GEOGRAPHIC AND ENVIRONMENTAL INFLUENCE ON MAYA SETTLEMENT
PATTERNS OF THE NORTHWEST YUCATAN: AN EXPLANATION FOR THE
SPARSELY SETTLED WESTERN CENOTE ZONE

by

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ABSTRACT

Most settlement pattern research and GIS analysis of the ancient Maya of the Northern Yucatan have focused on water availability in a dry landscape where cenotes are often the only water source. While water is of paramount importance, permanent settlement secondarily requires farmable soil, a resource often as precious as water in many parts of the Yucatan. The dynamics between these resources reveal areas of ideal settlement and more challenging landscapes for which the Maya developed strategies to overcome environmental conditions. A region of the southwest "Cenote Zone", however, appears to have presented the ancient Maya with insurmountably poor environmental conditions despite abundant water resources. The lack of dense population and stone architecture in this area emphasizes the lack of a simple correlation between cenotes and settlement. This thesis uses GIS analysis to identify and explore such problematic settlement areas to better understand the factors and complexities involved in the more successful settlements of neighboring regions.

Keywords: cenote, chultun, rejollada, soil, Maya, Yucatan, GIS

This work is dedicated to my late father, who first introduced me to the Mundo Maya through a

visit to the ruins of Tikal at the age of nine, and who instilled in me strength, curiosity, and a

love for exploring the world.

ACKLOWLEDGMENTS

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INTRODUCTION

The southwest area of the Chicxulub Rim (Fig 7.) is the location of a large region glaringly empty of even the most basic ancient Maya settlements. This empty quarter highlights the lack of a simple correlation between cenotes and Maya sites. Covered by a wealth of cenotes, the primary and often only potable water sources in that area, and surrounded by settlements of all sizes and time periods that found ways to cultivate the harsh landscape, what then prevented the Maya from developing this expanse? Did political, economic, or cultural factors render this no-mans land an unsafe or unwise place to settle for the Maya, or did environmental and geographical barriers preclude habitation? Furthermore, what implications might this lack of settlement have on our understanding of Maya settlement choices of the larger surrounding area, on comprehending the intricacies of the relationship between the Maya and the natural world that they inhabited, and on explaining the complexities of population decline? A neighboring area just to the east and still within the Chicxulub Rim have had similar queries posed by Brown et al. (2006), but this area has dozens of lower ranking sites, and upon survey and closer inspection of much of the area, that team found several more large ruins, some indicative of quite large settlements. I believe the southwestern region, however, will yield little in the way of such settlement upon closer inspection and survey. This is due to the particular geology of the region which here has created a trough of sorts which, although providing an excellent conduit for fresh water, has prevented the development of soils suitable to agriculture. Therefore, this geographic region presented the ancient Maya with a formidable landscape that was insuperable or perhaps simply not worth the manpower to alter and cultivate into a

settlement able to support a dense population on the level of stone-architecture building Maya sites.

The landscape of the Maya world (Fig. 1) offers a variety of environmental challenges and opportunities from mountainous rainforests to flat dry coastal regions. The primary focus of this research centers on the Northwest Yucatan peninsula, an area where many prominent sites did not really begin to burgeon until the Late Classic Period (550 - 800 A.D.), some enjoying most of their fluorescence during the Terminal Classic Period (800 - 900 A.D.), a time when many sites of the Petén and more central Maya heartlands had already been largely abandoned to the jungle. However, Preclassic Period (2000 B.C. - 250 A.D.) fluorescence is demonstrated in Maya sites like Yaxuna, Dzibilchaltun, and Komchen. The site of Xtobo in particular is an excellent example of this early settlement, having been abandoned after the Preclassic and thus allowing a rather unique archaeological insight into the time period in this area, and containing an advanced, sophisticated, and densely populated community complete with ballcourt, pyramids, and other markers of Maya cultural heritage (Anderson 2011). Smaller settlements appear even earlier in the archaeological record, and several key sites still held populations during the conquest and early colonial era, but the ruins suggest a hierarchical fractal settlement of the apex of ancient Maya population and monumental architecture of the region through the Terminal Classic.

Given the preference of many ancient, and indeed modern, cities and settlements to form and grow along rivers or some source of fresh water, a cursory glance at the distribution of many of the grandest of Maya ruins as related to proximity of such fresh water bodies would surely be

puzzling. Majestic cities like Tikal and Caracol seem purposefully and irrationally built away from easy access to fresh water sources that would have made every day life easier. While these sites and others are dotted with various sized reservoirs, if the modern condition of some of these reservoirs is any indication, even a well kept stagnant pool in the jungle was likely a far cry from a crystal clear spring after a period without replenishing cleansing rain through dry season spells. Were these once grand cities built at high points for defensive purposes, to be closer to the gods, and/or the great view and intimidating show of a polity's might and wealth through command of labor forces afforded by imposing structures such as Canaa at Caracol or Templo I of Tikal? Other cities, such as Palenque, are interlaced with waterfalls and streams, needing drainage systems in the rainy season so as not to flood. But the area of study here is by far the driest area of ancient Maya occupation (Winemiller 2003: 102), necessitating an entirely different strategy for water management and distribution.
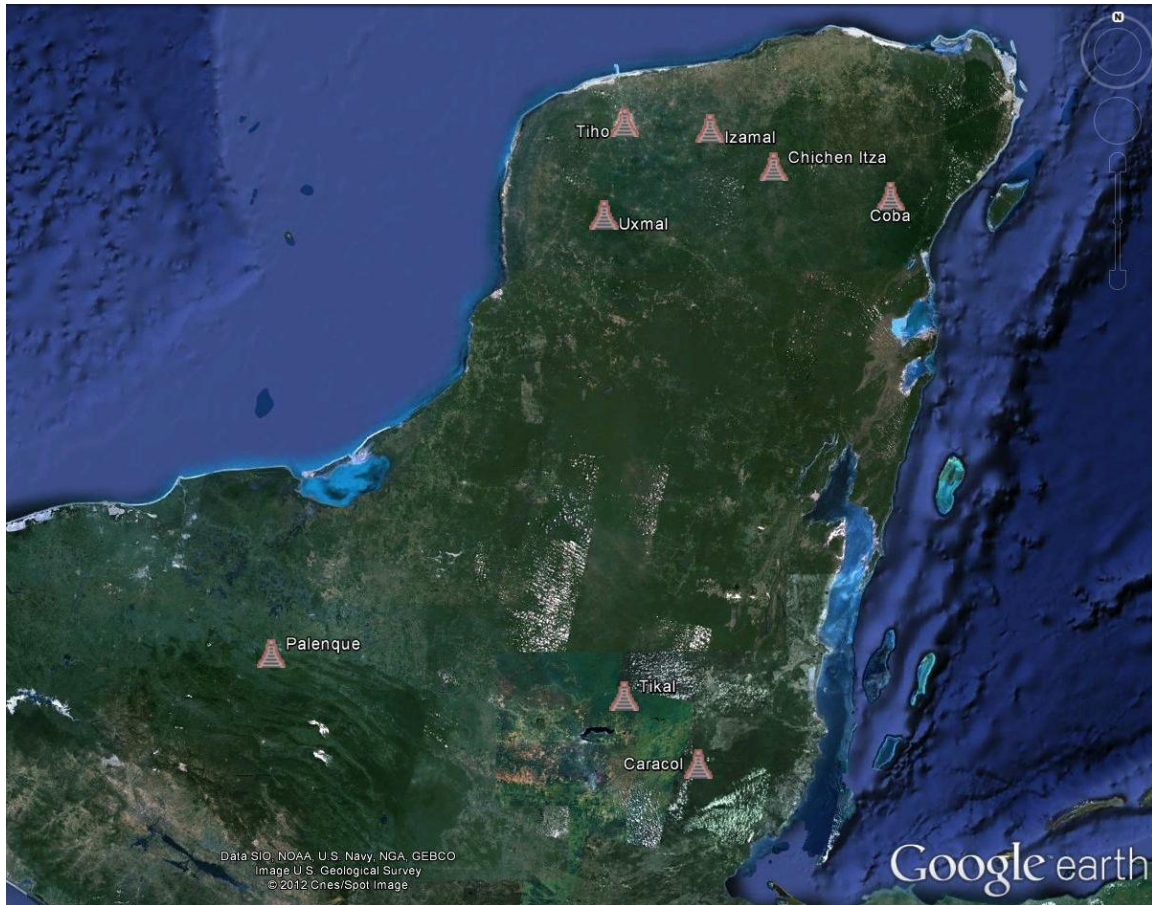
Figure 1: Yucatan Peninsula and Maya world, with some of the sites mentioned in text.

