cities that withstood the eruption show a marked decrease in in population and large building projects (Henderson 1997). Trade and cultural relationships between the Highland economic center, Kaminaljuyu (Figure 1) and both Maya and non-Maya Mexican groups are evidenced beginning in the fifth century through the presence of exotic good various regions of Mesoamerica, and architectural elements and methods that appear to mimic styles popular in the non-Maya city of Teotihuacan (Henderson, 1997), located in the Highlands of Mexico (McKillop 2007). Non-Maya influences appear to have co existed with Maya traditions (Henderson,1997). The influence of Teotihuacan styles is clearly restricted within the city center, not in the surrounding lands (Henderson 1997). This indicates that this inter regional relationship was a civic choice of the governing elite or controlling class of Kaminaljuyu, while the average rural inhabitant or regional citizen identified more strongly with their Maya neighbors to the north. The relationship between Kaminaljuyu and Teotihuacan seems to have been reciprocated, with pockets under Maya influence identifiable within Teotihuacan (Henderson 1997). The mutual influence began to fade during the late sixth century, with local Maya styles regaining popularity at Kaminaljuyu, and throughout the Highland region, during the seventh century (Henderson 1997). Many Highland communities continued throughout the Classic Period to support an aristocratic society and maintained ties both within and without the thriving Maya cities to their north despite great changes wrought early in this time period by the eruption of Ilopango. They did not maintain the cultural tradition of stelae complex to reinforce the reputations of their leaders. Also abandoned in the Classic period were the traditions of the Long Count calendar system, and hieroglyphic writing (Henderson 1997). Although many of the traditions currently associated with Mayan-ness originally developed within the Maya Highland communities during the Preclassic period, the Classic period did not result in growth in this area, as it did in the Lowland cities. This upstart region never gained the political, architectural, or economic clout found in the greater Maya region to the North (Henderson 1997).

The Terminal Classic period (Table 1) was a time of massive transition especially at the elite level of Maya society (Demarest et al. 2004, Webster 2002). Social, economic and political transformation occurred throughout the Maya region, expressed in very different local ways (Iannone 2005:26). The Southern Lowlands, for instance, suffered a massive decline of its major cities, with few exceptions. The ninth-century cultural collapse is defined by the process in which elite activities were halted and cities and regions were abandoned (Andrews et al. 2003; Webster 2002). Once considered an abrupt pan-Maya abandonment, this collapse is currently considered a more complex and staggered process that is most keenly observed in the Maya Lowland region. It is often observed that the Northern Lowlands, alternatively, continued to grow in both size and complexity. The Northern Lowlands were not immune to the impacts of the fate of their southern neighbors or the influence of external groups, and much of their culture and trade networks were altered during this time of transition. However, the collapse the Maya are famous for, characterized by a dramatic decline of elite functions, and cessation of building events was distinctive of the Southern Maya Lowlands (Demarest et al. 2004). Responses to the social climate were complex, especially in the Northern Lowlands where many sites continued to maintain building projects, albeit with decreased populations (Andrews et al. 2003).

This so called cultural collapse of the Southern Lowlands was primarily an urban phenomenon, recognized by the cessation of the use of Stelae monuments and a marked decrease in major public building programs, beginning around A.D. 800 (Demarest et al. 2004). Individual cities demonstrated differing degrees of resilience throughout the Terminal Classic. By A.D. 909 the last known long count date was recorded and the decline of administrative and elite functions was essentially complete within the region (Henderson, 1997). Particularly intriguing is that three of the Southern Lowland sites that demonstrated marked resilience during this social collapse, Lamanai, Santa Rita, and Wild Cane Cay, are located along waterways, and endured well into the Postclassic period (McKillop, 2006). Even in decimated regions, rural communities and survivors continued to maintain populations, and some remnants of their former cultural traditions in the region, both common and elite, but the general trend was a reduction of populations at all social levels, and the abandonment of elite and aristocratic functions (Demarest et al. 2004). In both the Southern and Northern Lowlands there are various cities and sites that continued to maintain occupations, if at a smaller level. These areas tend to be located in regions that provide favorable environments in regards to water sources, agriculture or commercial opportunities (Andrews et al. 2003). Eventually, during the Terminal Classic period a delayed collapse did overcome the Northern Lowland cities following a time of dramatic social and political change (Andrews et al. 2003). Although the Spanish arrived to find complex communities, large collections of ruins were also extant in the northern region demonstrating the processes of collapse that were underway prior to their arrival (Andrews et al. 2003). Following a presumed dark period in the Maya region, some areas started to demonstrate indications of resurgence. These possible new developments were cross cut and halted by the arrival of the Spanish, who began a new era in the Maya region (Andrews et al. 2003).

Initially, Terminal Classic transformation was minimal in the Maya Highlands, excepting an increased influence from communities along the Gulf Coast (Henderson, 1997). The degree to which this fraternization was actually a byproduct of Terminal Classic transitions is unclear. The Maya Highland communities had demonstrated in previous eras, openness to external influences and this is likely simply a continuance of this tendency. Highland resilience appears to have been taxed by the end of the tenth century, during which time elite and administrative levels of Highland society collapsed, and newly established cities demonstrate a preoccupation with defensibility and fortification (Henderson 1997).

The Post Classic society that emerged following the Terminal Classic transitions was clearly a cultural outgrowth of earlier Maya traditions, albeit on an aesthetically diminished scale. Populations continued to exist in all regions and many of their norms were maintained, with decreased elaboration. Notably, elite and administrative functions were greatly declined in regional influence and grandeur, likely alleviating a heavy economic burden that historically had been levied upon supporting populations (Henderson, 1997). Northern Lowland cities, such as Mayapan and Chichen Itza (Figure 1) managed to maintain regional power well into the Post Classic period, with the elite collapse being much more advanced in the Southern Lowlands (Henderson, 1997). In fact, there is evidence of some initial population increases along the Yucatan coasts and in the northern regions of the Maya Lowlands, perhaps due to a diaspora of Lowland Maya populations (McKillop 2006), an ability for northern populations to capitalize on the misfortunes of their southern neighbors, or a combination of these forces. Interpretations of the fate of northern cities are varied. Although there is evidence of post collapse fluorescence in the northern region, these gains appear to have eventually caught up with the northern cities, which succumbed to the same processes of collapse that affected the southern cities, in a delayed fashion (Andrews et al. 2003).

Moving into the historical time period, the Spanish conquest began in the sixteenth century. The descendants of the Classic Maya occupying Mexico's Yucatan Peninsula at the time were divided politically into at least 16 warring states that generally shared a homogenous language and similar cultural traits (Gabbert 2001). Despite the challenges faced by the Cultural Collapse, the Spanish did encounter a complex and dynamic culture that, especially in the Northern Lowlands, maintained and elaborated upon Classic Maya traditions. In the Northern Lowlands, elite social structures such as nobility and Kingship were still norms, and continued to extract taxes from the surrounding farmers. Urban centers still maintained much of their Maya architecture such as ball courts and temples, social stratification was still extant and priests still maintained books and codices (Webster, n.d.). Other traits had been lost or altogether altered from the Classic era. Alternatively, some may not have been such strong traditions in the northern regions, which were distinct and more heavily influenced by Mexican groups than their Southern counterparts (Webster, n.d.). Of particular note, demographically, the populations maintained in the sixteenth century were smaller than the Classic era, which would certainly have influenced other complex social institutions, and the use of the long count calendar was not maintained in the Northern Lowlands at the time of the Spanish arrival (Webster, n.d.), or at the very least, was not noted by the Spanish.

Under Spanish rule, these political groups were identified as administrative units, or republics. These ascribed republics became organizing factors for both social and religious activity (Gabbert 2001). Ascribed identities legalized by Spanish rule included Spaniards, Indians, and Castas (mixed ancestry). These were defined legal entities that carried with them access and restrictions based on associated rights and obligations regarding all aspects of social, legal and economic relations. Of particular importance identity dependent rights extended to influence over land tenure, and in some cities determined segregation of living spaces (Gabbert 2001). Within this system, relics of prior Indigenous forms of governance are recognized in the maintenance of class hierarchies within the Indian legal identity.

The social and political history of the Maya is a complex narrative, much of which has been pieced together through a variety of sources including archaeology, epigraphy, geography, and anthropology. A general history has been developed detailing many of the social, political, and ecological changes that took place within the Maya region (Sharer 2006; Webster 2002) . Periods of development, fluorescence and collapse have occurred throughout Maya history and pre-history many times and in diverse regions. Due to the diversity of their environmental challenges and responses to them, the ancient Maya are an excellent cultural group to study relations between communities, urbanism, social phenomenon, and environmental constraints.

4.2 Regional Geology

Those lands inhabited by the ancient Maya (herein the Maya region) are geologically complex and diverse. Several prominent features of the regional geology directly impacted the forms of urbanization and water management that developed in this region in antiquity. In particular, carbonate rocks prone to dissolution resulted in a karstic landscape that funneled water underground, and permitted access to water primarily at distinct locations. Karstic features, and regional geomorphological differences of the varied landscapes inhabited by the Maya, resulted in distinct settlement patterns defined by degrees of resilience to drought and climate change. This section will examine significant aspects of the geology and climate of this region. First, a general overview of the regions geology and climate will provide a context for the water management challenges faced by the ancient Maya. Second, the defining feature of the region, karst, will be examined as it related to water management in the region. This section will explain the antecedent geology and consequent diversity of features that contributed to the landscape inhabited by the ancient Maya, impacting their opportunities and management choices in relation to water management.

The region under study is located in Central America. The tectonic plates that comprise Central America include the Cocos, the North American, and the Caribbean plates. The North American plate contains the Maya block (also referred to as the Yucatan block) and the Caribbean plate contains Chortis block (Figure 4). These two blocks are separated by the Motagua – Polochic fault system (Draper et al. 1994). The present position of the Maya and Chortis blocks was achieved by the end of the Cretaceous period (Graham 2003). Earthquake activity has continued throughout ancient

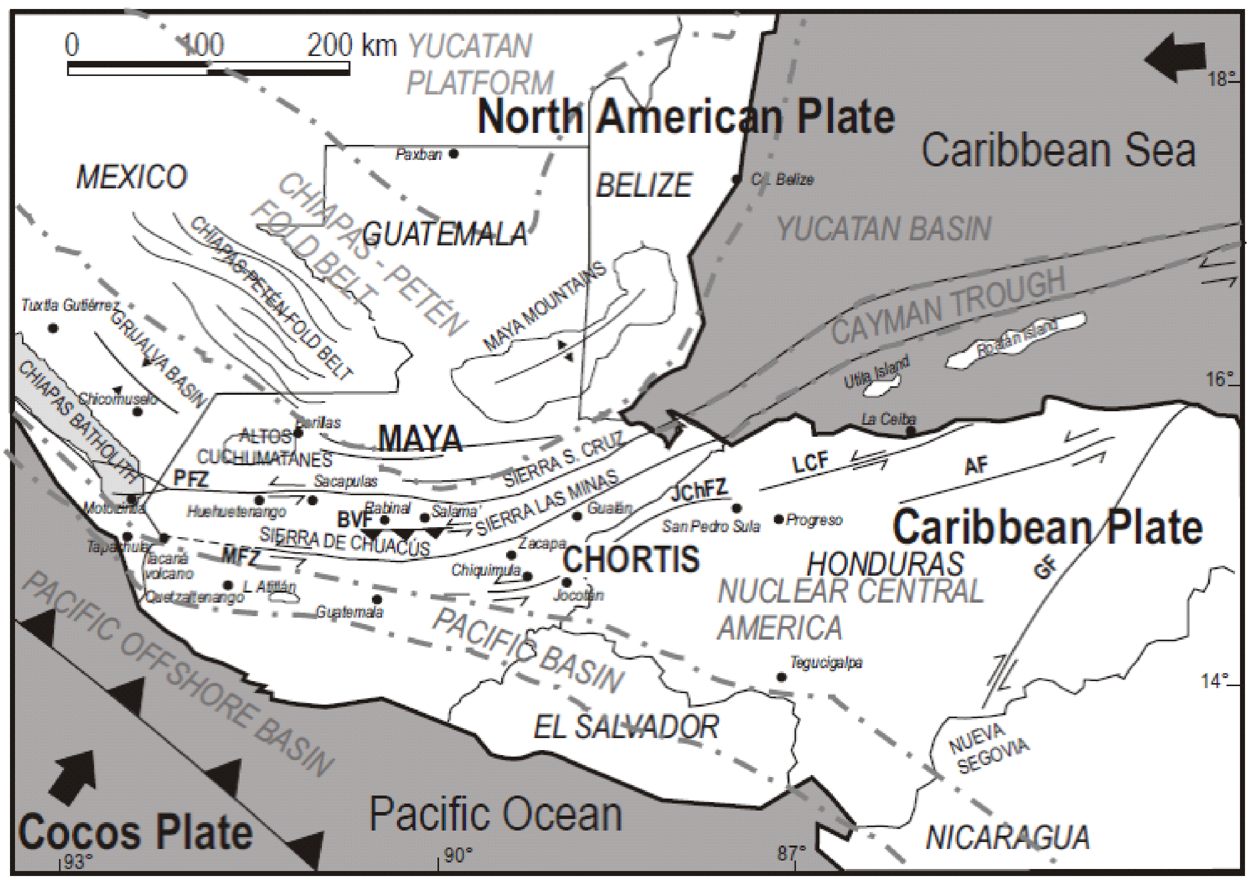

Figure 4. Map showing tectonic features mentioned in the text (Ortega-Gutierrez et al. 2006:68)

Maya and contemporary times along the active Motagua – Polochic fault system, which formed during the suturing of the Maya and Chortis blocks (Graham 2003).

The area under study is located within a region known as the Maya Lowlands, located upon the Maya block, which is divided by researchers into northern and southern parts (Figure 5). The Maya block contains basement outcrops in isolated regions that may have created point source locations for differing lithic resources. The presence of water and lithic resources in distinct locations likely encouraged inhabitants to settle in specialized and centralized locations.

The Maya block is underlain by a pre-Carboniferous basement composed of schists, marbles, quartzites and granitoids (Draper et al. 1994). Resting unconformably upon the basement of the Maya block are volcanic rocks and Upper Carboniferous through Permian sedimentary rocks (Draper et al. 1994). This sequence is uncomformably overlain by a Jurassic 'red bed' sequence, and Cretaceous dolomitic limestones. Lying atop these carbonate platform rocks is a layer of Upper Cretaceous to Tertiary olistostromes and immature sandstones (Draper et al. 1994). The basement rocks form outcrops in the southern regions of the Maya block, comprising the Maya Mountains (The Mayas) (Figure 4). The Mayas formed by uplift following the middle Cretaceous. Relative uplift continued well into the Mid-Tertiary (Miller 1996). Currently, elevation of the Mayas extends over 900m above sea level (Marfia et al. 2004).

The Maya Mountains are underlain by Triassic igneous intrusives and non-soluble Paleozoic metasediments (Miller 1996). Outcrops that are readily visible in this feature include Palaeozoic granites, Santa Rosa group sedimentary rocks, and Maya series metamorphics. The Maya block also contains the Yucatan Peninsula. This low-lying shelf is composed primarily of Tertiary and Quaternary carbonates (Mazzullo 2006) as well as some basement presence of metamorphic schists and gneisses (Burkart 1994). Carbonates dominate the peninsula, comprising greater than 125,000 km^2 of the feature. The northern and western margins of the Maya block have been passive since the Mesozoic, however, the southern region underwent strike-slip faulting throughout the Miocene and Holocene due to suturing between the Maya and Chortis blocks (Rosenfield 2003).