The physical environment and landscape have always heavily influenced location and distribution of Maya settlements throughout their history (Dunning 1992; Dunning and Beach 2011). Of chief concern in planning and analyzing archaeological research and results are the causal relationships between environmental factors and settlements patterns. "Cenote", a Spanish word derived from the Yucatec Mayan "dz'onot", is the name given to any well naturally formed by a sinkhole in Mesoamerica. They are often the only source of water throughout the northern Yucatan, especially in the western area (Winemiller 2003: 115-126).

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Like caves, they were seen by the ancient Maya as entrances to Xibalba, the underworld, but their life-giving waters made them all the more important. In addition to their obvious uses for drinking water, irrigating crops, and the many other functional uses of a water source, these sacred symbols were often the scene of ritual. Today some make excellent objectives for underwater archaeology, containing ceramics and other artifacts, and even human skeletal material (Romey 2004: 21). Today cave divers seek cenotes to enter this underworld to map and chart the tunnels and underwater rivers created by this remarkable geological phenomenon.

A source of water is paramount to any human settlement for basic survival. As the population increases in a settlement, more water is required. The Maya relationship with cenotes was profound, both for practical purposes and as a connection to the underworld. Preferred areas around cenotes were built upon by the Maya of the Late and Terminal Classic Periods, who built wondrous architecture in epicenters supported by the surrounding rural populations and agriculture (Kepecs and Boucher 1996; McAnany et al. 2006: 125-127). Many know of Chichén Itzá and its famous Sacred Cenote or Well of Sacrifice, but the abundance of water in this and many other cenotes of the area and the suitable soil is truly what allowed for the rise of Chichén Itzá and its ability to gather the wealth displayed in artifacts recovered from its depths.

Cenotes are not the only geographic and environmental factors influencing Maya settlement, however. The unique geology of the Yucatan, its soils, vegetation, and relationship to the surrounding coastlines, in addition to the culture, politics, and economics of the Maya themselves, all played vital roles in determining the location of what are now the ruins of Yucatec Maya civilization. Physiographic regions under primary discussion in this paper are the

coastal district of the Northwest Yucatan, the Puuc, and the Merída district. The landscape of the ancient Maya, as with all civilizations, heavily influenced settlement patterns, and nowhere is this more apparent than in the Northern Yucatan Peninsula (Fig. 2). A sufficient source of potable water is naturally of paramount importance, with decent soil a close second to allow for the possibility of a dense population distribution supported by intensive agriculture. In the Northwest Yucatan, virtually all groundwater may be found via cenotes, sinkholes either exposing a window to underground rivers and water passages or to deep pools of more stagnant groundwater (Winemiller 2003: 94-97). Soil quality varies across the landscape as a result of its geologic history and precipitation distribution, as will be addressed later, but anomalous pockets of richer soils may be found in rejolladas, dry sinkholes often the leftovers of more ancient dried up cenotes (Winemiller 2003: 115-116).

Given this environmental and geographic layout then, some preferences of the reality of ancient Maya settlement may seem puzzling at first glance, some of which may be explained by an understanding of the cultural adaptations of the Maya, and others by a careful look into and comparing various sets of geographic data through the help of GIS software. The full picture emerges, however, by keeping both of these tools in mind and marrying them with previous research and emerging data about the political and economic landscape to pinpoint and either support or refute ideas about the Northern Yucatec Maya.

CHICXULUB CRATER AND THE CENOTE ZONE

The Chicxulub Crater (Figure 2) is an impact structure dating to about 65 million years ago, placing the devastating asteroid impact event at the end of the Cretaceous Period and casting it as the prime suspect for the mass extinction of the dinosaurs as suggested by the K-T boundary, a geologic signature with high levels of iridium (Hildebrand et al. 1991: 898). The crater is more than 180 kilometers in diameter, making the feature one of the largest confirmed impact structures in the world; the impacting superbolide that formed the crater was at least 10 km in diameter (Hildebrand et al. 1995: 415). This alien impact legacy must be kept in the mind when tackling some archaeological questions, lest the geologic record, from shock-melted quartz and tektites to ejecta far beyond the crater boundaries, be misinterpreted when analyzing such phenomena as building materials and distribution patterns when the geographic origins of certain artifacts like quartz jewelry or use in water filtration could be in doubt. The layers of rocks on top of the impact feature are made up of limestone and marl to depths of nearly 1,000 meters dating back to the Paleocene. Settled under these are over 500 meters of breccia and andesite glass (Hildebrand et al. 1995: 415). The perimeter of the crater, roughly defined as a 5km wide area with a radius of about 90km, is now home to a slew of cenotes so clustered (thousands) that it has been dubbed the "Cenote Zone", or "Anillo de Cenotes" (Figure 8), suggestive of the idea that a water basin, a naturally formed moat, existed within the bowl through the Tertiary period, after impact (Pope and Ocampo 1996: 527). This theory would allow that basin's groundwater to dissolve the limestone and create the caves and cenotes now dotting the region, its ring faults and sedimentation laying the literal groundwork for the water flows, soil buildups, and intricate cave system of today (Pope and Ocampo 1996: 527). However, not all caves are formed equally, and

the attributes of the various cavities throughout the landscape, such as size, depth, water level, salinity, and alkalinity are just a few of the important variables. In addition, we must keep in mind the lifecycles of these features and how these variables have themselves changed through time (van Henstrum et al. 2010: 2795-2796).
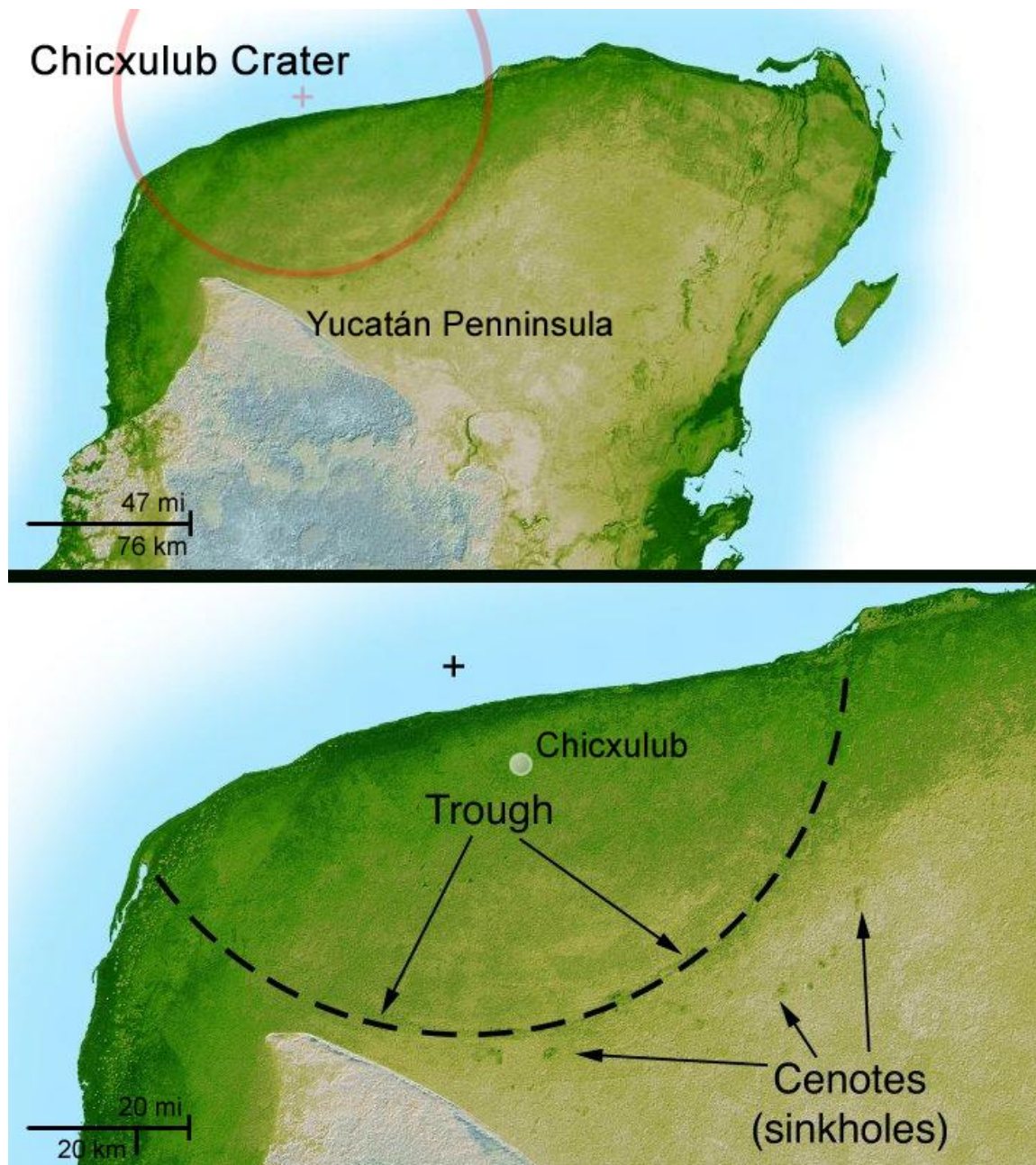
Figure 2: Reimagining the Chicxulub crater through NASA's Shuttle Radar Topography Mission (NASA/JPL 2003)

A more geological definition of a cenote is a wall-sided doline at least partially filled with water. The Yucatan holds over 3,000 cenotes, with less than half of that number studied and

charted in any way. Some cenote networks are only part of a large once-dry cave system; others flow with a current out to sea and therefore contain a halocline with freshwater sitting atop the salty seawater layer; and, still others are singular isolated pits that have filled with rainwater and groundwater over the years. Local modern Maya distinguish between several other characteristics, having more to do with ease of access than anything (Mathews and Morrison 2006: 64-65, See also Winemiller 2003). One group is essentially underground lakes, like the locally famed thirteen cenotes of Las Grutas de Tzabnah of Tecoh. In some cases, such as that of X'tacumbilxuna'an, these pools were some distance underground, making access difficult, and requiring ladders and some sort of assembly line of clay jars and ollas to carry water to the surface. Partially underground cenotes lie at the bottom of a pit; land level cenotes function as lakes or pools like the popular tourist and local swimming hole of Dzibilchaltun. A fourth distinction, open wells, are, for all intents and purposes, springs with water flowing toward the surface and able to be directed like rainwater; examples of this kind of cenote are found at Chichén Itzá, and may help explain that site's rise to prominence through advanced water management (De la Mata et al 2004: 2-3).

The formations of the many cenotes were not a concurrent event, of course giving rise to the question of whether or not these wells were present during given periods of Maya habitation. Some that were formerly used may have been covered over by debris and are now unrecognized; conversely, some may be the result of more modern collapses and, thus, inaccessible and nonexistent to the ancient Maya. However, the geological time periods these formations go through is easily long enough to encompass the entire history of the Maya. In any case, the stages for the development of a cenote are as follows. Solution caverns form when naturally

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acidic groundwater seeps through cracks in the limestone bedrock and dissolves areas of softer rock lying beneath the hard surface crust (Dreybrodt et al. 2009: 202). Over time, this process creates large underground caverns roofed with only a thin layer of surface limestone. A young cenote appears as erosion continues and its thin roof eventually collapses, leaving an open, water-filled hole. Cenotes are known as mature when, after thousands of years, erosion gradually fills the cenote with organic and mineral debris, reducing its depth (Mathews and Morrison 2006: 63-64). The Cenote of Sacrifice at Chichén Itzá is currently in this stage. Finally, at the end of its life as a well and symbolic entrance to Xibalba, a cenote is aptly called "dry" when, as erosion continues, it completely fills, becoming a waterless, shallow basin supporting trees and other vegetation; it then becomes a "rejollada". Another related feature is a "dzadz", the Maya term for a karst fenster, which is a similar doline that only just touches the water table and so usually contains a mix of water and wet soil; however, dzadzob are far less common than rejolladas (Mathews and Morrison 2006: 63-65). In fact, the distinction between dzadz and cenote, along with size and other attributes, may also be correlated with rank-size of archaeological site (Brown and Witschey 2003: 1620-1623), and site organization.