The Chortis block underlies the current boundaries of Nicaragua, El Salvador, Honduras, and southern parts of Guatemala (Marshall, 2007). The basement is composed of pre-Mesozoic metamorphic rocks. Mesozoic plutons outcrop in the northern and central regions of the block. Although carbonates are present, they do not characterize the region as strongly as the Maya block to the north (Marshall, 2007). The same Jurassic ‘red bed’ sequence found on the Maya block also overlays the Chortis block basement. The next layer is composed of Lower Cretaceous limestones, which is overlain by a Cretaceous ‘red bed’ sequence. Finally, the Chortis block contains Mesozoic and Cenozoic volcanic deposits, separated by a major uncomformity.

The Maya Lowlands are divided into the Northern and Southern Maya Lowlands (Figure 5) based upon geological, environmental, and cultural differences. The research area is located within the Southern Maya Lowlands. The Southern Maya Lowlands include the current boundaries of southern Mexico, Belize, and northern Guatemala, including the Yucatan Peninsula (Marshall, 2007; Webster et al. 2007).

Approximately 15,000 km^2 of Cretaceous and Tertiary carbonates were deposited throughout Guatemala's Peten region, extending into Belize (Keuny and Day 2002)(Figure 4). The Tertiary also shows evidence of deposition of shales, siltstone and limestone (Miller, 1996). Cretaceous and Tertiary carbonates dominate in the northern regions of Belize, (Figure 6) overlain discontinuously by Pliocene sands and gravels, as well as quaternary alluvium (Metcalfe et al. 2009). The southern region of Belize is dominated by the Maya mountains (Miller 1996).

Research has been conducted in the North Vaca Plateau of Belize, east of the Guatemalan and Belizean border. This region is well drained (Polk et al. 2007) and characterized by high relief, variable elevations, and a fluvio karst landscape (Colas et al. 2008). The North Vaca Plateau is primarily composed of the Campur Limestone formation that extends into Belize from central Guatemala (Figure 6) (Miller 1996; Colas et al. 2008). This feature is composed of the Cretaceous carbonates deposited as reef associated limestones, with samples of dolomite, shale, siltsone, and limestone breccias (Reeder et al. 1996).

This environment is heavily dependent upon the southeasterly Maya Mountains, whose clays and sands were transported north via fluvial action. Although contributing sediment, the Mayas do not provide a water source. Waters draining from the Maya mountains are diverted by the Macal River prior to reaching the North Vaca Plateau. This leaves the region completely dependent upon meteoric rainfall as a water source (Reeder et al. 1996).

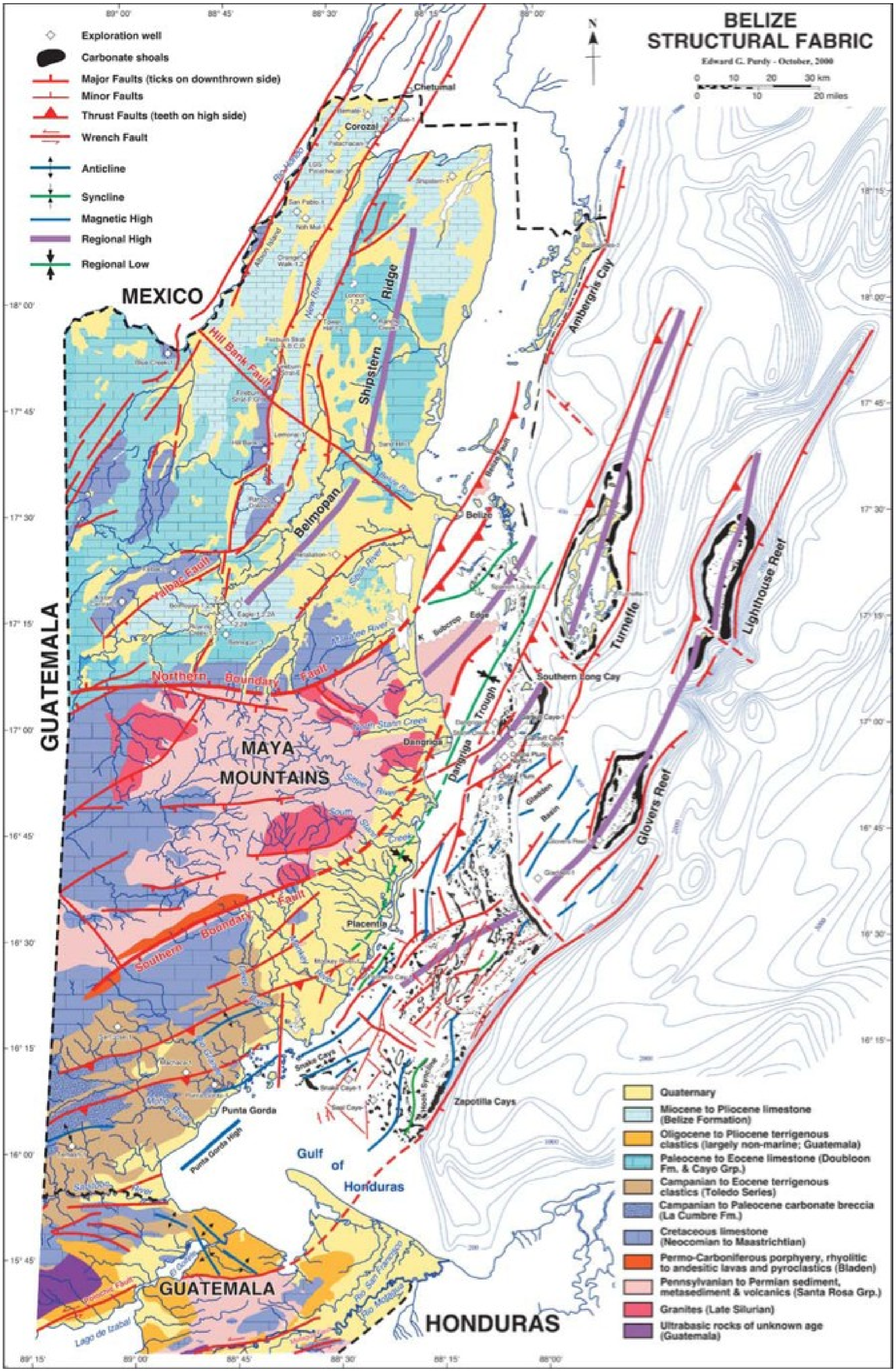

Figure 5. Map of Belize showing geologic structure (Purdy et al. 2003:554).

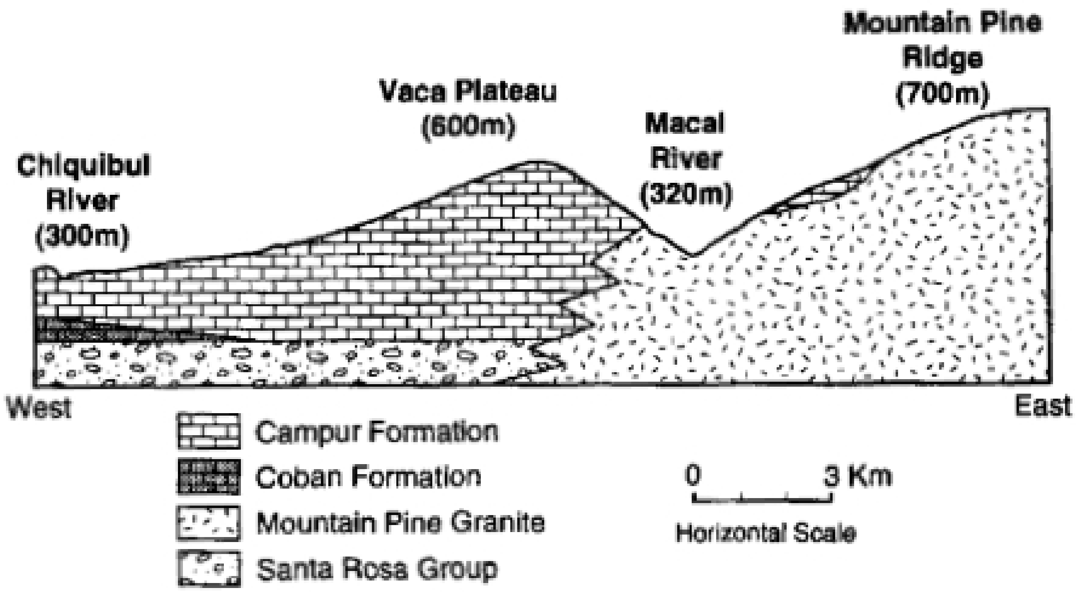

Figure 6. General lithologic section showing the Vaca Plateau and other regions mentioned in the text. (Reeder et al. 1996: 123)

4.3 Meteorology.

The Yucatan Peninsula is characterized by a humid tropical climate (Rice, 1993) with a seasonal desert regime (Peterson and Haug, 2005). Precipitation patterns in the region vary in both time and space. The precipitation and climactic systems of the Yucatan Peninsula are impacted primarily by the atmospheric moisture provided by the Caribbean Sea, the actions of the northeast trades, and the subtropical calms (Rice, 1993), and finally the Intertropical convergence zone (ITCZ). The ITCZ is the process in which easterly tropical trade winds converge and migrate. This migration is responsible for heavy summer rains, and their contrasting winter droughts (Peterson and Haug 2005). Local factors also include coastline orientation and topography (Hodell et al. 2000). The general trend is that of an increase in average rainfall in the more southerly regions of the peninsula. On average, the dry season endures longer as one moves north along the Peninsula (Rice, 1993). Despite these climactic trends, the Peninsula is characterized by variety and variability with large ranges of normalcy. For example, the northwest Maya Lowlands has rainfall estimates that range from as low as 500 mm/annum to 4000 mm/annum (Dunning and Beach 2000; Peterson and Haug 2005). Of this precipitation, up to ninety percent may fall during heavy rains between June and September (Peterson and Haug 2005).

Variability of climate is not limited to annual trends of oscillating wet/dry cycles and regionally predictable differences. There is also a great deal of variance between years. The range of wet/dry cycles is great, resulting in rains during the seasonal dry seasons or protracted drought for one or a number of years. Fluctuations in expected trends of flood and drought had implications on activities such as forest fires, locusts and other pests, and cold spells associated with drought (Gunn et al. 2002). Cold spells, although extant, did not provide sufficient temperature extremes to exterminate the vast variety of pests that thrive in semi-tropical environs (Lucero et al. 2010).

The research area in Belize generally reflects the trends found on the Yucatan Peninsula with some minor specifications. The precipitation patterns range from 1500mm/annum to 4000 mm/annum in the north and south regions, respectively (Webster et al. 2007). In the Vaca Plateau, in particular, average rainfall is approximately 1500 mm/annum (Primrose, 2001). The temperature can range between approximately 10 – 35 degrees Celsius (Webster et al. 2007). Some climate fluctuations and changes are highly localized. Many variables, such as topography, location, and size of study area can impact local climate regimes. Further, some regions are more susceptible to certain climate factors. External events such as El Ninos and solar emissions, for example, may impact regions differently, and localized factors can further differentiate climate regimes and responses (Gunn et al. 2002). Many of the long term droughts, including those discussed above, would have impacted the study area directly, or by affecting trade routes, social partners, and enemies of the citizens of Minanha.

4.4 Karst and Water

Karst is formed by the dissolution of rock calcite ($CaCO_3$) by carbonic acid (H_2CO_3) produced by carbon dioxide present in precipitation (Jennings 1985). This process produces a variety of formations including channels, caves, faults, fractures and a variety of dissolution features that increase rock porosity (Bogli 1980) (Figure 7). These formations create a distinct hydrological regime in which water is funneled vertically underground, creating a paucity of accessible surface water (Johnston 2004).

Characteristics of any karst environment include a dominant presence of soluble rock, an alkaline and calcium rich regime, meager soils, high humidity, dark underground spaces and caverns into which water may be funneled, and stable temperatures (Daoxian 2001). Rocks that are prone to dissolution include evaporates and carbonate rocks. Quartzite is also prone to karstification in the humid tropics. The rate and degree of dissolution is influenced by climate, precipitation and evapotranspiration rates (Bogli 1980). The term karst refers not to the process of its creation, but to the *"sum of bedrock dissolutional phenomena"* (Ford 2006:2). Karstification is therefore a descriptive definition of the features created through specific forms of rock dissolution in total rather than the process that forms the landscape.

The primary impact which karst features have upon human communities is decreasing their ability to reach underground water sources because it is either located too deep within the underground system to be accessed, or is overlain by a layer of rock and/or sediment, and a paucity of surface waters.

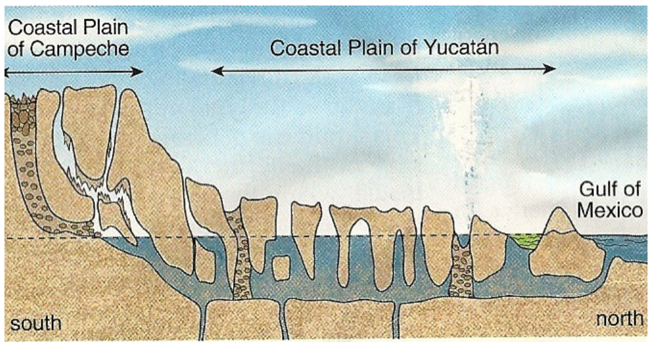

Figure 7. Cross section illustration of the Yucatan Peninsula (Peterson and Haug 2005:328)

The sum total of karst processes creates a topography characterized by one or more of a variety of surficial features that are used to define the karst landscape. There are many such features including, but not limited to; 1) karrens 2) dolines 3)cockpits 4) *poljes* 5) *chultuns* 6) sinkholes 7) *bajos* and 8) aguadas.

Karrens are small features formed by rock dissolution, generally measuring between a few millimeters and a few meters in size. The size and morphology of karren is influenced by the degree of soil cover or bareness with respect to the limestone layer, and the amount of time the precipitation consequently spends on the surface. Generally, the patterns of combined karren features impact hydrology by creating surface drainage patterns. Surficial water, although extant, is likely to absorb underground at short distances in a karren environment (Bogli 1980).

The most common karstic feature is the doline. Doline can form various morphologies including funnel, bowl, flat, dish and trough shaped dolines (Bogli 1980). Since dolines form in every type of karst landscape, they are often considered a diagnostic feature of karst. The size of doline varies between several meters and one thousand meters. Their form is consistent, defined as closed karst cavities with a diameter greater than their depth, and with underground drainage (Bogli 1980). Solution dolines form in carbonates under a layer of soil, via the dissolution of limestone. Subsidence dolines form through the gradual downward movement of a mass. Finally a rapid collapse due to a near-surface cavity causes the formation of collapse dolines (Bogli 1980). Dolines that reach into a high water surface, with vertical walls are known as *cenotes*. Cenote features are particularly frequent on the Yucatan Peninsula (Bogli 1980). By reaching down to the deep karst water level, cenotes may provide an access point to waters that are otherwise sequestered underground. Cenotes may have greatly influenced settlement patterns, and certainly had spiritual significance to the ancient Maya, as is attested to by the importance of the great Cenote as a point of sacrifice at the ancient Maya site of Chichen Itza.