Caverna Cuarteles, a large dry cave near El Zacatón Cenote, provides more evidence of this variation in cave systems (Sahl et al. 2011: 226). The traditional "top down" theory of cave formation is that rock was slowly carved out through dissolution from somewhat acidic water on the surface that seeped down. While this is certainly one fashion whereby caves are formed, the process can occur bottom up. Both Cuarteles and neighboring Zacatón started to take shape throughout the Pleistocene as a consequence of volcanic activity, which made the deeper water

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acidic and eroded the surrounding limestone in a process known as hypogenic karstification (Sahl et al. 2011: 232-233).
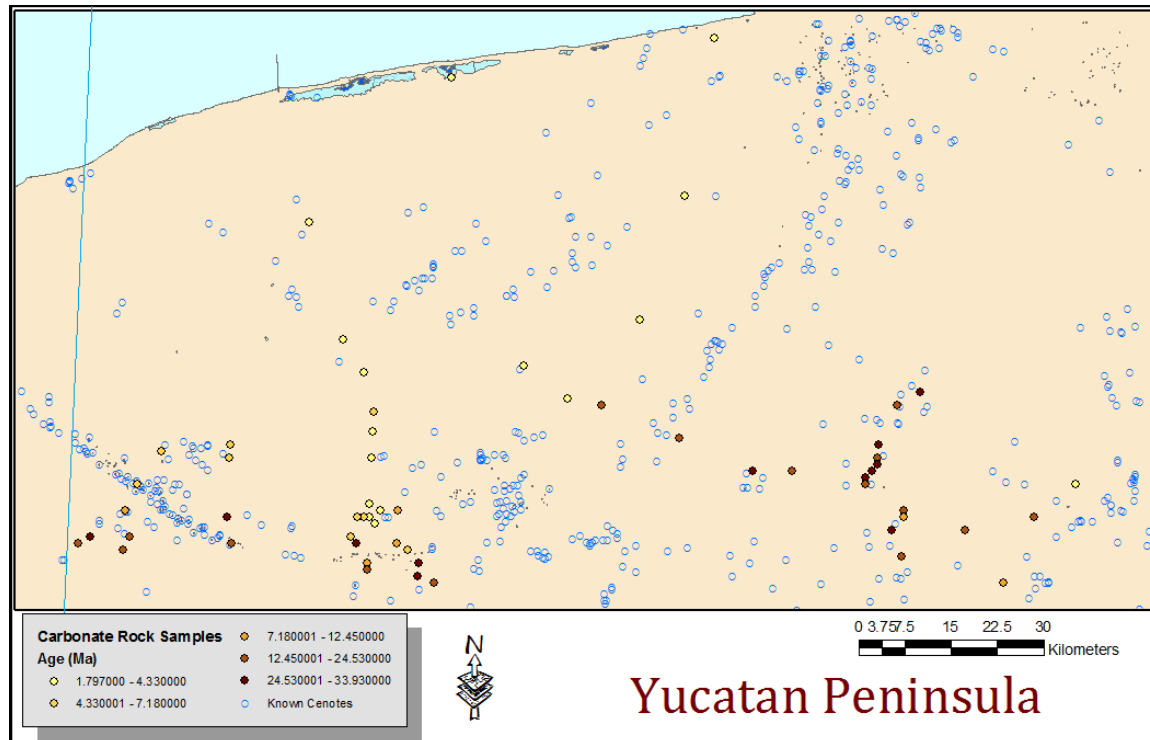
Figure 3: Locations of cenotes and dated rock samples define crater rim densely in the southwest but somewhat more dispersed into "ripples" in the east.

Due to factors such as thick vegetation, its advanced age, and its only slight change in sea level, the appearance of the Chicxulub Crater features may not be apparent to the average observer of satellite images of the Yucatan. However, the legacy of Chicxulub appears as a clear gravity anomaly in NASA imagery and the rim can be made out in certain SRTM images.

Strontium isotope dated rock samples, when plotted spatially (Figure 3), also not only display this crater basin rim but aid in the realization that the rim is not a paper-thin, clear-cut, perfect circle, but the varied corridor that one would expect from such a violent impact (Gilli et al. 2009: 724). The seemingly secondary outside concentration of cenotes has been postulated to "relate to subsurface control by the fallback material." (Short 2009: 1). The surface geology of the leftovers of the impact crater has been reexamined and better defined in recent years. The Strontium isotope data recovered from outcrops of limestone carbonate rock expose similar signatures within the Cenote Zone, further establishing its identity as the Chicxulub Crater rim, its latest sediment fill dating to around the early Pliocene. "Discovery of a large terrain of near-uniform strontium isotope ratios in northwestern Yucatán offers new geoarchaeological opportunities to track ancient Maya migration and determine sources of manufactured goods. Our results have implications for applying the Sr isotope method to Maya archaeological sites, such as Mayapán, the last Maya capital, and Chichén Itzá." (Gilli et al. 2009: 723)

SOIL SCIENCE AND HYDROLOGY, PRECIPITATION AND DROUGHT

Like cenotes and caves, there is a discrepancy in the divisions and names of soil types between general Western vernacular, geologic, scientific terminology, and Maya categories (Bautista and Zinck 2010; Winemiller 2006: 139). Soil science and geology need a universal standard of pedological measurement based on texture, color, porosity, grain size, depth, etc.; but, due to the number of these aspects and the various degrees of importance placed on them depending on the subject of study, even in this there are multiple classifications; however, general terms are agreed upon with the most common general system being the World Reference Base for Soil Resources (WRB), with roots in USDA soil taxonomy (Nestroy 2007), and which terminology will be used here. The ancient Maya, on the other hand, are again primarily concerned with function when differentiating soils, the focus of attention placed on suitability (or not) for various types of agriculture and agricultural products.

The soil cluster with the greatest representation worldwide is Leptosols, a rocky and/or shallow layer of surface soil dispersed amongst outcrops of hard bedrock and compromising twelve percent of classified soils. This percentage doubles for the area of Mexico and jumps to eighty percent for the Yucatán (Bautista et al. 2006: 310-311, Figure 5). There are more detailed classifications of Leptosols, with qualifiers and adjectives added, but these still leave archaeological investigation in the Yucatan wanting. So, soil scientists, geologists, and archaeologists have turned to the local Maya themselves, for who better to aid in the understanding of Maya settlement and agriculture than the Maya, who settle and farm there? Some of the more common Mayan terms for soils include "*sahcab* or *sascab* (a soft weathered limestone marl), *ka'kab* (a red loamy soil), *ek lum* (a rich black soil), and *tzekel* (a stony soil)"

(Winemiller 2006: 139). The Yucatec Mayan terms for soil types are actually not very distant from the scientific system, which is not surprising given that modern soil science has its proverbial roots in agronomy and agriculture. This terminology has been tailored to this rocky karst Leptosol landscape based on centuries, if not millennia, of cultivation and generational knowledge (Dunning 1992: 30). Local inhabitants also hold a profound understanding of indigenous flora (Bautista and Zinck 2010: 8). In the early 1990s, Dunning further defined these Maya terms, and in the mid 2000s Bautista and company performed new comprehensive surveys, both using the WRB classification system and asking Maya peasant farmers to identify and describe soil types based on similar standards as the WRB, but in their own terminology; they also ground-truthed the classifications in the field, the lowlands of the northern Yucatán. "The MSC and WRB classifications are complementary. It is recommended to use both systems for a maximum level of detail, as together they offer a good vision of the soil resource in the study area." (Bautista et al. 2006: 1) Figure 4 is an excellent aid toward visualizing the soil distribution of the Yucatan with geomorphology also considered; however, it fails to incorporate the Maya system, as was recommended (Bautista et al. 2011).
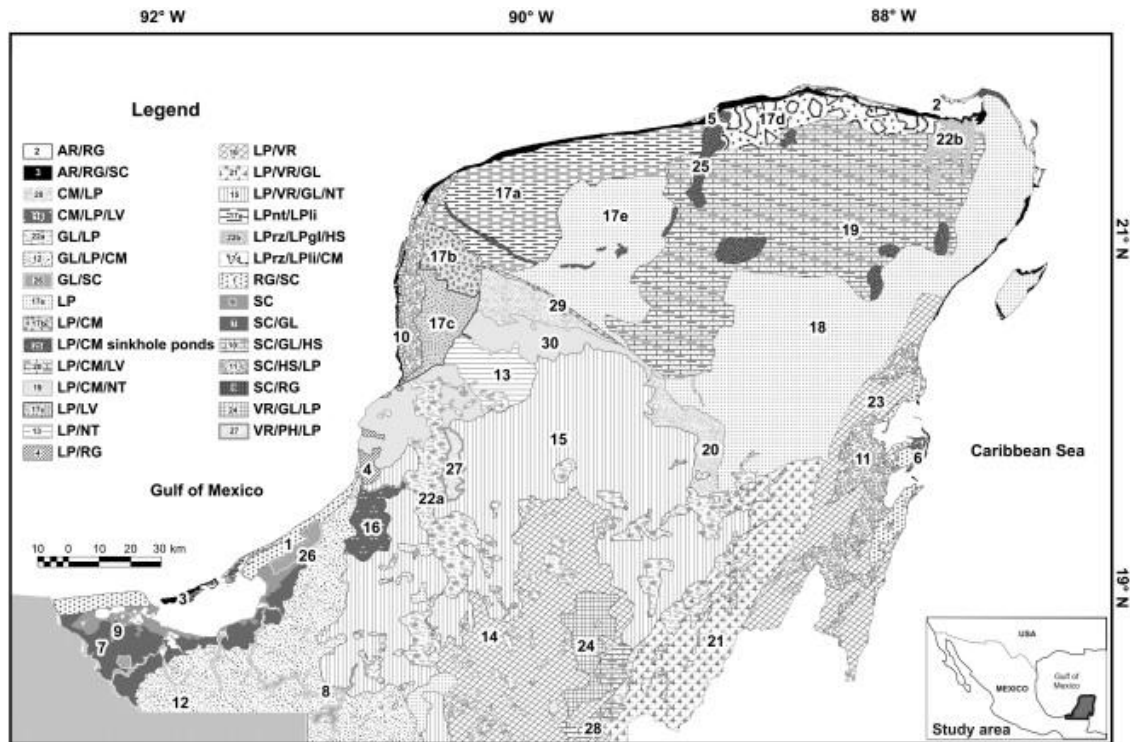
Figure 4: Soilscapes of the Yucatan considering geomorphology and soils. LP = Leptosols, CM = Cambisols, VR = Vertisols, GL = Gleysols, SC = Solonchak, RG = Regosols, AR = Arenosols, NT = Nitisols, PH = Pheozems, HS = Histosols, nt = Nudilithic, li = lithic, rz = Rendzic, and gl = gleyic (Bautista et al. 2011: Fig. 5)

Edaphology, the study of how soils affect vegetation and other life forms, is also important and elucidating to settlement strategies of the region (Figure 10), and indeed in a way it might be said that the Maya system is a functional marriage between the practical aspects of edaphology and parts of pedology. This brief overview is enough for our purposes, but a further review and understanding of modern Maya agricultural habits and soil terms, as matched with scientific terminology, can be found in "Lords of the Hills: Ancient Maya Settlement in the Puuc Region, Yucatan, Mexico" (Dunning 1992: pp. 29-38).

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Precipitation, general climate, and environmental history are also important to consider in the waxing and waning of settlement patterns in any region. Overall trends in climate change like overarching weather patterns, average temperature, and average rainfall have not permanently altered the landscape drastically in the past two thousand years, but one of those trends may actually be a 200-year cycle of drought. Geologists at the University of Florida have undertaken reconstruction of the climatic history of the Yucatan by examining lake-sediment cores from the area. Their data uncovered a recurrent pattern of drought with a dominant periodicity of 208 years (Hodell et al. 2005). They also concluded that this periodicity corresponds with what is believed to be 206-year cycles of spikes in solar flare activity and that the former is a direct consequence and result of the latter. Some "discontinuities in Maya cultural evolution" (Hodell 2001: 1), also fall within these drought maxima, a likely explanation for the relatively short-lived Terminal Classic Period florescence of about 200 years. The prospect of thousands starving can surely be an impetus for mass migration and possible emptying of a large percentage of a city's population, forcing either their absorption by neighboring polities or, if enemies, the exploitation of this weakness for capture and possible sacrifice. These cycles of solar activity and drought may reflect the cycles of time expressed through Maya astrology or calendric divination (Van Stone 2011: 15-16), which predicts periods of drought during two katuns especially, 3 Ahau and 10 Ahau, one for each baktun half, a period of just under 200 years. Turner (2010), however, makes sound arguments for the inclusion of many other contributing factors for decline, and certainly many settlements with an abundance of cenotes would have been virtually unaffected by all but the most extreme droughts, if not immune to the aforementioned pressures of effected neighboring populations.

CULTURAL ADAPTATION

The environmental pressures and geographic playing field of the ancient Maya have already hinted at effects on Maya culture and civilization, but cultural preferences and adaptations molded the role these external factors played in the constant feedback between culture and environment. Chichén Itzá and its polity have Puuc architecture in their roots and early years, but it has been argued that a Toltec invasion established a foreign influence and created a Toltec-Maya culture with its capital at Chichén Itzá but extending into the Merída area, a narrative refuted in recent years though allowing for cultural borrowing between Central Mexican peoples and the site of Tula in particular (Kowalski and Kristan-Graham 2007). In any case, Puuc sites show less of this influence than do their flatland neighbors, and instead display a very unique and distinguished architectural style with Chaac mask facades, advanced corbelled vaults, and concrete core foundations (Smyth 2006; Carmean et al. 2011). This cultural and political rift appears to evolve from a settlement based on environmental advantage, yet the divergent cultural adaptations to these geographic boundaries may have in turn served to reinforce settlement loci while discouraging opportunities in others through political pressures.