Cockpits are a karst feature that are similar to dolines, with star shaped contours as opposed to the rounded doline outline. Cockpits form primarily in the humid tropics (Bogli 1980). As with the doline, the cockpit can open up the landscape, exposing underground sources of water that, depending on their depth, may be exploited by nearby human communities.

Poljes are hollow features with underground drainage, a relatively flat floor that may be impermeable and are enclosed along all sides (Bogli 1980). The presence of water in poljes may be permanent, semi permanent, or almost non-existent. When they do contain water, however, it is often provided via surface water washing in from the sides, as well as by water pushing up from pressured underground karst tubes (Bogli 1980).

Chultuns are excavated chambers extending into the bedrock. These occur both in the Northern and Southern Lowland Maya regions. The porous limestone of the south likely precludes their role in water storage, and they may have been used for other functions. In the Northern Lowlands, they are established as water holding features (Harrison 1993). Although chultuns can be modified and excavated throughout the karstic regions, socially they are multi-purpose, and can only be considered water management features where the water holding capacity of the limestone is sufficient to render their use efficient.

The term sinkhole refers simply to any location where the underground cavern has a collapsed roof. These features often increase accessibility to the underground aquifer. Sinkholes are common in the northern end of the Yucatan peninsula. These features may have increased dry spell and drought resilience in the northern regions of the Yucatan peninsula by decreasing the northern settlements dependence upon rainfall as a primary water source (Peterson and Haug 2005).

Bajos are karst depressions. In antiquity bajos may have contained perennial wetlands that are only minimally evidenced in the contemporary landscape (Dunning et al. 2002). Bajos are associated with many large urban Mayan centers as well as many of their earliest settlements (Dunning et al. 2002), demonstrating their potential influence over settlement patterns. Anthropogenic changes caused by Maya agriculture and land use may have decreased the productivity of these wetlands. As bajo productivity decreased, Maya groups would likely have had to relocate their settlements, or develop increasingly complex and efficient methods of water collection and storage (Dunning et al. 2002).

Topographic depressions that fill with water, like ponds, are known as aguadas (Wahl et al. 2007). Aguadas are well known sources of water in the Maya region, and often provided potable water during the dry seasons. The efficiency of the water holding capacity of an aguada was often altered through modifications such as plaster seals that decreased limestone porosity and water loss, and by building artificial terrace walls around the exterior of aguadas, where viable (G. Iannone personal communication, 2007).

As indicated by the actions of these features, the karst landscape is characterized by the vertical funneling of meteoric precipitation beneath the surface to varying depths. This created the challenge of water being sequestered at, often, unattainable depths. The karst features also, however, served to open up areas of the landscape, exposing the water, with the potential opportunity to access and store it at seasonal, episodic, or year round intervals. All of the common karst features permitted water access as a point resource. A point resource is more easily monitored by a controlling elite or a single community than that of a long surface river, which may cross borders shared by multiple groups. In Central America in general, and the Yucatan peninsula in particular, the extensive karstification of the landscape meant that this lack of surface water, and characteristic experience of water sources as centralized point resources was characteristic of the Lowland Maya experience.

Chapter 5

5.1 Minanha

Minanha is an ancient Maya city located on the tallest hill in the North Vaca Plateau of Belize (Figure 8) (Iannone 2005:27). The environment at Minanha is variable, including flat and sloping areas of dry and scrub vegetation (Primrose 2001). The influence of karst in the region is rendered visible by the lack of surface rivers. Due to the karstic landscape, and a deep water table resting as far as 40 meters below the surface in antiquity (Primrose, 2001), the management of meteoric precipitation would have been necessary to sustain communities through dry seasons and droughts. The importance of water is felt in contemporary times, as it was in ancient. The very name of the site, in fact, translates to mean "place without water" (Iannone personal communication: 2002).

In antiquity, the location of Minanha landed it equidistant between two large warring states, Caracol and Naranjo (Iannone 2005). Settlement at Minanha began during the late Middle Preclassic (Table 1) (Iannone 2005, St. Hilaire 2011). Despite this precarious location between hostile polities Minanha flourished during the 8th Century, installing a royal court at that time (Iannone 2005) growing into a mid sized Maya city. Dramatic political changes in the 9th century resulted in the burial of the royal court structures. This vandalism is associated with social upheaval. Occupation continued through parts of the Early Postclassic (Table 1), which was the last period that the site was inhabited (St. Hilaire 2011).

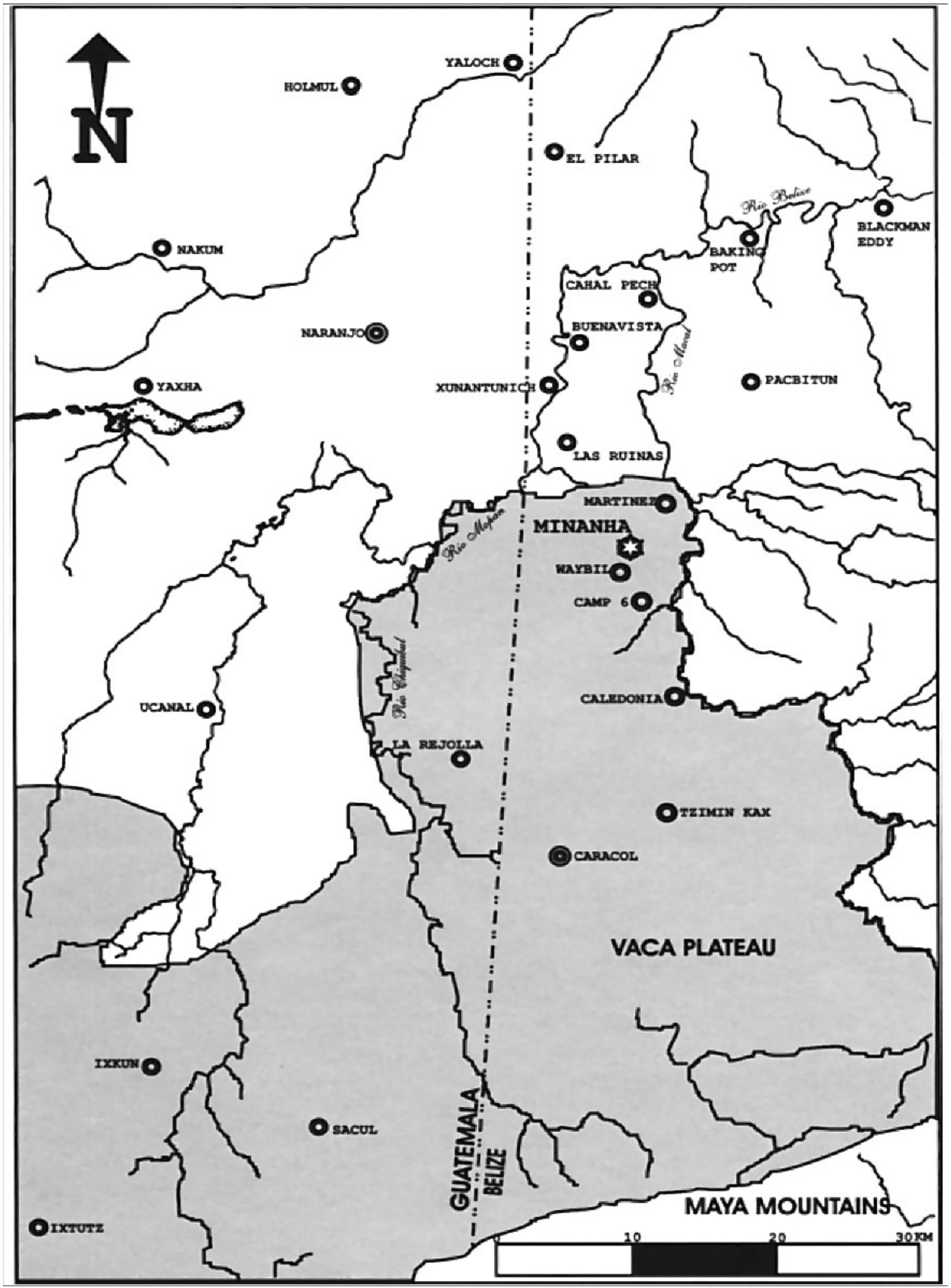

Figure 8. Map of the Maya Lowlands showing Minanha and associated sites (Iannone 2007:9)

5.2 The Mayo Aguada

The Mayo aguada is located approximately one kilometer northeast of the Minanha city center (see figure 9). The aguada is a bowl shaped depression surrounded by hills that may have served as a natural structure to collect and store water during dry seasons (Primrose 2001). Modifications by the surrounding inhabitants, such as the construction of terraces and walls along the exterior, may have served to enhance the storage capacity of the feature, as well as minimize the influx of sediments from the surrounding slopes (G. Iannone personal communication, 2007).

To the north of the aguada, are several structures, and what appears to be one long access corridor formed by natural topography and terraces. Further excavations will be required to confirm these observations that are so far based on surface examinations.

The association between the aguada and the small settlement may indicate that the nearest population was involved in the management or protection of the waters of the aguada. Due to the proximity of the aguada and small settlement to the primary site population, it is unlikely that this settlement existed at the location without the approval of the larger site. The association between the small collection of buildings and the aguada is supported by the presence of the level corridor that may have served as a restricted pathway through the settlement to the aguada.

The proximity of the aguada to the main city core led the initial investigator (Primrose, 2001) to hypothesize that the Mayo aguada served as a central precinct reservoir (Primrose, 2001), as defined by Scarborough (1993). This definition carries further implications. Central Precinct Reservoirs are considered by Scarborough (1993) to indicate centralized political systems. As discussed by A. Chase (2008 SAA conference), the proximity is close enough to discuss the Mayo aguada as a potential central precinct reservoir, however, it is further away than would generally be expected. Chase suggested that a central precinct reservoir would be expected within the site core, and the remains of one may still exist beneath the excavated level of the royal compound (A. Chase personal communication, 2008). Whether or not the Mayo aguada is located closely enough to the site core to satisfy the function of a central precinct reservoir, and therefore indicate political and social centralization, is subject to interpretation. Landscape analysis can contribute to hypothesis generation, however, in the absence of further examinations the hypotheses remain untestable and numerous.

5.3 Past Research At the Mayo Aguada

The water management system of Minanha was initially studied by Ryan Primrose in 2001. The research goals of 2001 were primarily concerned with establishing and describing the nature of the site's domestic water supply system in antiquity. This research included a variety of investigative techniques including soil coring, comparison of vegetation to surrounding areas, examination of topography, and the search for a path to a major water feature. These investigations were able to determine that Minanha was primarily supplied, in antiquity, with water during the dry season, by a large aguada (the Mayo Aguada), located ca. one kilometer northeast of the site core (Figure 6).

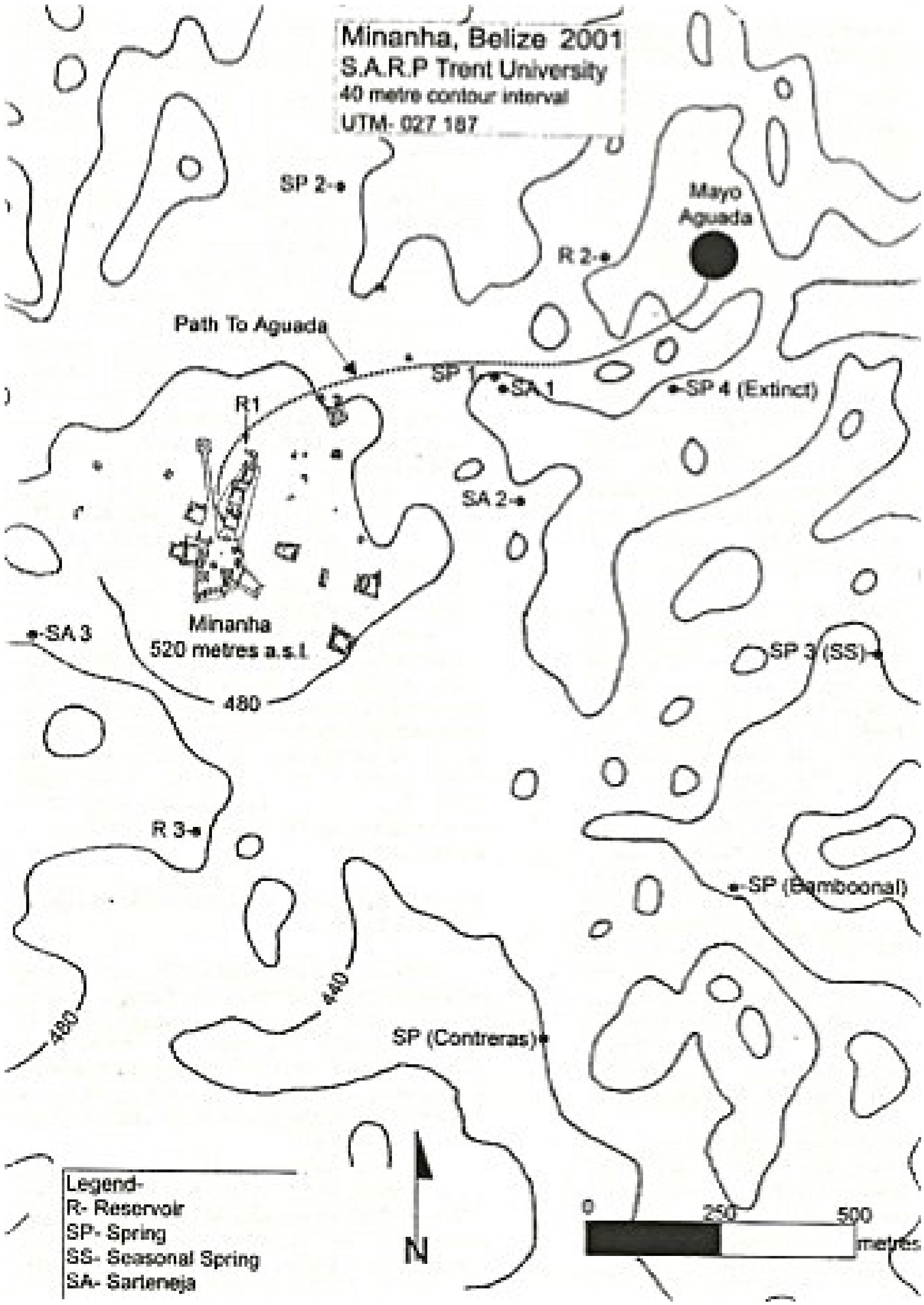

Figure 9. Map showing location of Minanha, the Mayo aguada and other water management features (Primrose 2001:103)

Three principal areas were examined in 2001, these include the rugged terrain to the north of the site, the peripheral settlements south and west of the site, and the primary water management system northeast and east of the site (Primrose, 2001.)

No water features were located in the northwestern area during the 2001 investigations, however the presence of *waymil*, or rugged low – bush vegetation, caused by contemporary forest regrowth may have obscured water management features that may be uncovered with future examinations. Interestingly, a *sacbe*, or ancient Maya causeway, extends North from the epicenter into this area. Sacbeob are often associated with water management features, or as entrances to site centers.