Chunchucmil, an outlier of the Puuc region, has stronger Puuc cultural affiliations relative to most other contemporary sites outside the Puuc geographic region, despite easy and abundant clean water access (Luzzadder-Beach and Saner 2000) and sparse soils, the opposite of the typical Puuc sites. Findings at the site through chemical and physical soil analysis concur with the arboriculture and shifting cultivation models practiced outside the Puuc (Sweetwood et al. 2009). Perhaps due to its location and the conditions there, Chunchucmil declined far earlier

than the Puuc proper despite valiant efforts to intensify agricultural yields (Dunning and Beach 2010) in the beginning of the Late Classic after a relatively short-lived florescence (Dahlin et al. 2005: 344). Bruce Dahlin (2009: 348-350) argues that this relatively early florescence of dense population yet sprawling architecture was the product of Chunchucmil's function as an advanced economic trade hub, connecting maritime traders with inland populations, allowing it to overcome the environmental drawbacks of its physical geography and providing an excellent example of an exception to settlement in the region dictated by environment alone.

No matter how the water comes to a people and is accessed, management is key to maintaining the livelihood of the populace throughout the year. Palenque had all manner of methods to channel and manage water, including aqueducts, bridges, dams, drains, walled channels, pools, and likely even knowledge of water pressure systems (French and Duffy 2010). Though Palenque may be uniquely advanced in its city planning when it comes to water control, all major settlements took measures to insure a yearlong water supply. In parts of the dry Puuc region where there are no cenotes nearby, chultunob' were installed to collect and store water and sustain life through the dry season (Dunning 1992: 60-62). To accomplish this, chambers were carved out of the limestone and lined with lime stucco. Considering that the limestone might be carved with relative ease, it might indeed have been possible for the Maya to hunt down solution caverns waiting to become cenotes and helped them along with manpower. If so, how might they have been able to find these locations, and what evidence of such carving would be required to confirm such a theory? The age of a cenote can be vaguely determined by the stability and sharpness of its outer rim, a technique that might be honed to detect cenotes that have formed in recent centuries and perhaps even determine which were likely to form during

the Late and Terminal Classic periods. A large portion of the Northern Yucatan presents a layer of *sascab*, the Yucatec Maya term for the hard surface layer of limestone just above bedrock. The strength and depth of this *sascab* layer affected the ability and methods used by the Maya to dig chultunob', wells, and modify aguadas (Winemiller 2003), and simultaneously provided the added benefit of using this excavated limestone for building material and stucco (Folan 1978: 80). Perhaps, taking note in the variation in sascab, the Maya were able to best predict not only where to dig wells but where wells might give way to cenotes. In addition, natural depressions in the rolling Puuc hills were modified by the ancient Maya to form aguadas, reservoirs, or *xuch*. These varied larger water holders have been best explored at the eponymous western Puuc site of Xuch (Isendahl 2011). These modifications to the landscape, along with chultunob', could explain the sites far from cenotes, but what about the cenotes far from sites (Fedick and Morrison, 2004: 210)? Why were all cenotes not used extensively and, therefore, have signs of nearby associated settlement? The answer is the same as the reason for heavy settlement and population density in the northern Puuc region: soil quality.

The unique landscape discussed above, the Chicxulub legacy, high density of minor fault lines, and climate disparities left a degree of variation in soil quality at the micro level that is lost on a cursory glance of soil data in the region at large (Figure 11). This will be explored further in GIS analysis, but even that does not cover the micro world of Maya agriculture, best exemplified in the rejollada phenomena. Rejolladas contained rich soil deposits left over from dried-out cenotes. These were cultivated extensively throughout the region (Kepecs 1996: 70), as they are still today in the form of primarily fruit trees. Though non-endemic crops like mango and banana are becoming more popular and slowly replacing species familiar to the pre-

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Colombian inhabitants, in many modern rejolladas chicozapote, avocado, nance, and other native crops are still grown (Triplett and Arden 2006), including a remnant cacao species, *Theobroma cacao*, identified near Valladolid (Gomez-Pompa et al. 1990). This association may help explain the location and prominence of Chichén Itzá, one of many high-ranking stratified sites where cacao was considered highly valuable. The beans of cacao may have been used as currency and, therefore, controlled by elites (Kepecs and Boucher 1996: 82; McAnany and Murata 2007: 14). There is even a perfect example of supportive iconographic evidence in the form of a Chichén Itzá frieze portraying elites presumably dancing amidst monkeys in a cacao grove growing out of a depression, undoubtedly a rejollada (Kepecs and Boucher 1996). In addition, the ancient Maya transported rich earth from rejolladas and other pockets of accretion back to their settlements to improve agricultural yield (Dunning and Beach 2010: 379). Minor pouches of soil discovered in bedrock were also cultivated as "container gardening", so named for the ability of the bedrock to contain moisture along with the fairer soils and produce isolated pockets of trees and other crops (Fedick and Morrison 2004). Existing geographical data for these natural rejollada agriculture hot spots, anthropogenic soil distribution, and minute container gardens are almost non-existent. Though not reflected in the GIS analysis of the greater area to follow, it may be hoped that some further geographic survey, whether carried out by geologist, archaeologist, soil scientist, or government worker or cartographer of any kind, will take note of such features and include them in data tables. Previous GIS research has included rejolladas on a more micro level.

Geographers at Kent State (Munro-Stasiuk et al. 2011) have used GIS to analyze the site of Xuenkal, a Rank II site at the eastern outskirts of the Cenote Zone, and investigate its relationship with rejolladas. The epicenter, and indeed all surveyed buildings at Xuenkal,

corresponds to an area of density of rejolladas as well. In fact, some house mound plazas were built with a rejollada in their centers, whilst other structures sit on the edge of a depression.

In truth, these agricultural oases dot the land in even greater numbers than cenotes and caves, and archaeological markers accompany them in many areas and mark forgotten oases of years past. Agricultural vestiges also come in the form of berms, small rock and cobble piles called "chich" mounds, which combined as a sort of functional mulch and stabilizer for young vulnerable trees (Kepecs and Boucher 1996, Scarborough et al. 2003); small localized limestone quarries known as "sascaberas"; modified and terraced slopes; and, even walled rejolladas in rare cases associated with elite centers, and most likely serving as a barrier of control (Munro-Stasiuk et al. 2011). The historical development of these agricultural plots was quite gradual and highly localized for agricultural endeavors (Scarborough et al. 2003: 104), perhaps as much a result of the environment as from Maya political, economic, and social organization – and, perhaps in this case, the latter a result of the former. There is also a correlation in size between rejollada and structures, in that the biggest rejollada near the epicenter lies in the shadow of the largest building at Xuenkal (Munro-Stasiuk et al. 2011). The ruins of the northeast Yucatan, in a region known as Yalahau, display this same size correlation but with cenotes and dzadzob rather than rejolladas, and confirm an elite control over preferred water sources, with smaller settlements utilizing cenotes with narrow openings (Fedick and Morrison 2004: 210).

Therefore, we must take into account size, both surface area and depth, of cenotes, dzadzob, and rejolladas when predicting and analyzing size and scale of ancient Maya settlement. Again, any future surveying or GIS data gathering should be advised to include such measurements in these endeavors, if at all possible.

Some major centers like T'ho were positioned around fault lines, most likely because of their disposition for forming sinkholes, and thus cenotes, as can be seen in Figure 5. This knowledge could be utilized to check specific areas for well drilling and chultunob' activities.
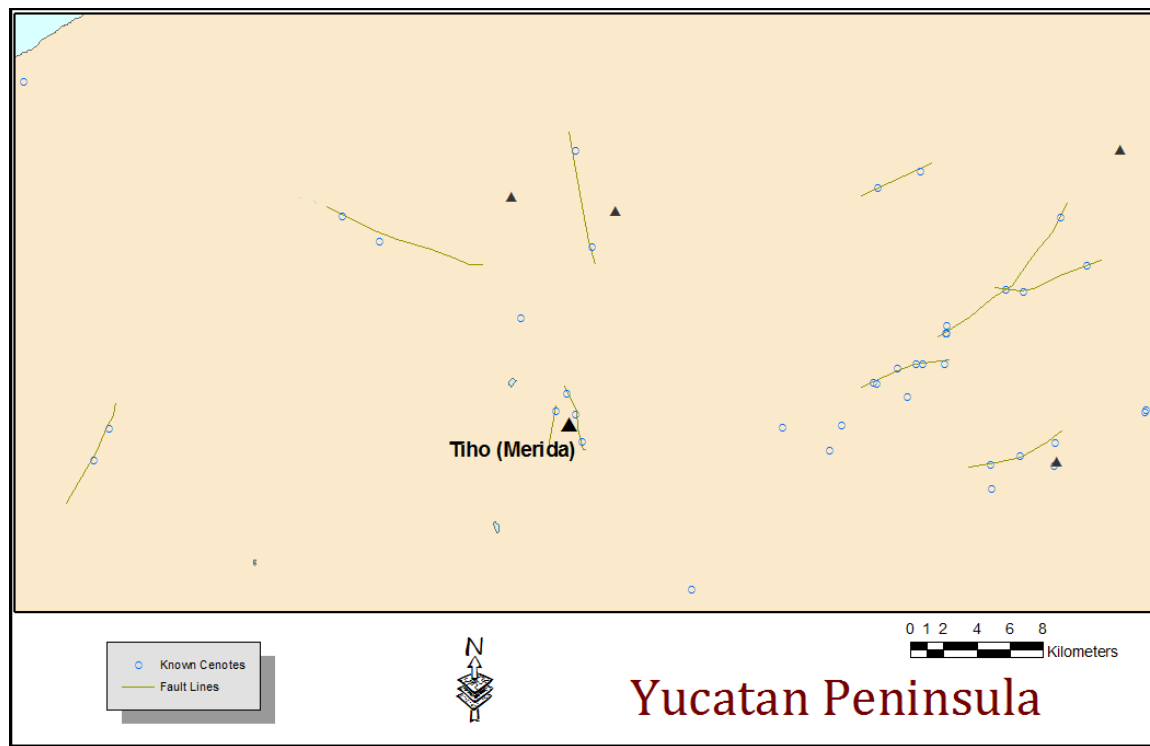
Figure 5: The site of T'ho has easy access to cenotes and is surrounded by fault lines.

Cenotes along fault lines and/or close to coastlines often connect one to another in an underground cave system of a flowing underground river, their water levels affected daily by tidal motion rather than the more slowly changing water levels of single lone cenotes not connected to others or to the sea, and thus containing no saltwater underbelly or tidal flow. The Maya may have noted the difference between these and interacted with them in different

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manners according to their needs and the attributes of each cenote, and perhaps even according to their cosmic world view, especially if different cenote types and sizes had varying status as underworld portals or associations with different gods.

In addition to a spiritual or cosmological connection, the ancient Maya may have had a more functional relationship to the discrepancies in these underground conduits, turning understanding into resource advantage and perhaps political gain or elite control. In many instances, especially along the Caribbean coast of the Yucatan, several cenotes belong to a connected web of underground tunnels (Figure 6). Today locals use this knowledge to find nearby cenotes or to open new man-made wells with little effort rather than wait for nature to provide her sinkholes. If the ancient Maya were privy to this understanding and utilized the information in a similar fashion, perhaps an unnatural alteration of the limestone might be indicated by similar markings as those found at chultunob' or sascaberas. If a set of criteria could be formed for such indicators, even more light might be shed on the technological and even political control the Maya had over cenotes.
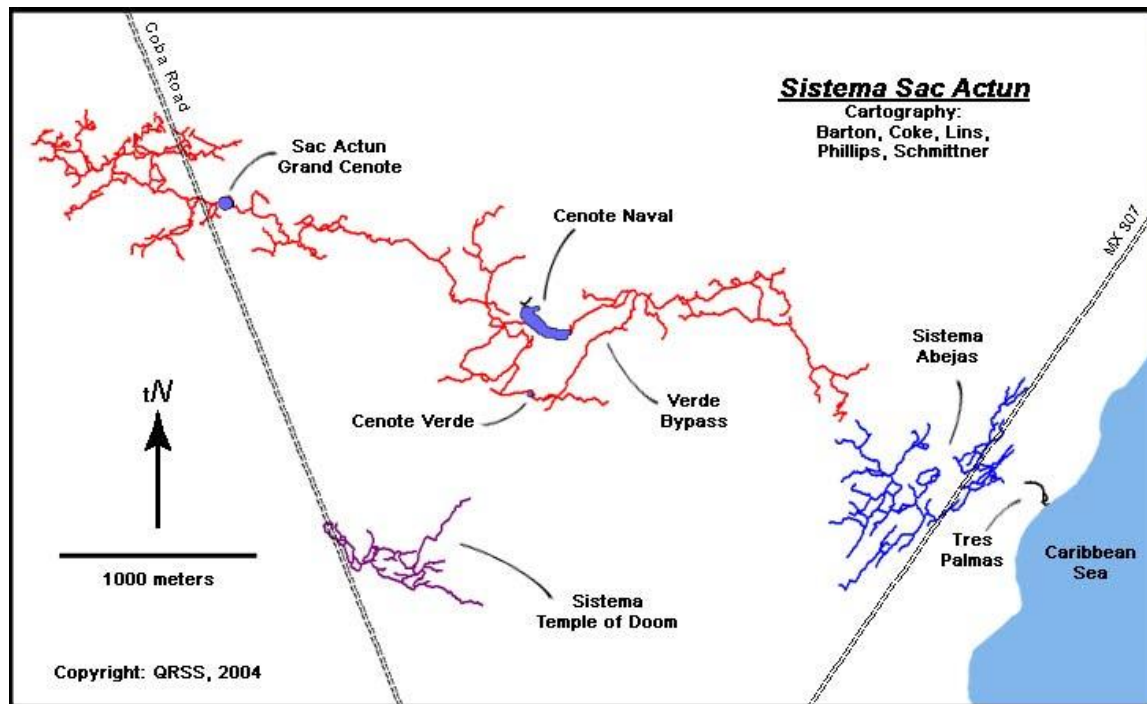
Figure 6: Map showing underwater tunnels connecting cenotes of Sistema Sac Actun. (Quintana Roo Speleological Survey, 2004)

Cenotes are providers of life water but also are associated with the entrance to the land of the dead. Were sacrifices perhaps not only to ask the Maya rain god Chaac to bring rains, but also to appease his and/or the earth monster's (a deity associated with cave openings imagined as the creature's mouth) appetite for swallowing up the earth in the literal real-world display that may have been witnessed if any ancient Maya saw the violent formation of a cenote formation through rough collapse? The sheer number of such caves dotting the landscape makes this occurrence highly probable. Perhaps the occasional collapse was even spurred on by human action while attempting to dig a chultun and becoming the sudden sacrificial victim of the earth monster via collapse.