The South and Southwest regions contained agricultural terraces, indicating intensive agricultural practices. Three peripheral settlements were located, one unnamed, the Contreras community, and Bamboonal. The unnamed group is located West of the site Core. There were some areas conducive to water management features identified, however actual features were only located within the group proper. One small reservoir (reservoir 3) was located within the group. This reservoir may have provided primary water storage for a small residential group. The Contreras community was located approximately a kilometer from the Minanha epicenter. This community appears to comprise an independent water management system. Several mound groups were located associated with three springs that follow the slope of the hill, beginning on the lower flank. The uppermost spring, currenty producing the cleanest water, appears to be a natural feature, demonstrating no human modification, although it was likely used in antiquity. This spring demonstrates a low recharge rate, as demonstrated by Primrose and Martinez (Primrose 2001).

Through these investigations, Primrose identified many water features of various sizes and levels of efficiency in the landscape, including springs, sarteneja, and the large Mayo aguada. Conclusions drawn from this research include, differentiated water sources between the periphery and the site core, labour intensive and centralized water management focused within the site core, and the identification of the Mayo aguada as a viable candidate for the principal source of water for the center (Primrose, 2002).
The conclusions reached during the 2001 expeditions indicated that the Minanha water management system fits Scarborough's (1993) centralized water management model. Further, Primrose maintains that this system does not contain the common features of a Late Classic Maya water management system, specifically a central precinct reservoir feature, unless the Mayo aguada is interpreted as fulfilling this role (Primrose 2001). Alternatively, a centrally located reservoir may rest within a more centralized area, however, having been filled in at a later date in history, may yet be excavated (A. Chase personal communication, 2008). In this instance, the Mayo aguada may still have served as a primary source of water, however, its role as such would have changed throughout time.

Chapter 6

6.1 OP114

Excavations at the relic Maya aguada were conducted in 2007 for the purpose of collecting soils samples to undergo geomorphological analysis. OP114 consisted of a 2m x 2m x ca. 4m excavation unit, located centrally within the Mayo aguada, in an area that appeared to retain significant moisture in the region even in the dry season. The unit was oriented North – South, and was indicated by the presence of spider lilies along, and outside, the eastern flank of the unit.

Excavations continued to an approximate depth of 390cm BUD (Below Unit Datum). The primary site datum measured 42cm. above land surface. Soil samples were taken from the western wall of OP114. Level changes were assigned when visible changes in the soils were observed during excavation. Where there was a section where the soil appeared uniform in color and texture, levels were designated based on arbitrary measures. As the excavations got deeper 10 cm levels were adopted, as moisture in the soils may mask changes in composition and texture (Figure 10).

Soil samples were collected from each level except for level 1. This was not subjected to laboratory analysis because of its composition and recent deposition. Level 1 was primarily composed of recent litter mat, roots and rootlets, and only approximately10% soil. Field analysis revealed that level 1 soils resembled level 2 soils.

Samples 2 through 12 were pre-processed to remove organic content that would otherwise obscure the sediments and skew the results of particle size analysis (Friedman et al. 1992). The procedure for sediment treatment is presented in Appendix 1. During pre-processing the sediments were ignited in order to burn away the organic compounds. The loss on ignition was calculated, providing a percentage of organics in each sample. Hydrogen peroxide treatment was applied to the sediments to remove any remnant organic material. The sediments were subsequently oven dried. Particle size analysis was then conducted on the sediments. All samples were examined for salient attributes regarding composition, depositional and sediment transport processes.

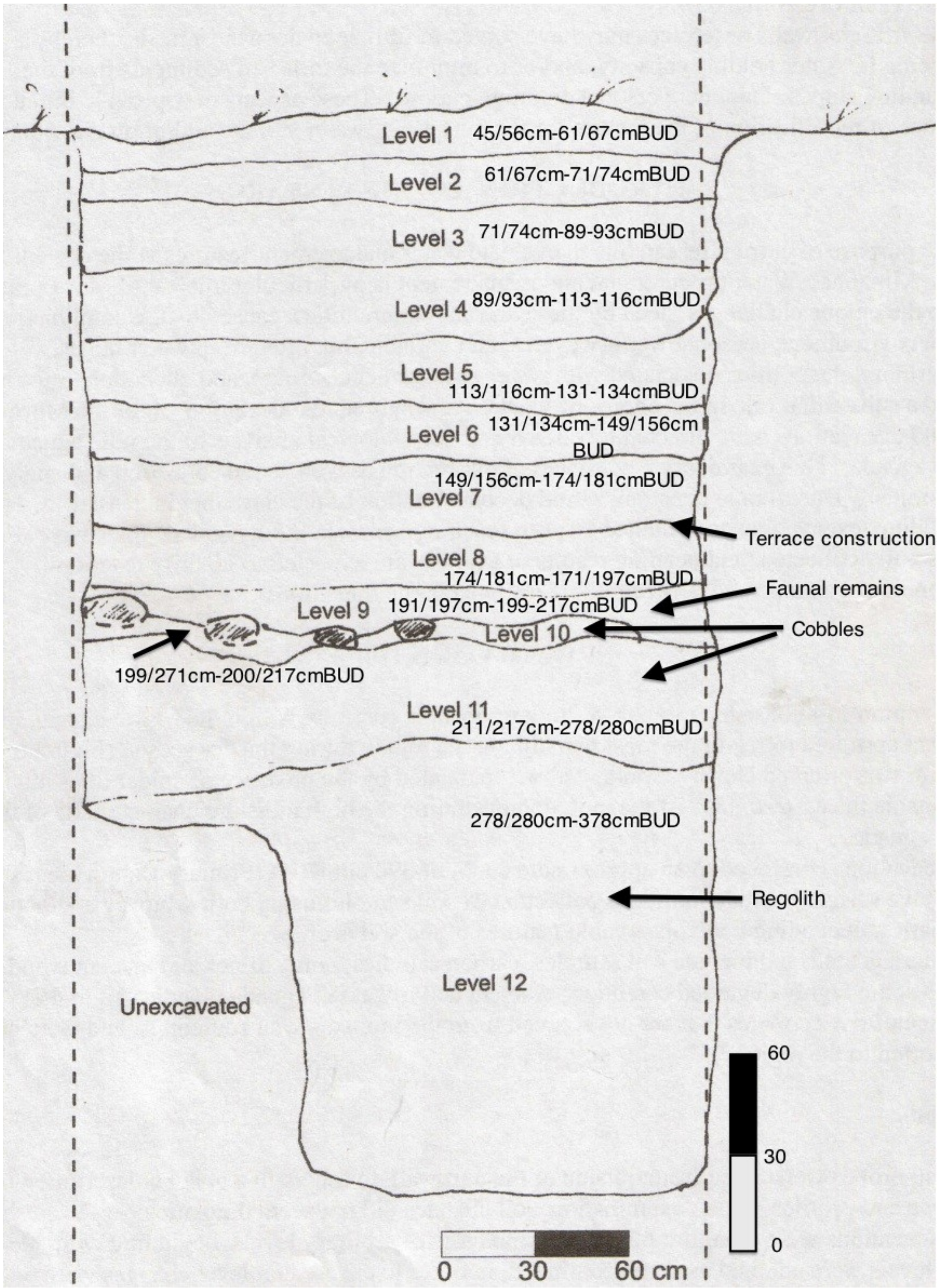

Figure 10. Operation 114, facing West

6.2 Review of Relevant Attributes of Sediments

Colour

The colour of sediment is the product of its parent material, moisture content, chemical attributes, formation history and depositional environment (Schiffer 1983). Weathering processes determine sediment color in many ways including biochemical alteration, leaching, precipitation, oxidation and reduction (Schiffer 1983). Where there is the formation of hematite iron oxides, the resulting pigmentation is the primary source of color for the sediments (Young 1976).

The identification of sediment colors is achieved by the use of the Munsell soil color chart (Cleland 1921), which provides standardized comparison chips of hue, value, and chroma with corresponding values and letters indicating each attribute of the color. Letters designate colors; R stands for red, Y for yellow, G for green, B for blue and P for purple. Colors can combine to form intermediate colors such as RY for red yellow. Numbers to the left of letters refer to the value, or degree of lightness of the color(s). Low numbers are dark and high numbers are lighter. The numbers to the right of the letters indicates the chroma, or degree of saturation of the color.

Shape

Particle shape refers to the particles sphericity and the degree to which edges are smoothed into roundness. These attributes are the product of the particle size, composition, past erosion, transport regimes and depositional environments (Friedman et al. 1992). Breakage that results in the rounding of sediment corners is associated with erosion by water or air. Energetic water transport results in distinctive rounding of sediment (Leeder 1982).

Size

The relative sizes of sedimentary particles are the product of chemical and physical weathering, the availability of various size particles, the sorting action of water and air transport, and deposition processes (Friedman et al. 1992). The composition of the parent materials, climate, and any obstacles or filters located along the transportation route can dictate the particle sizes that are available at the deposition site. Microbial or chemical actions can alter the size of particles by weathering larger particles into smaller components or promoting flocculation of smaller particles into aggregates (Friedman et al. 1992). Finally, the velocity or energy of a solution containing particles determines which sizes will settle into the deposition site. Particles remain suspended insofar as the energy of the solution is sufficient to offset the effects of gravity. Large particle require high energy, fast moving solutions to remain suspended, while smaller particles only settle in static solution (Friedman et al. 1992; Leeder 1982).

Chemical Weathering

Chemical weathering is the product of many processes including bacterial and microbial activity, many of which occur in solution, most commonly water (Leeder 1982). Many of these processes leave discernable marks upon sediments. The amount of chemical weathering that occurs is directly correlated to the amount of water present (Young 1962) and to the climate (warm or cold) of the region (Ruddimen 2008). Rocks and the minerals that they contain are differentially susceptible to dissolution. During chemical weathering, least resistant materials are dissolved and altered, until they no longer occupy the sediment profile. For instance, as granites are weathered, they break apart as unstable feldspars dissolve into clay (Friedman et al. 1997) and more resistant materials such as quartz remain intact.

Leaching is a form of chemical weathering by which a solution removes components of sediments and transports these components in the solution (Young 1976). The components are either carried away by a current, or precipitated onto sediments during an oxidizing event.

Pitting is a form of chemical weathering characterized by a dissolution of rocks and their mineral components. Pitting occurs in solution, and is an indicator of saturation at the site of deposition

Organic Matter

Organic matter in soils is derived from the decomposition of flora and fauna (Schumacher, 2002). Organic matter content is influenced by the availability of biomass, and the rate at which the organic matter is fully decomposed. The latter variable is largely determined by climate (Young 1976).

Rubefication

Rubefication is the process by which amorphous iron oxides coat other minerals, adding pigmentation to the sediment (Young 1976). Iron rich rocks exposed to an oscillating wet/dry regime leach iron into the surrounding solution forming suspended iron salts. Upon drying these iron salts precipitate onto other clasts (Young 1976; Friedman et al. 1997). Two common oxides that are relevant to the samples under examination are hematite (Fe_20_3), an iron oxide and the oxyhydroxide goethite ($HFe0_2$).

Hematite forms in an oxidizing environment (Friedman et al. 1997). Over long periods of time, goethite and hematite can transform into one another. Hematite transforms into goethite when an aerated soil remains moist. Yellow and yellow-brown pigmentation indicates that goethite is present, while hematite provides red to reddish-brown coloration (Friedman et al. 1997).

The amount of iron oxide pigmentation in the sample is indicative of the amount of leaching and precipitation acting upon the sediments. Precipitation of iron oxides relates to the duration of time the sediments were in an oxidizing environment. The ratio of goethite to hematite may correspond to durations of saturation and oxidation respectively (Fontes and Carvalho 2005).

Association with artifacts

Artifacts on, in, or near archaeological sediments can indicate functions and provide dates regarding the use of areas, structures and features. The shape of a ceramic vessel, for instance, is indicative of its function. Furthermore, decoration styles are subject to popularity and change, allowing for relative dating based on seriation techniques (McKillop, 2006).

6.3 Description of Sediments of Operation 114

Colour

All of the sediments collected have hue values corresponding to Munsell designation 5YR except for levels 7 and 8, which correspond to Munsell designation 7.5YR (Table 2).

Level	White 5YR 8/1	Pink 5YR 7/3	Pinkish Gray 5YR 6/2	Gray 5YR 3/1 4/1 7/2	Pinkish Gray 7.5YR 7/2	Black 5YR 2.5/1	Yellowish Red 5YR 4/6 5/6 7/6	Reddish Brown/ Dark Reddish Brown 5YR 4/4 4/3 3/2 3/4 6/4	Brown/ Dark Brown 7.5YR 4/2 4/4
Level 2	x						x	x	
Level 3	x						x	x	
Level 4				x		x	x	x	
Level 5				x		x	x	x	
Level 6				x			x		
Level 7									x
Level 8			x						x
Level 9				x			x	x	
Level 10			x	x			x	x	
Level 11		x					x		
Level 12	x						x	x	

Table 2. Sediment colours based upon Munsell Colour designations

Shape

Sediment shapes in the Mayo aguada range from sub rounded to angular (Table 3). Sub rounded sediments occur at levels 9, 8, 6, 3, and 2 (Table 3).

Level	Rounded	Sub rounded	Sub angular	Angular
Level 2		x	x	x
Level 3		x	x	x
Level 4			x	x
Level 5				x
Level 6		x	x	
Level 7			x	x
Level 8		x	x	
Level 9		x	x	
Level 10			x	
Level 11			x	
Level 12			x	

Table 3. Sediment shape

Size

Particle size analysis of the Mayo aguada sediments reveals two distinct groups (Figure 11). The first group consists of levels 4, 5, and 8 through 11. The second group refers to levels 2, 3, 6, and 7. Level 12 is distinct from these two groups. The first group of samples (levels 4, 5, 8, 9, 10 11) have homogenous size distribution and are characterized by a high frequency of coarse grains. The second group (levels 2, 3, 6, and 7) show more variability and is characterized by finer grained sediments.

Pitting

Degree of sediment pitting reveals three distinct groups of sediments (Table 4). The first group consists of levels 11 through 8, and is characterized by very little pitting. The second group consists of levels 7 through 4 and is characterized by moderate pitting. Finally, group three contains levels 2, and 3 and is characterized by extensive pitting.

Organic Matter Content

Organic matter content is lowest at levels 7 through 11 (Table 5). The highest organic matter content is at level 5, while the remaining levels (2, 3, 4, and 6) range between 4.62% and 5.58%.

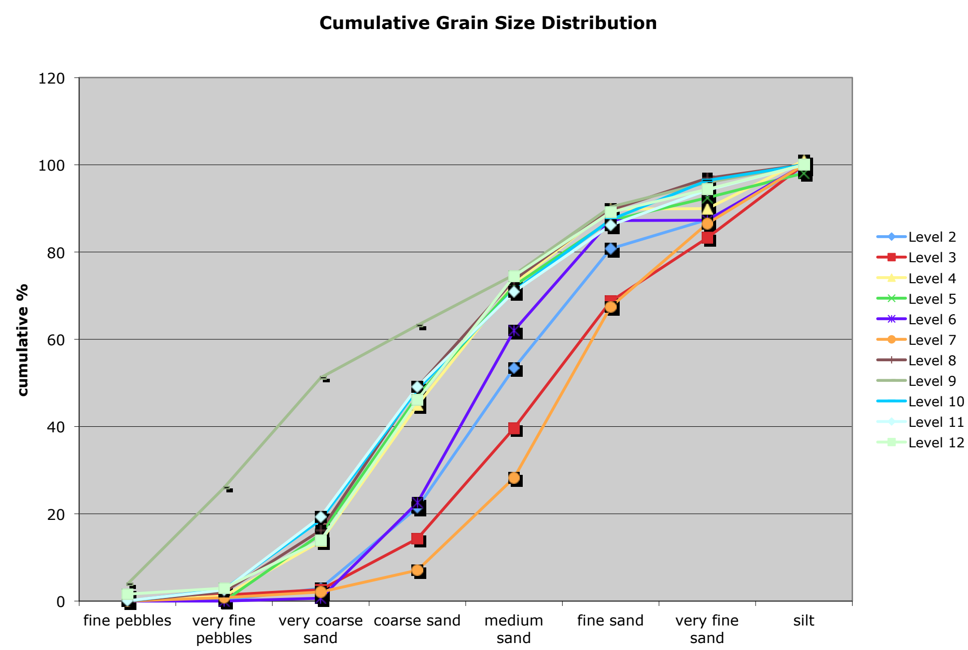

Figure 11. Particle Size Analysis

Level	Very Little Pitting	Moderate Pitting	Extensive Pitting
Level 2			x
Level 3			x
Level 4		x	
Level 5		x	
Level 6		x	
Level 7		x	
Level 8	x		
Level 9	x		
Level 10	x		
Level 11	x		
Level 12		x	

Table 4. Degree of pitting observed on sediments

Level	Net Loss of Organic Content (g)	% Total Organic Matter
2	2.59	5.58
3	2.49	5.37
4	2.14	4.62
5	2.85	7.29
6	2.42	5.55
7	1.4	3.06
8	1.11	2.25
9	0.88	1.74

10	1.21	2.44
11	1.16	2.41
12	2.14	5

Table 5. Percentage of organic matter

6.4 Association with artifacts

Ceramics were collected from levels 2, 3, 4, 5, 7, and 8. Ceramics collected from OP114 were highly weathered and not suitable for type analysis. Ceramic sizes ranged from several centimeters to millimeter sized fragments. All ceramics were highly degraded. Ceramic samples are collected into small bags catalogued, as a unit as ceramic bulk lots. Bulk lots refers to a collection of ceramic shards that do not contain diagnostic features, such as painting, incising, or rims that could provide information regarding location or time of production (G. Iannone personal communication 2007).

6.5 Level Descriptions

Level 12 was only excavated in the NW quadrant of OP114. Level 12 excavations were situated at ca. 278-280cm BUD and excavated to a depth of ca. 378cm BUD. Level 12 was composed of the base of the aguada. Excavation at this level was halted due to dangerous conditions caused by heavy precipitation and the collapsing of the excavation unit walls. Level 12 was primarily composed of sandstone fragments and shows moderate pitting and rubefication. Sediment shape was subangular and the organic matter content was high.

Level 11 was situated at ca. 211 – 217 cm BUD and excavated to a depth of ca. 278-280cm BUD. Level 11 soil sample is primarily composed of sandstone, granite, mafic fragments and fragments of quartz. Particle size analysis indicates a dominance of coarse grains. Pitting and rubefication were minimal. Sediment shape was subangular and the total organic matter is low. Twenty-three very rounded cobbles were collected from this level.

Level 10 was situated at ca. 199-217cm BUD and excavated to a depth of ca. 200-217cm BUD. This level was restricted to a central area of the unit. The level is primarily composed of cobbles, small boulders, and sediment. The level 10 sediment sample has a composition of primarily quartz fragments, feldspars and granite. Particle size analsyis shows medium to coarse sized grains. Pitting was minimal, rubefication was moderate, Sediments were subangular and the organic matter content was low. Carbon and a small fragment of decomposing wood were collected from this level.

Level 9 was situated at ca. 191-197cm BUD and excavated to a depth of ca. 199 – 217cm BUD. Level 9 consists of quartz, feldspars and specular hematite. Particle size analysis shows a coarse grained profile. Pitting was minimal and rubefication was moderate. Sediments were sub rounded – sub angular, and the organic matter content was low. Faunal remains were collected from the northwest quad of the excavation unit. The bone was highly deconsolidated. The largest intact piece of bone measured approximately 3cm x 10cm and was surrounded by smaller bone fragments. A carbon sample was also collected from this level.

Level 8 was situated at ca. 174 – 181cm BUD and excavated to a depth of ca. 191-197cm BUD. This level is primarily composed of granite and quartz grains. Pitting is minimal. Sediment pigmentation contains hues and values in the 7.5YR designation. Sediment shape is sub rounded – sub angular and the organic matter content is low. A ceramic bulk lot was collected from this level.

Level 7 was situated at ca. 149 – 156cm BUD and excavated to a depth of ca. 174 – 181cm BUD. This level is well sorted and dominated by fine sand particles. Pitting is moderate and pigmentation is in the 7.5YR colour category. Sediment shapes are sub angular – angular, and the total organic matter is low.

Level 6 was situated at ca. 131 – 134cm BUD and excavated to a depth of ca. 149 – 156cm BUD. This level shows moderate pitting and minimal rubefication. Particle size analysis shows a dominance of fine grains. Sediments are sub rounded – sub angular, and the organic matter content is high. A ceramic bulk lot was collected at this site.

Level 5 was situated at ca. 113 – 116cm BUD and excavated to a depth of ca. 131 – 134cm BUD. Level 5 is composed of quartz fragments, chlorite schists, mafic rocks and sandstones. Sediments are dominated by coarse particles. Pitting and rubefication are moderate. Sediment shape is angular and the organic matter content is very high. A ceramic bulk lot was collected at this site.

Level 4 was situated at ca. 89 – 93cm BUD and excavated to a depth of ca. 113 – 116cm. BUD. This level is composed of felsic and mafic minerals including quartz fragments and pieces of very fine sandstones and granite. Particle size analysis shows that level 4 is dominated by coarse particles. Pitting and rubefication are moderate. Sediment shape is sub angular – angular, and organic matter content is high. A small ceramic bulk lot was collected at this site.

Level 3 was situated at ca. 71 – 74cm BUD and excavated to a depth of ca. 89 – 93cm BUD. This level is composed of sandstones and weathered granite fragments. Pitting and rubefication are both extensive. Sorting is very poor and coarse particle dominate. Sediment shape ranges from sub rounded through to angular, and organic matter content is high. A small bulk lot of ceramics was collected from this level.

Level 2 was situated at ca. 61-67cm BUD and excavated to a depth of ca. 71 – 74cm BUD. This level consists of sandstone and weathered granite fragments. Pitting and rubefication are extensive. Particle size analysis reveals fine grains. Particle shapes range from sub rounded through to angular, and organic matter content is high. A ceramic bulk lot was collected from this level.

Level 1 was excavated from surface to ca. 61 – 67cm BUD. This level was subjected only to in field analysis. Initial examination revealed that its soil was consistent with level 2. The soil was intermingled with litter mat.

6.6 Interpretation

The product of rubefication, hematite, is on the majority of the sediments. There are two locales that are conducive to pigment creating rubefication, the Mayo aguada and the surrounding hillsides from which the sediments were probably transported into the aguada. The primary transport mechanisms acting upon sediments are wind and water (Leeder 1982). If the coatings were produced at another location and transported to the aguada by water the iron oxides would dissolve and re-leach into the surrounding solution. Air transportation results in patterns of physical weathering characterized by abrasions and rounding of sediments, this would also damage iron oxide coatings. Therefore this rubefication indicates that the dry season resulted in the drying out of the aguada.

Sediment pigmentation indicates that all samples likely contain hematite and goethite (Table 1). The amount of overall pigmentation varies, but the majority of the samples have profiles with a high hematite to goethite ratio. Levels 7 and 8, however, are characterized by a higher goethtite content, with little or no hematite pigmentation. All of the sediments were subjected to oxidizing environments, with the exception of level 7. Conditions at level 8 are inconclusive. There may have once been hematite oxidation of these sediments, however, moisture moving downward from level 7 may have saturated level 8 sediments causing the hematite to transform into goethite. A level 7 terrace construction event likely increased the water retaining capacity of the aguada resulting in a lack of hematite formation for level 7, and the conversion of any hematite extant at level 8 into goethite.

Steady reductions of hematite iron oxide pigmentation combined with moderate to low pitting (Table 2) indicate decreasing chemical weathering of sediments deposited at levels 12, 11, and 10. By level 10, feldspars occupy the sediment profile, demonstrating that chemical weathering was very inactive in the area of provenance and transport.

Level 11 contains the first indications of human activity in the aguada. The river cobbles located in level 11 could not have formed in the vicinity of the aguada, but must have been transported by humans to the aguada, as no other transport regime in the area has sufficient energy to transport these cobbles. These river cobbles may have been collected from the Macal River (E. Martinez personal communication 2008) in antiquity and transported to the aguada. The placement of river cobbles may have been intended to decrease the porosity of the aguada floor at isolated spots. Alternatively, the association between river cobbles and plentiful water may have made their placement at level 11 a symbolic method of increasing the Mayo aguada's efficacy as a water source. A combination of both purposes is also plausible.

Cobbles collected at level 10 are further indication of human activity. The orientation of these cobbles is very flat and regular indicating that they did not fall into the aguada by natural forces, but were placed along the aguada floor as a means to increase its water retaining potential. It is possible that at level 10 the aguada was growing increasingly dry for longer durations each year. Local Maya attempted to further increase its water holding capacity by placing cobble surfaces to block porous areas of the aguada floor.

Dry conditions continued at level 9, as indicated by hematite precipitation and the remains of a large animal that may have walked on the ancient dry surface of the aguada. The faunal remains are poorly preserved, however there is sufficient material to deduce that the bones are the remnants of a large animal, not a burrowing animal (G. Iannone personal communication 2007). This indicates that at the time of deposition of level 9 the aguada was dry for a portion of the year. The remains of a large animal are unlikely to have been transported by currents to the center of the aguada. On the contrary, if the aguada was nearly dry, the animal may have wandered close to the central area for remnant water and died sufficiently close for his remains to be found at this location (G. Iannone personal communication 2007).

A major change in climate or transportation or human intervention is evident at level 7. The level 7 profile is characteristic of a sediment sample exposed to extensive weathering. The well sorted fine sand (Figure 12) is indicative of a low energy transportation regime which is different from the higher energy which carried the coarser sand of levels 11 through 8 into the aguada. An explanation that reconciles these observations is that level 7 sediments were filtered during their transport into the Mayo aguada by newly constructed terraces on the hillsides. Terraces are described in the following section.

At level four, it appears that an event caused a temporary return to former conditions. Levels 4 and 5 may be reworked sediments from earlier levels within the aguada. Level four and five sediments may have been collected from the aguada floor at earlier levels during maintenance of the aguada, and used as fill for the terrace walls. A high energy regime resulted in these sediments floating above overwhelmed terraces, and breaking through collapsing terrace walls as a result of driving storms and a lack of regular terrace maintenance.

Once human management was underway, it is likely that the aguada floor was subjected to other management activities to maximize and protect the quantity and quality of water stored. Such activities may have included the removal of sediments and flora from the aguada bottom. Levels 11 through 7 have the lowest organic matter contents recorded in this analysis (Table 4). Removal of flora and sediment as a management practice may have decreased the availability of organics at these levels. Sediments removed by management actions may have been reused as fill in the surrounding man made terraces.

6.7 Terrace Excavations

OP 115 and OP116 were excavated during 2008 investigations of the Mayo aguada at Minanha, Belize. OP 115, and the subsequent OP116 were intended to address research questions regarding the modifications, functions, and temporal construction details of the Mayo aguada. Excavation units were placed so as to expose terrace-like structures along the periphery of the aguada. These terraces may have served several functions. The water retaining capacity of the aguada may have been improved by the building of terraces in the dips between the hills of this mountainous region. Further, the presence of a terrace may have decreased materials washing into the waters from the surrounding hills (G. Iannone personal communication, 2007). This interpretation is re-inforced by the grain size analysis, which shows a distinct change from coarse to fine grained sediments at level 7. These investigations were directed towards identifying the features, chronicling the modifications that constitute their construction, and collecting any associated artifacts or materials

Operation 115

OP 115-1 was a 1m x 2m unit located in the Southwest section of the Mayo aguada. The unit was placed along the wall in what appeared to be a terrace. OP115 was oriented east – west. This unit was intended to expose extant modifications along the edges of the aguada, and for the collection of cultural materials. OP 115 was excavated to an approximate depth of 67-125cm BUD.

Discussion

Excavations at OP115 failed to provide sufficient materials to reach the research goals. There was little material found therein, modifications were minimal and unclear, and there were no diagnostic ceramics recovered. Indications, however of use and modification were sufficiently identifiable for a brief discussion. A layer of clasts in the level 3 matrix had the appearance of ballast, and where there was no retaining wall, there was a natural bedrock formation that would have served the function of such a modification.

The area of the aguada investigated in OP115 appears to have remained minimally modified. This is likely due to the opportunistic use of a natural topography that was only modified insofar as it was likely and necessary to improve water retention.

Operation 116

OP116 -1 was a 1m x 3m unit located along the northern wall of the Mayo aguada. This excavation was initiated to expose extant modifications to the wall of the aguada, and to facilitate the collection of cultural materials for analysis. The unit was oriented 50 degrees west of North encompassing the presumed top of a terrace wall, and extending to the aguada floor. OP116-1 was excavated to a depth of 74-154cm BUD.

Discussion

OP116 provided a great deal of data. This excavation unit contained a well preserved constructed terrace. The identification of two retaining walls separated by construction fill is a clear indication of modifications to the aguada structure. Diagnostic ceramics were collected from within the construction fill. The terrace contained shards from unslipped water jars of Late Classic origin (R. Dell personal communication, 2008). The terrace was therefore constructed prior to or during the Late Classic period. The vessel types indicate that water collection occurred at the Mayo aguada.

Chronological Data

Recovered carbon materials were too degraded for C^{14} isotope dating to provide absolute dates. Recovered ceramics indicate that aguada modifications began during or prior to the Late Classic Maya period.

Chapter 7

7.1 Conclusions

Excavations and geomorphological analysis at the Mayo aguada have provided sufficient data to address many questions that were presented in this thesis (p.6) regarding aspects of water management at Minanha. These questions are posed again, below, with the conclusions derived from this research. The use of archaeological materials is not uniformly applicable to all of the research goals of this project. By utilizing an interdisciplinary approach, awareness of the limitations of the dataset has informed viable interpretations.

Can it be confirmed that the Mayo aguada was used in antiquity as a water management feature?

The Mayo aguada was certainly used in antiquity as a water management feature. The presence of modifications including terrace construction and the use of cobbles to decrease the porosity of the aguada floor demonstrate that this feature was used and altered for the purpose of water retention. Furthermore, sediment analysis indicates that such modifications were both necessary and were likely successful. The sediment analysis can only demonstrate that the soils remained saturated year round during the deposition of level 7 sediments. This alone does not prove that the aguada retained sufficient water for human consumption. The vicinity of house groups indicates a level of commitment to the aguada that suggests that its water retaining goals were achieved. Furthermore, the presence of reworked sediments at levels 4 and 5 indicate that maintenance and servicing of the aguada endured for many seasons.

How was the natural aguada modified for water management?

During the Late Classic period (Level 12), the local Maya population began to modify the Mayo aguada by clearing out sediments that could contaminate the drinking supply, at which point a new sediment profile began to accumulate. The placement of river cobbles at level 11 may have served plug or block pores in the aguada floor. The aguada must have continued to dry out for at least part of the dry season, and further modification was required. The Maya then added layers of cobble (Layer 10) wherever there was still porosity. While the aguada did retain water for much of the year, the goethite/hematite deposits in the sediments indicate that seasonal dry seasons still proved to decimate the water level.

Finally, the construction of terraces (Level 7) between the dips in the hillsides that encircle the aguada served to keep the aguada saturated year round. Management of the aguada continued in the form of clearing out sediments when water levels were low, subsequently using these soils to fill the surrounding terraces.

Eventually, as the aguada fell into disuse, repairs and management decreased and the terraces failed resulting in a return of coarse grained sediments that were previously being trapped in the terraces, and a dramatic increase in organic matter content rushing into the aguada.

The exact motivations for each building/modification event are complex. Modifications to the Mayo aguada may have been limited in scope because the population was satisfied to rely on natural topography wherever it was advantageous. It is likely that the water managers invested the least amount of energy for the maximum gains of water security. Alternatively, heterogeneous modifications of the aguada may be due to a lack of resources, labor, or because the work was halted prior to completion. Sediment analysis does reveal that the modifications undertaken were sufficient to keep the aguada saturated throughout the dry season, for a limited amount of time. The reason for its abandonment, and the cessation of maintenance, however, is not made clear by excavations at the aguada.

How effectively could the known water feature have supported Minanha at its peak population?

It is improbable that this water feature supported Minanha at its peak population, or that it was intended to. As was the case at the neighboring site, Caracol, the population of Minanha likely did not rely on one source for their year round water needs. Many smaller features have been located within and around Minanha that would have contributed to the water needs at the site. The Mayo aguada is reminiscent of the large reservoirs mapped at Caracol outside of the city center. Like Caracol, Minanha may have had another reservoir within the city center, to service the elite, or supplement the population's needs when personal water storage units failed during dry seasons. Such a reservoir may yet be discovered.

How much labor was required to construct and maintain the Mayo aguada?

It is not known how much labor was required to service the Mayo aguada. Regular maintenance was probably conducted by the inhabitants of nearby structures that are yet to be excavated. Regular upkeep would have involved the maintenance of terraces, the dredging and collection of sediments, and supervision of use. When the water was low, porous areas were blocked with cobbles, and possibly plaster seals applied, although plaster seals were not located during excavations.

How did the elite of the city center control access to available water sources?

Control of the Mayo aguada was probably exercised by the occupants of the residential structures nearest the aguada. From their location, the Mayo agauda could have been easily monitored, and regular maintenance performed. Excavations of these residential structures is necessary to discover the relationship between the Mayan elite and this reservoir. The Class identity of the residents of these nearby structures may indicate the level of involvement the elite of Minahna had with the water provided by the Mayo aguada. Examinations of the aguada alone are not sufficient to extrapolate the identity of the inhabitants of these nearby structures, or the relation between them and the citizens of the city center. The class identity of the inhabitants of this structure will need to be ascertained, however, this is problematic, relying upon archaeological materials. Identity is a mutable and complex trait that is not easily accessed through material culture. If located, the presence of elite materials may indicate an ongoing dialogue between these aguada managers and the city center elite. If extant, any burials in the vicinity of the nearby structures would provide data regarding their status. It is however, also likely that the status and class identity of these inhabitants changed depending upon the availability of water, and the importance of the Mayo aguada.

How did water accessibility influence settlement patterns in the area of Minanha?

The presence of the Mayo aguada probably reinforced the choice of settlement location at Minanha. The Mayo aguada, when modified, offered water security in a water scarce region. However, it is just as likely that the presence of the Macal River, one of the few surface rivers, attracted early settlers. The limitations of the archaeological dataset are keenly felt in regards to this question. Analysis of the hydrological regime indicates the importance of the Mayo aguada and the Macal river, and it is likely that access to water was of tantamount importance for the local inhabitants. However, the inhabitants of Minanha were not settling in virgin territory. The location of Minanha may also have been a response to the greater settlement patterns already established by neighboring sites.

How were the non elite impacted by the water management regime of Minanha?

The impact of this reservoir over the non-elite at Minanha probably changed seasonally. As smaller reservoirs dried up during the dry season, a larger portion of the community likely relied on this reservoir. Maya with their own sources of water would likely oscillate between water independence and regulated use of the Mayo aguada. If there was a centrally located reservoir within Minanha proper, further examination would be required to determine the extent of its influence over the population.

Did climate changes or drought cycles have an impact on this Maya city?

Seasonal and exceptional droughts would, certainly, have influenced the inhabitants at Minanha. The fate of Minanha was, however, influenced by the broader socio-political context in which it existed. The timing of flourescence and protraction at Minanha is inversely correlated to the successes and failures of its neighboring states Naranjo and Caracol (Iannone, 2005). Furthermore, excavations in the site core indicate that the survival population following the decline at Minanha were capable of conducting rigorous labor in the form of the careful burial of the Late Classic royal residential compound. The careful burial does not appear to have been conducted by a population suffering from starvation or the decimating impacts of drought (Iannone 2005:37).

Did a crisis of resilience threaten this community?

The Mayo aguada was successfully modified to retain water and a variety of small water features complemented this successful enterprise resulting in a decentralized and adaptable water management regime. If droughts caused the aguada failure and abandonment, this was likely just one factor amongst many that challenged the Royal court, and eventually the entire population beyond their resiliency.

How did the Maya conception of land, water, and resources influence their choice of water management systems?

The Maya conception of their water and landscape is not accessible through the investigations undertaken in this project. The Mayo aguada is oe feature with a specific role in the city scape of Minanha. The aguada is primarily functional, excepting potential symbolism that may have been intended by the transport of river cobbles to the Mayo aguada. A lack of intentional symbolism does not, however, render the structure devoid of information. Functional structures both past and present have provided fascinating windows into broader social analysis. For instance, analysis of Baltimore, Maryland, showed that the changing morphology of the urban infrastructure correlated well with changes in economic organization (Olson 1979). It is problematic, however, to derive meaning from correlations. Various motivations can result in similar functional results, and there are often many ways to functionally address the same challenge or motivation. The hydrologic regime of the North Vaca Plateau is well disposed to an opportunistic water management style maximizing natural features for the purpose of storing meteoric precipitation, and employing small ephemeral water sources when appropriate.

The choice of water management systems was also influenced by the region's greater socio-political context. The water management regime at Minanha resembles that found at Caracol, characterized by a variety of water holding features, both natural and modified in various contexts. Minanha may have modeled their water management structure after that of their large, successful neighbours. Various realities of the Mesoamerican world impacted the choices of water management regimes used in antiquity, isolating specific motivations from material cultures is a problematic endeavor that threatens to conflate correlation with causality.

What is the relationship between water management systems and systems of governance?

The relationship between water management systems and systems of governance is complex. Insofar that water requirements are cross cultural, and physical realities are universal, the challenges of water stress and choices of management made, can provide insight into the social and political economy of a group. For instance, large structures often require a great deal of human labor to procure building materials and contribute to building projects. Furthermore, control over important resources, especially point resources (resources with a defined rather than dispersed area of collection) are easily monitored and isolated, conferring economic control upon a controlling elite.

Arguments emphasizing environmental determinism neglect the complexity of community interaction and the role of culture in regards to management choices. By disregarding social components of the decision making process, environmental determinism results in simplified narratives regarding the relationship between water and governance. For instance, cooperation can be a profitable response to water challenges.

Instances of cooperation may not be well represented in the archaeological record as they may erroneously be interpreted as indicative of coerced labor. Via the iterative process between community and environment, long term use and accretive development can result in landscape patterns that appear to be have been planned, as they developed organically.

The Interdisciplinary Approach.

In the course of this work, attempts were made to study many of the dominant themes pertinent to studies of water management from an interdisciplinary perspective. With these analyses, the limitations of the archaeological dataset derived from excavations for some of the research objectives became apparent. This resulted in varying degrees of success examining research questions, and the abandonment of certain inquiries throughout the interpretive process. For instance, at the outset of this project, a greater variety of research questions regarding concepts of identity, cultural continuity and social theory were posited. I had the opportunity to explore these questions and their underlying concepts with Dr. Freeman and Dr. Amit. Examples of these inquiries that were initially posited, but abandoned included;

1) Can archaeologists discuss ancient identity?

2) Is the concept of identity real, and is that relevant when archaeologists explicitly define their subject?

3) Is the explicit definition of the subject of inquiry a responsible way to engage with identity, or is it a manipulation?

4) Is cultural continuity real or myth?

5) What is the interplay between the means of production and power over vital

resources?

These questions underlay the interpretation of the data collected from the Mayo aguada, as it relates to its broader social role. The ability to directly address such issues was, however, constrained by the emphasis upon material remains, and the necessary scope of the individual research project. Questions of identity, cultural continuity, and social memory could not be sufficiently addressed in the context of aguada excavations. The aguada excavations, however, may, in future research, contribute to such inquiries as an integral aspect of the greater social structure in the Maya Lowlands.

Initially, as part of this work I had hoped to demonstrate a research methodology that emphasized the role of implicit social theory. By undertaking an interdisciplinary approach thatcontributed to the rigorous application of social theory, it became clear that a specific data set and research goals pose limitations upon the scope of inquiry that can be efficiently examined. Although this could be characterized as a failure of the interdisciplinary approach, this is not so. The interdisciplinary emphasis of this research succeeded to increase the rigorous application of social theory, making clear the constraining aspects of the data set. In the absence of an interdisciplinary approach, mis-application of social theory may have resulted in over simplified applications of constructs such as environmental determinism and ascribed identities construction.

I have not demonstrated a new research methodology in which the social theory underlying analysis is rendered both integral and explicit to each project. I contend that such discussions do belong as the supporting structure of the research project. A section acknowledging the methodologies and paradigms being applied to the interpretive process, as is customary, addresses this aspect of research without over burdening the research scope of individual projects. Social theory is highly complex, and rendering all of its implications explicit within each project impedes the presentation of interpretations. That said, however, rigorous application of interdisciplinary concepts must be present within the research structure. By education and collaboration a thorough examination of the concepts implicit to archaeological research must be thoroughly conducted before they are applied to interpretations. Such a system is currently reflected in the placement of archaeology within the field of anthropology at many universities, and the access students have to both specializations and elective courses at the undergraduate level. An increase in communication between archaeology departments and other disciplines that contribute to its methodology, such as biology, chemistry, and geology, would further support the archaeological endeavor.

APPENDIX

<u>Soil Grain Analysis: Protocol.</u>

Sedimentological analysis will be conducted on soil samples collected from the relic aguada, Mayo Aguada in the ancient Maya site of Minanha, located in the North Vaca Plateau of Belize. Physical aspects to be described include particle size distribution, grain morphology, organic matter content, and mineral composition of the grains. The following protocol will address pretreatment of the sediments, as well as Particle size analysis.

The purpose of the Particle Size Analysis (PSA) is to determine the relative proportion of each particle size range in the sample (Department of Sustainable Natural Resources:2). The Particle Size Distribution (PSD) will be expressed as a cumulative frequency distribution, or as a relative frequency distribution (Laswell et al. 1972).

Summary of Sample preparation and treatment:

1) Wet weighing.

Following collection, all samples are weighed while moist (as they were in situ).

2) Air dry

All samples are set out to air dry in a flat layer (<1cm), until fully dry (approximately 1 week). Samples are protected from contamination by being shielded with plastic

3) Transportation

Samples are secured in clean secure plastic bags and transported to the laboratory.

4) Dry weight.

Samples are weighed dry.

5) Moisture Content

Moisture content is determined by the following equation:

$$\text{Field Moisture Content} = \frac{b - c}{c - a} \times 100\%$$

Where: a= weight of plastic bag

b=weight of moist soil + plastic bag

c=weight of air dry soil + plastic bag

(Moore.1995:3)

6) Colour Determination

In situ descriptions were recorded in the field using Munsell notation to describe hue, value, and chroma. This will be repeated in the controlled laboratory environment (Moore.1995:3).

Laboratory Analysis

Sediments must be disaggregated. Aggregation is caused by many distinct processes. One solution is rarely sufficient to disrupt the effects of each of the causes of flocculation (Vanoni, 2006). Due to the limitations of each method, several methods are necessary to render the sediments unique particles. Mechanical, temperature, and chemical processes are necessary.

Mechanical disaggregation is the initial step. This is conducted by grinding the samples lightly in a mortar and pestle. During this process, collect large organic debris per sample, to be stored separately in glass jars.

Disaggregation by ignition: Heating the samples to 400^0C 8 hours serves to remove organic materials that adsorb to the sediment particles, and may promote aggregation. Furthermore, by weighing the samples prior to and following ignition, the Loss on Ignition difference supplies an approximation of the samples organic content. (Moore, 1994; Laswell et al. 1972, Mann and Wetzel, 2000)

Chemical disaggregation is the use of reagents to break up aggregated sediments.

Note: Determining Organic Matter Content is conducted by incinerating the sample Organics. After determining Organic Matter content by the following method, it may still be necessary to oxidize remaining Organic matter with hydrogen peroxide.

STEP 1: Mechanical Disaggregation by mortar and pestle.

STEP 2: Disaggregate by Ignition, and calculate the Loss on Ignition Organic content.

Organic Matter Content

Determine Organic Matter Content by Ignition.

A) oven drying

Place 1g of air dry fine (<2mm) organic soil, or 5g of fine mineral soil into a weighed porcelain crucible. Heat in an oven for 24 hours at 105^0C. Cool in a dessicator. Weigh remaining sample.

B) ignition.

increase temperature to 400^0C. Place samples (in crucibles) into oven (using protective gear such as long tongs and asbestos gloves).

Keep at this constant temperature for 8 hours.

Allow samples to cool in a dessicator.

NOTE: During ignition process, have an external map of the placement of sample crucibles, as the ink will be removed during the process.

Calculate Organic Matter Content using the following Calculation:

$$\text{air dry moisture content} = \frac{b - c}{c - a} \times 100\%$$

$$\text{loss on ignition} = \frac{c - d}{c - a} \times 100\%$$

organic matter content = (loss on ignition)-2%

organic carbon = 0.58 (organic matter content)

Where a = crucible weight

b=crucible + air dry soil weight

c = crucible + oven dried soil weight

d = crucible + ignited soil weight

(Moore, 1995:6)

STEP 3: Chemical Pre treatment

Hydrogen Peroxide Pretreatment:

H_20_2 performs a peroxidic type reaction resulting in the oxidation of organic compounds (Mikkuta et al.2005) that would otherwise skew particle size analysis by increasing the size of discrete particles as well as their shape. A change in the size of the particle would directly alter the results of PSA (Vanoni, 2006). The change in shape would have equal impacts as the sediment particle shape may block its passage through a dry sieve, and a change in shape could impact settling velocity during any future analysis by pipette or hydrometer.

Treatment with Hydrogen Peroxide is a popular pre treatment for Particle Size analysis (Vanoni 2006 ,Mikuta et al.2005, Moore 1995, Laswell et al. 1972, Mann and Wetzel 2000). Drawbacks that must be well understood include a lack of standardization in methodology of applying Hydrogen Peroxide to samples and subjectivity in determining the completion of the pretreatment. There is in fact no accepted objective determination for the completion of H_20_2 treatment, accept for a general cessation of reaction (Mikutta et al. 2005). Finally, the efficiency of the removal of organic materials is far from 100%

depending upon many factors including ph levels,temperature, contact time, soil properties, and the presence of protective mineral phases (Mikutta et al. 2005)

Method (Vanoni, 2006)**:**

-For each gram of dry sediment add 5ml of 6% H_20_2 in 40ml of water.

-Stir mixture thoroughly

-Cover for 5 – 10 minutes.

-Remove any sediment free organic matter that floats to the top – set aside in a glass jar.

-Following the cessation of a pyroxide reaction raise the temperature of the mixture to 93^0C.

-Stir occasionally and add more H_20_2 as needed.

-Rinse sediment several times with distilled water, to remove all H_20_2

-Alternatively, a hot water bath for 1 hour (90^0C) can be used to dissolve the hydrogen peroxide (Mann and Wetzel, 2000).

STEP 4: Separate coarse and fine sediments by wet sieve analysis.

Procedure for wet sieve analysis

:(http://www.lifesciences.napier.ac.uk/teaching/MB/sedgran02.html):

Wet sieving is used to separate the coarse sandy grains from the fine (<2mm) silts and clays. The following instructions are to be followed after pretreatment with mortar and pestle, as well as removal of organic material.

The initial step of this process is to separate fine particles through use of a dispersing reagent such as sodium hexamaetaphosphate (calgon) (Moore, 1995:7;Dept. of Sustainable Natureal Resources.)

-Mix 250 ml. of tap water, and 10 ml of calgon (6.2g/litre) and the sample.

-stir throroughly for 30 minutes.

-Immerse the sediment sample in a 62um sieve in the calgon mixture. The coarse sediments will remain in the sieve while the fine fractions will pass through.

-Dry the sand sample for 24 hours in an oven at 70-100^{0}C

-Weigh the coarse sample (taking the weight of the container into account)

-The weight of the fines is the difference (with a margin of error for any sediments trapped within the sieve.

-Proceed to dry sieve the coarse sediments.

Step 5: Dry sieve coarse materials

Dry Sieving:

Dry sieving is used to determine the particle size distribution of course grained sediments by passing each sample through a tower of sieves with graded, known sizes, beginning with the coarsest size at the top. The sieves are then agitated in lateral and vertical directions for approximately 15 minutes (Vanoni, 2006:246).

Andrews, Anthony P. E., Wyllys Andrews, and Fernando Robles Castellanos.
2003. The Northern Maya Collapse and Its Aftermath. *Ancient Mesoamerica*, 14, 151-156. Print.
Angelakis A.N. and D. Koutsoyiannis.
2007. Water Supply. Insights into Water Management. Lessons from Water and Wastewater Technologies in Ancient Civilizations. IWA Publishing. Print.
Anschuetz, Kurt F, Richard H. Wilshusen, and Cherie L. Scheick.
2001. Archaeology of Landscapes: Perspectives and Directions. *Journal of Archaeological Research.* vol. 9, no. 2. Print.
Ashmore, Wendy. Site Planning Principles and Concepts of Directionality among the
1991. Ancient Maya. *Latin American Antiquity*, Vol 2., No., 3 (Sep., 1991), pp. 199-226. Print
1994 "Function and Meaning in Classic Maya Architecture: A Symposium at Dumbarton Oaks 7th and 8th october, 1994." Ed. Stephen D. Houston.
Ashmore Wendy and Jeremy A. Sabloff.
2002. Spatial Orders in Maya Civic Plans. *Latin American Antiquity*, vol. 13, no. 2 (June, 2002), pp. 201-215. Print.
Bakalowicz, Michel.
2006. Importance of regional study site conditions in elaborating concepts and approaches in karst science. In *Perspectives on Karst Geomorphology.* Russell S. Harmon and Carol M. Wicks (eds). The Geologic Society of America. Colorado. Print.
Binford, Lewis.
1962 Archaeology as Anthropology. *American Antiquity* 28(2):217-225.
1964 A Consideration of Archaeological Research Design. *American Antiquity* v.20 (4) April. Print
1983 Data, relativism, and the archaeological science. in Debating Archaeology. Ed. L.R. Binford. Pp. 55-68. San Diego, Academic Press. Print.
1989 Debating Archaeology. Academic Press. (535pp.) 1989.
Bogli, Alfred.
1980 *Karst Hydrology and Physical Speleology*. Berlin Springer-Verlag, Berlin Heidelberg, New York.
Brumfiel, Elizabeth M.
2003 It's A Material World: History, Artifacts, and Anthropology. *Annual Review of Anthropology*, Vol. 32. pp. 205-223. Print.
Burkart, Burke,
1994 Northern Central America. In:S.K. Donvan and T.A. Jackson (editors), Caribbean Geology: an introduction. I.W.I Publisher's Association. Kingston, Jamaica. Pp. 265-284. Print.
Chase, Diane Z. Arlen F. Chase and William A. Haviland.
1990 The Classic Maya City: Reconsidering the "Mesoamerican Urban Tradition". *American Anthropologist,* New Series, Vol. 92 (Jun., 1990), 499-506. Print.
Clarkson, Persis B.
1999 "Archaeological Imaginings: Contextualization of Images". *Reader in Archaeological Theory: Post-Processual and Cognitive Approaches.*

ed. David S. Whitley. London and New York: Routledge Publishers. pp.119-130. Print

Cleland, T.M.

1921 The Munsel Color System: A Practical Description With Suggestions For Its Use. Munsell Color Company, Baltimore. Print.

Colas, Pierre R, Ulrich Wolfel, Philip P. Reeder, Katja C. Stengert, and James Webster.

2008 Sites and Sinkholes: Archaeological Investigations of Terminal Classic Maya Society on the Northern Vaca Plateau, Belize. *Mexicon,* vol. XXX December. Print.

Crandall, James M.

2009 Water and the Mountains: Maya Water Managemetn At Caracol, Belize. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in the Department of Anthropology in the College of Sciences at The University of Central Florida Orlando, Florida. Spring Term. Print.

Culbert, T. Patrick and Don S. Rice (editors)

1990 *Precolumbian Population History in the Maya Lowlands.* University of New Mexico Press, Albuquerque. Print.

Curtis, Jason H, David Hodell and Mark Brenner.

1996 Climate Variability on the Yucatan Peninsula (Mexico) during the Past 3500 years, and Implications for Maya Cultural Evolution. *Quaternary Research* 46, 37-47. Print.

Daoxian, Yuan.

2001 On the Karst Ecosystem. *Acta Geologica Sinica.* Vol. 75, No.3. Sept.

Demarest, Arthur, Prudence M. Rice and Don S. Rice (editors)

2004 *The Terminal Classic in the Maya Lowlands*. University Press of Colorado, Boulder. Print.

Draper, Grenville, Trevor A. Jackson and Stephen K. Donovan.

1994 Geologic Provinces of The Caribbean Region. In Caribbean Geology: an Introduction. UWI Publishers Association, Kingston.(pp.3-12). Print.

Dull, Robert A., John R. Southon, and Payson Sheets

2001 Volcanism, Ecology, and Culture: A Reassessment of the Volcan Illopango TBJ Eruption in the Southern Maya Realm. *Latin American Antiquity* 12(1):25-44. Print.

Dunning Nicholas P, and Timothy Beach.

2000 *Stability and Instability in Prehispanic Maya Landscapes*. in Imperfect Balance. Landscape Transformations in Precolumbian Americas. ed. David Lentz. Columbia University Press (pp. 179-202). Print.

Dunning Nicholas P, Sheryl Lazzader – Beach, Timothy Beach, John G. Jones, Vernon Scarborough and T. Patrick Culbert.

2002 Arising from the Bajos: The Evolution of a Neotropical Landscape and the Rise of Maya Civilization. *Annals of the Association of American Geographers*. 92(2), pp.267-283. Print.

Eisenstadt, S.N.

1958 Review: The Study of Oriental Despotisms as Systems of Total Power. *The Journal Of Asian Studies*, Vol. 17, No. 3 (May, 1958), pp.435. Print.

Fagan, Brian M.

1992 *People of the Earth, an Introduction to World Prehistory.* tenth edition. University of California, Santa Barbara: Prentice Hall. (628pp.) 443pp. Print.

Fairley, Terry P.

2003 Geologic Water Storage in Precolumbian Peru. *Latin American Antiquity*. Vol. 14, No. 2 (Jun., 2003), pp. 193-206. Print

Fash, William L.

1994 Changing Perspectives on Maya Civilization. *Annu. Rev. Anthropol.* 23:181-208. Print.

Fishman, Charles.

2011 *The Big Thirst.* Simon and Schuster. New York. 388pp.

Flannery, Kent V, and Joyce Marcus.

1997 "Cognitive Archaeology". *Reader in Archaeological Theory: Post-Processual and Cognitive Approaches*. Ed. David S. Whitley. New York and London: Routledge. 1997. 35-48. Print

Fleurant, C, G.E. Tucker and H.A. Viles.

2008 Modelling Cockpit Karst Landforms, *Geological Society,* London, Special Publications. v. 296, p. 46-62. Print.

Fontes, Mauricio P.F. and Ildeu A. Carvalho, Jr.

2005 Color Attributes and Mineralogical Characteristics, Evaluated by Radiometry, of Highly Weathered Tropical Soils. *Soil Science Society of America Journal*. Vol. 69, July – August. Print.

Ford, D.C.

2006 Karst Geomorphology, Caves and Cave Deposits. In Perspectives on Karst Geomorphology, Hydrology and Geochemistry – A Tribute Volume to Derek C. Ford and William B. White. (2006). Russell S. Harmon and Carol M. Wicks (eds). The Geological Society of America, Colorado. Print

Ford, Derek and Paul Williams.

1989 *Karst Geomorphology and Hydrology*. Unwin Hyman Ltd. London. pp.601. Print.

Friedman, Gerald M. John E. Sanders and David C. Kopaska-Merkel.

1992 *Principles Of Sedimentary Deposits: Stratigraphy and Sedimentology.* Macmillan Publishing Co. New York. 717p. Print.

Gabbert, Wolfgang.

2001 Social Categories, Ethnicity and the State in Yucatan, Mexico. *Journal of Latin American Studies,* vol. 33. No. 3 (Aug. 2001), pp. 459-484. Print.

Gill, R.B.

2001 *The Great Maya Drought*s: *Water, Life and Death*. Alburquerque: University of New Mexico Press. (464pp.) Print.

Gillespie, Susan D. Rosemary A. Joyce and Deborah L. Nichols.

2003 Archaeology Is Anthropology. Ed. S.D. Gillespie and D. L. Nichols. *Archaeological Papers of the American Anthropological Association* No. 13. Pp. 155-169. Print.

Graham, Alan.

2003 *In the Beginning: Early Events in the Development of Mesoamerica and the Lowland Maya Area*. in The Lowland Maya Area - Three Millennia at the Human - Wildland Interface. (eds) Gomez Pompa, M. Falled, S.L.Fedick, JJ. Jimenez. The Haworth Press. Print.

Griffith, Cameron, Jennifer Birch and Simone Philpot.

2004 The Caves of the Minanha Periphery and the Upper Macal Valley. Paper presented at the 68th Annual Meeting of the Society for American Archaeology. Montreal.

Gruhn, Ruth and Alan L. Bryan

1977 Los Tapiales: A Paleo-Indian Campsite in the Guatemalan Highlands. *Proceedings of the American Philosophical Society* 121:235-273

Gunn, Joel D, Ray T. Matheny and William J. Folan.

2002 Climate – Change Studies in Mesoamerica: A Diachronic Analysis. *Ancient Mesoamerica* 13, 79-84.

Hall, Edward T.

1966 *The Hidden Dimension.* Doubleday: New York 1966. Print.

Handler, Richard.

1996 Is "Identity" a useful cross-cultural concept. *Commemorations: the politics of national Identity*, John R. Gillis ed. Pgs. 27-40 Princeton, NJ: Princeton University Press. Print.

Haviland, William A.

1997 *Anthropology*. 8th ed. Vermont. Harcourt Brace and Company. Print.

Healy, Paul (editor)

1983 An Ancient Maya Dam in the Cayo District, Belize. *Journal of Field Archaeology*, vol. 10, No.2 (Summer, 1983), pp. 147-154. Print.

1997 *Belize Valley Preclassic Maya Project: Report on the 1996 and 1997 Field Seasons.* Trent University, Occasional Papers in Anthropology #13. Peteroborough, ON.

Healy, Paul F. and Jaime J. Awe (editors)

1995 *Belize Valley Preclassic Maya Project: Report on the 1994 Field Season.* Trent University, Occasional Papers in Anthropology #10. Peterborough, ON.

1996 *Belize Valley Preclassic Maya Project: Report on the 1995 Field Season*. Trent University, Occasional Papers in Anthropology # 12. Peterborough, ON.

Henderson, John S.

1997 *The World of the Ancient Maya*. Cornell University Press. New York (329pp.) Print.

Hervik, Peter.

1999 The Mysterious Maya of National Geographic. *Journal of Latin American Anthropology.* 4(1):166-197. Print.

Hodell, David A., Mark Brenner, Jason H. Curtis and Thomas Guilderson.

2001 Solar Forcing of Drought Frequency in the Maya Lowlands. *Science*, 18 May (pp.1367-1370). Print.

Hodder, Ian.

1999 *The Archaeological Process: An Introduction*. Blackwell Publishers. Massachusetts. (pp241)

Iannone, Gyles.

1999 Archaeological Investigations at Minanha, Belize: A Research Proposal. In *Archaeological Investigations in the North Vaca Plateau Belize: Progress Report of the First (1999) Field Season,* edited by Gyles Iannone, Jeffrey Seibert, and Nadine Gray, pp. 1-28. Social Archaeology Research Program, Department of Anthropology. Trent University, Peterborough. Print.

2001 Archaeological Investigations at Minanha, Belize. The 2001 Research Proposal. In *Archaeological Investigations in the North Vaca Plateau, Belize: Progress Report of the Third (2001) Field Season*, ed. G. Iannone, R. Primrose, A. Menzies, L. PcParland, pp.1-3. Social Archaeoology Research Program. Dept. of Anthropology, Trent Unviersity. Peterborough. Print.

2005 The Rise and Fall of an Ancient Maya Petty Royal Court. *Latin American Antiquity*. Vol. 16, No. 1 (Mar., 2005) pp. 26-44. Print.

2006 Detailed Description of the Proposed Phase II Research. In *Archaeological Investigations in the North Vaca Plateau, Belize: Progress Report of the Eighth (2006) Field Season*, edited by Gyles Iannone, Jeffrey Seibert, and Jason Seguin, pp. 12 – 26. Department of Anthropology, Trent Universtiy, Peterborough. Print.

2007 Archaeological Research at Minanha: Summary of the 2007 Investigations. In *Archaeological Investigations in the North Vaca Plateau, Belize: Progress Report of the ninth (2007) Field Season*, edited by Gyles Iannone and Scott Macrae. Social Archaeology Research Program, Department of Anthropology, Trent University, Peterborough. Print.

Jennings, J.N.

1985 *Karst Geomorphology*. Basil Blackwell Ltd. pp.293. Print.

Johnston, Kevin J.

2004 Lowland Maya Water Management Practices: The Household Exploitation of Rural Wells. *Geoarchaeology*. 19:265-292. Print.

Kelley, Jane H. and Marsha P. Hanen.

1988 Archaeology and the Methodology of Science. University of New Mexico Press. Alburquerque. Print.

Knox, Paul L.

1991 The Restless Urban Landscape: Economic and Sociocultural Change and The Transformation of Metropolitan Washington, DC.*Annals of the Association Of American Geographers*, Vol. 81, No. 2 (Jun., 1991),pp. 181-209.

Kueny, Jeffrey A, and Michael J. Day.

2002. Designation of Protected Karstlands in Central America: A Regional Assessment. *Journal of Cave and Karst Studies.* 64(3):165-174.

Laswell, Scott, Susanne J. McDonald, Alan D. Watts and James M. Brooks.

1972. *Determination of Particle Size Distribution (Gravel, Sand, Silt and Clay) in sediment samples*. Laser Geo-Environmental. Austin Texas 78748. Web. New Series, Vol. 74.No.3 (June.1972)pp.411-425

Lawrence, Henry W.

1993 The Greening of the Squares of London: Transformation of Urban Landcapes and Ideals. *Annals of the Association of American Geographers*. Vol.83. No.1 (Mar. 1993) pp.90. Print.

Lawrence, Denise L. and Seth M. Low.

1990 The Built Environment and Spatial Form. *Annual Review of Anthropology*. Vol. 19. pp. 453 – 505. Print.

Leeder, M.R.

1982 *Sedimentology: Process and Product*. George Allen and Unwin. London. 344p. Print.

Lohse, Jon C.

2010 Archaic Origins of the Lowland Maya. *Latin American Antiquity* 21(3): 312-352

Lucero, Lisa J, Joel D. Gunn and Vernon L. Scarborough.

2011 Climate Change and Classic Maya Water Management. *Water* 2011, 3,479; www.mdpi.com/journal/water. WEB (last accessed: 05, 09, 2011)

Metcalfe Sarah, Ann Breen, Malcolm Murray, Peter Furley, Anthony Fallick and Angus Mackenzie

2009 *Journal of Quarternary Science*. vol 24, issue 6. pp. 627-641 (Sept.)

Mann, Carroll J., and Robert G. Wetzel.

2000 Hydrology of an Impounded Lotic Wetland.Wetland Sediment Characteristics. *Wetlands*. Vol. 20 No. 1., March 2000 (pp. 23-32). Print.

Marfia, A.M., R.V. Krishnamurthy, E.A. Atekwana, W.F. Panton.

2004 Isotopic and geochemical evolution of ground and surface waters in a karst dominated geological setting: a case study from Belize, Central America. In *Applied Geochemistry* 19. pp. 937-946. Print.

Marshall, Jeffrey S.

2007 The Geomorphology and Physiographic Provinces of Central America.in Central America: Geology, Resources and Hazards. ed. Bundschuh Jochen and Guillermo E. Alvarado. Taylor and Francis. London. 1,436pp.

Mazzullo, S.J.

2006 Late Pliocene to Holocene platform evolution in northern Belize, and comparison with coeval deposits in Belize and the Bahamas. *Sedimentology*, 53, 1015-1047. Print.

McKillop, Heather.

2006. *The Ancient Maya New Perspectives*. W.W. Norton and Company, New York (453pp.) Print.

Midlarsky, Manus I.

1995 Environmental Influences on Democracy: Aridity, Warfare, and a Reversal of the Causal Arrow. *The Journal of Conflict Resolution.* Vol. 39, No. 2 (Jun., 1995), pp. 224-262.

Mikkuta R., M. Kleber, K. Kaiser and R. Jahn.

2005 Review: Organic Matter Removal from Soils using Hydrogen Peroxide, Sodium Hypochlorite, and Disodium Peroxodisulfate. *Soil Sciences Society of America Journal*. 69:120-135. Print.

Miller, Thomas E.

1996 Geologic and Hydrologic Controls on Karst and Cave Development in Belize. *Journal of Cave and Karst Studies* 58(2):100-120.

Moore, D.C.

1995 The Geography of Soils. Laboratory Manual. Concordia University. Department of Geography: Geog 477/7. Winter 1995. Personal Communication.

Newell, William H.

2001 A Theory of Interdisciplinary Studies. *Issues in Integrative Studies*. No. 19, pp. 1-25. Print

Newell, William H and William J. Green.

1982 Defining and Teaching Interdisciplinary Studies. In *Improving College and University Teaching*. Vol. 30, No. 1 (Winter, 1982), pp. 25-30. Print.

O'brien Michael, Dennis E. Lewarch, Roger D. Mason and James A. Neely.

1980 Functional Analysis of Water Control Features at Monte Alban, Oaxaca, Mexico. *World Archaeology*, Vol. 11, No. 3. Water Management (Feb, 1980), pp. 342-355. Print.

Olson, Sherry H.

1979 Baltimore Imitates the Spider. *Annals of the Association of American Geographers,* vol. 69 no. 4 (Dec.1979) pp. 557-574

Orser, Jr. Charles E.

2001 The Anthropology in American Historical Archaeology. *American Anthropologist,* New Series, Vol. 103, No. 3 (Sep., 2001), pp. 621-632. Print.

Ortega-Gutierrez Fernando, Luigi A. Solari, Carlos Ortega-Obregon, Mariano Elias - Herera, Uve Martens, Sergio Moran-Ican, Mauricio Chiquin, John Duncan Keppie, Rafael Torres de Leon and Peter Schaaf.

2006 *The Maya Chortis Boundary: A Tectonostratigraphic Approach.* Instituto de Geologia, Universidad Nacional Autonoma de Mexico, Department of Geological and Environmental Sciences, Stanford University, USA, Universidad de San Carlos, Coban, Guatemala and Instituto de Geofisica, Universidad Nacional Autonoma de Mexico. WEB

Ortloff, Charles R.

2009 *Water Engineering in the Ancient World. Archaeological and Climate Perspectives on Societies of Ancient South America, the Middle East, And South-East Asia.* Oxford University Press: New York. Print.

Peet, Richard.

1985 The Social Origins of Environmental Determinism. *Annals of the Association of American Geographers*. Vol. 75, No.3 (Sep.1985)pp.309-333. Print.

Peterson, Larry C, G. Haug.

2005. Climate and the Collapse of the Maya Civilization. A series of multi-year droughts helped to doom and ancient culture. *American Scientist* 93(4)322-329. Print.

Philpot, Simone.

2007 Excavations in the Mayo Aguada at Minanha: The 2007 Field Season. In *Archaeological Investigations in the North Vaca Plateau, Belize: Progress Report of the ninth (2007) Field Season*. ED. Iannone, Gyles and Scott Macrae. 2007. Social Archaeology Research Program. Dept.

of Anthropology, Trent University, Peterborough.
Primrose, Ryan.
2001 A Preliminary Assessment of Minanha's Water Management System in *Archaeological Investigations in the North Vaca Plateau, Belize: Progress Report of the Third (2001) Field Season*. ed. G. Iannone, R. Primrose, A. Menzies, and L. McParland pp. 99-109. Social Archaeological Research Program. Dept. of Anthropology, Trent University.
2002 The Ancient Maya Water Management System at Minanha, West Central Belize. A Thesis submitted to the Committee of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Arts in the Faculty of Arts and Science. Trent University, Anthropology M.A. Program, Peterborough. Ontario, Canada.
Polk, James S, Philip E. van Beynen, Philip P. Reeder.
2007 Late Holocene environmental reconstruction using cave sediments from Belize. *Quaternary Research* 68(2007) 53-63. Print.
Purdy, Edward G, Eberhard Gisschler and Anthony J. Lomondo.
2003 The Belize Margin Revisited. 2. Origin of Holocene antecedent topography. *International Journal of Earth Sciences* (Geol. Rundsch)(2003) 92:552-572. Print.
Reeder Philip, Robert Brinkman and Edward Alt.
1996 Karstification on the North Vaca Plateau, Belize. *Journal of Cave and Karst Studies*. (58)(2):121-130. Print.
Renfrew, Collin and Paul Bahn
1996 Archaeology: Theories Methods and Practice. Second Edition. Thames and Hudson, New York 608pp.
Rice, Don S.
1993 "Eighth Century Physical Geography, Environment and Natural Resources in the Maya Lowlands" in *Lowland Maya Civilization in the Eighth Century A.D.: A Symposium at Dumbarton Oaks 7th and 8th October, 1989.* (pp. 2-46) Washington, DC. (eds). Sabloff, Jeremy A. and John S. Henderson. Dunbarton Oaks Research Library and Collection, 20. Print.
Rockstrom, J.
2003 Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth Parts ABC* vol., 28, Issue: 20-27, pp. 869-877. Print.
Rosenfield, Jushua H.
2003 Economic Potential of the Yucatan Block of Mexico, Guatemala, and Belize. The Circum – *Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics,* American Association of Petroleum Geologists Memoir 79, pp 340-348.
Ruddiman, Wm. F.
2008 Earth's Climate Past and Future. Second edition, W.H. Freeman and Co., New York, 388 pp. Print.
Salazar, Karla L. Davis.
2006 Late Classic Maya Drainage And Flood Control At Copan, Honduras. *Ancient Mesoamerica*, 17 pp.125-138. Print.
Scarborough, Vernon L.

1991 Water Management Adaptations in Nonindustrial Complex Societies: An Archaeological Perspective. *Archaeological Method and Theory*, vol. 3 pp 101-154. Print.
1993 "Water Management in the Southern Maya Lowlands" *Research in Economic Anthropology Supplement 7: Economic Aspects of Water Management in the Prehispanic New World.* Ed. Scarborough Vernon L, BarryL. Isaac. Connecticut : JAI Press INC. 17-119. Print.
1998 Ecology and Ritual. Water Management and the Maya. *Latin American Antiquity*. Vol. 9, No. 2 (Jun., 1998), pp. 135-159. Print.
2003 *The Flow of Power: Ancient Water Systems and Landscapes*. Santa Fe. The School of American Research. Print.

Schiffer, Michael B.
1983 Identification of Formation Processes. In *American Antiquity.* Vol. 48, No. 4, pp. 650-706. Print.

Shabad, Theodore.
1959 Non-Western Views of the "Hydraulic Society". *Annals of the Association of American Geographers*, Vol. 49, No.3 (Part 1) (Sept. 1959) pp. 324-325. Print

Shanks, Michael and Ian Hodder.
1997 Cognitive Archaeology. *Reader in Archaeological Theory: Post-Processual and Cognitive Approaches*. Ed. David S. Whitley. New York and London: Routledge. 35-48. Print.

Sharer, Robert J.
2006 *The Ancient Maya*, 6th edition. Stanford University Press, Stanford, CA.

Sluyter, Andrew.
2006 Intensive Wetland Agriculture in Mesoamerica. Space, Time and Form. In *Annals of the association of American Geographers.* vol. 84,Issue 4. pp. 557-584. Dec. 1994 Vanoni, Vito A. (ed.). Sedimentation Engineering. American Society of Civic Engineers. Virginia. (413pp). Print.

Smyth, Michael P. Christopher D. Dore, and Nicholas P. Dunning.
1995 Interpreting Prehistoric Settlement Patterns: Lessons from the Maya Center of Sayil, Sayil, Yucatan. *Journal of Field Archaeology*, Vol. 22, No. 3 (Autumn, 1995). Print.

Stark, Barbara L.
1999 Formal Architectural Complexes in South-Central Veracruz, Mexico. A Capital Zone? *Journal of Field Archaeology*. Vol. 26, no.2 (Summer, 1999)

St. Hilaire, Maxime Lamoureaux.
2011 The Last Inhabitants of Minanha, Belize: Examining the Differential Abandonment of an Ancient Maya Community. Thesis submitted to the Committee of Graduate Studies in Partial Fulfillment of the Requirents for the Degree of Masters of Arts in the Faculty of Arts andScience. Anthropology M.S. Graduate Program. Trent University Peterborough, Canada. (Oct. 2011). 174pp. Print.

Turner, Billie Lee, II and W.C. Johnson
1979 A Maya Dam in the Copan Valley, Honduras. *American Antiquity* 44:299-305.

Trigger, Bruce.
1989 *A History of Archaeological Thought*. Cambridge University Press. New York. (498pp). Print.
1990 Monumental Architecture: a thermodynamic explanation of symbolic behaviour. World Archaeology, Vol. 22, No. 2, Monuments and the Monumental. (Oct.1990), pp.119-132. Print.
Vanoni, Vito A. (ed).
2006 *Sedimentation Engineering*. American Society of Civic Engineers.
Virginia. 2006 (413pp). Print
Wahl David, Thomas Schreiner, Roger Byrne and Richard Henson.
2007 *Latin American Antiquity*, 18(2), pp.212-222. Print.
Watson, Michael O and Edward T. Hall.
1969 On Proxemic Research in *Current Anthropology*, vol. 10, No. 2/3 (Apr – Jun), pp. 222-224. Print.
Watson, Patty Jo.
1995 Archaeology, Anthropology, and the Culture Concept. *American Anthropologist*. New Series, vol. 97, No. 4. (Dec. 1995), pp. 683-694. Print.
Webster, David.
n,d. The Uses and Abuses of the Ancient Maya. Prepared for *The Emergence of the Modern World* Conference. n.d. Otzenhausen Germany. Print
2002 *The Fall of the Ancient Maya*. Thames and Hudson, London. Print.
Webster, James W, George A. Brook, L. Bruce Railsback, Hai Cheng, R. Lawrence Edwards, Clark Alexander and Philip P. Reeder.
2002 Stalagmite evidence from Belize indicating significant droughts at the time of Preclassic Abandonment, the Maya Hiatus, and the Classic Maya collapse. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 250 (2007) 1-17. Print.
Weiss-Krejci, Estella and Thomas Sabbas.
2002 The Potential Role of Small Depressions as Water Storage Features in the Central Maya Lowlands. *Latin American Antiquity*, Vol. 13, No.3 (Sep.,2002),pp.343-357. Print.
Wells, Christian, E and Lorena D. Mihok.
2010 Ancient Maya Perceptions of Soil, Land and Earth. *Soil and Culture*. (ed.) E.R Lander and C. Feller, pp. 311-327. Springer. New York. (E.C. wells and L.D. Mihok). 2010. Print.
Whitley, David S.
1997 New Approaches to Old Problems: Archaeology In Search of an Ever Elusive Past. *Reader in Archaeological Theory: Post-Processual and Cognitive Approaches*. Ed. David S. Whitley. New York and London: Routledge. pp.1-28. Print
Wittfogel, Karl A.
1957a. *Oriental Despotism: A Comparative Study of Total Power*. Yale University Press, New Haven. Print.
1957b. Chinese Society: An Historical Survey. *The Journal of Asian Studies*. Vol. 16, No. 3 (May, 1957), pp. 343-364. Print.
Young, Anthony.
1976 Tropical Soils and Soil Survey. Cambridge University Press

New York. 468p. Print.

WEB resources:

Department of Sustainable Natural Resources Soil Survey Standard Test Method. Particle Size Analysis.
http://naturalresources.nsw.gov.au/care/soil/soil_pubs/soil_tests/pdfs/psa.pdf (last accessed: November 15, 2011

2012 NASA : http://earthobservatory.nasa.gov/ (last accessed: Feb. 1, 2012)