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If the Maya did recognize predictable areas more prone to cenote formation, perhaps from subtle differences in sascab and the condition of the ceilings of nearby cenotes, surely they would be drawn to these areas. Again, if future survey and data collecting made distinctions and notes of the type of cenote by its several classifications, there might indeed emerge a preference and clustering of settlement for certain cenote attributes over others. This deficit should soon be resolved, thanks to the fervor of interest in diving and exploring throughout the Maya world. Guillermo de Anda (2007), in particular, has been leading dives in the Merída area as the coordinator of the Universidad Autónoma de Yucatán's underwater archaeology department, but recent discoveries from surveys have not published location names or coordinates for fear of looters scooping up artifacts. As is, alkalinity, salinity, and water table will serve the purposes of initial analysis. Of course, the wealth of cenotes in the region is known both for tourist cool-off spots and specific famous wells of sacrifice associated with major sites like Chichén Itzá are well documented. The "Sacred Cenote" at Chichén Itzá was dredged in 1904 to the excitement of artifact recovery, and is back in the spotlight in recent years as the prime break-through to decode the formula of Maya Blue pigment, an astoundingly resilient paint sacred to the Maya (Arnold et al. 2008).

Of great significance, then, and important to keep in mind when discussing cenotes, is that each cenote is unique. Not only do they vary due to age and the previously mentioned lifecycle, cenotes are formed in different ways and take on vastly different qualities dependent upon the geology, geography, weather, and local vegetation. At Cara Blanca for instance, an area of recent cenote study in Belize (Lucero 2005), the limestone acting as bedrock for the area is crumbly. Thus underground rivers are less likely to form due to collapse, whereas the firmer

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stuff of the Yucatán and of the Maya Mountains allows for the renowned underwater rivers hundreds of miles long (Gondwe et al. 2010). Curiously, the cenotes of Cara Blanca, situated between Yalbac and a small site dubbed M195 complete with an 11-meter high pyramid, were devoid of heavy settlement despite the obviously convenient water supply they provided. Was the water unsuitable for drinking, or was some other factor at play? In this case the soils may be to blame, as they were unsuitable for crops around Cara Blanca, and therefore not likely or not practical to support a population (Lucero 2005: 354). The same possible scenario applies to an area of the Cenote Zone as defined in Figure 7's empty quarter.

Yaxha and other Petén centers are increasingly at least partially blamed for their own downfalls by way of environmental destruction or environmental stress combined with natural climate change pressures (Turner and Sabloff 2012), but whether the abandonment of several major Northern Yucatan sites was a consequence of this same population pressure and overuse of resources or if they were merely victims of the drought cycles and solar flares is still a matter of some debate. While keeping up with the population increases and depleting resources was surely part of the problem for the stability of Maya polities, most archaeologists agree there was no one single cause of collapse (Dunning et al. 2012; See also Turner and Sabloff 2012). Pollen and soil samples collected in an archaeological context to project how the ancients altered the environment, even if from bajos outside this area of study, contribute to our knowledge of Maya settlement as well. Through the beginnings of Maya history to the end of the Classic Period, rural populations doubled about every 400 years in the Yaxha-Sacnab basin (Rice and Rice 1990). Pollen data and soil analysis indicate the Maya deforested the area around their urban centers and construction altered the soil, and therefore, the productivity of the crops (Deevey et al. 1979).

Although this case was in lakes and swampy areas of the Petén much different than the cenote-riddled Yucatan landscape, similar pollutants and degradation to the water supply and soil may have eventually disrupted the Yucatan Maya, as well. The Maya Blue pigment previously mentioned was recovered as sludge at the bottom of the sacred cenote due to its resilience, but what other waste and run-off collected in the cenotes of urban centers may have acted as contaminants but left no trace after years of recovery?

In fact, shifting trade routes and economic and political changes may have played vital roles as well, especially for specific sites serving as trade hubs (Golitko et al. 2012). Obsidian origin is an excellent marker of Maya trade and distribution, and many sites in the Northwest Yucatan hold, predictably, and overwhelmingly central Mexican type of obsidian dating to the Terminal Classic period, especially in Chichén Itzá, whereas the Puuc is dominated by El Chayal obsidian (Golitko et al. 2012). This would seem a political and economic, as well as cultural divide, then, mirroring the geology and geography of the landscape. Mayapán has a more even mix, not only of Mexican and El Chayal obsidian sources, but also of Ixtepeque obsidian, perhaps supporting historical and ethnographic reports of its use as a Postclassic "capital" and mediator or stage for power struggles between the Xiu, Cocom, and other elite Maya families in the form of a *mul tepal*, Mayan for joint government, in a time seemingly of greater mobility and turmoil in the centuries leading up to Spanish conquest (Brown 2005).

Another consideration for geographic cultural divisions is migration. The Yucatan likely experienced its population increases and Terminal Classic fluorescence in part due to the collapse and abandonment of once grand sites of the Petén and other southern lowland regions of the Maya world. The Itza Maya are believed to have their roots near modern Flores, long before

returning to Lake Petén Itza after the power and majesty of Chichén Itzá waned (Caso Barrera and Aliphat 2002). Others like the Putun Maya have different and more muddled geographic origins. The varied cultural heritages and environmental conditions of the origins of these waves of northerly Maya migrations may have also influenced the initial preference of a group for certain environmental conditions which best mirrored that to which they were accustomed.

METHODOLGY

       ArcGIS software and Google Earth were employed to display, manipulate, and analyze geographic data, primarily in the form of downloaded shapefiles. Clifford Brown and Walter Witschey (2002) have made available to the public such a file containing all known ancient Maya sites after compiling locations and data from a myriad of sources, including their own extensive survey projects. Virtually all other geographic and environmental data of the Yucatan, including hydromorphology, geology, pedology (Figure 11), edaphology (Figure 10), cenote locations (Figure 8), faults, water table, elevation, salinity, alkalinity, aquifer vulnerability, water flow, precipitation, and drought, were all accessed via the Bitacora Ambiental del Programa de Ordenamiento Ecologico Territorial del Estado de Yucatan (Morin, 2012), which compiled data from various Mexican government surveys and data sets, including the Instituto Nacional de Estadistica y Geografia (INEGI). Strontium isotope data (Gilli et al. 2009) was compiled into a spreadsheet and converted to GIS display for spatial analysis. Each of these datasets were then converted and fed into ArcGIS, Google Earth, or both and examined separately and in conjunction with various combinations of related data to identify patterns, Maya settlement preference, and conditions that might preclude such settlement. Through these methods were the images here found created by the author unless otherwise cited, toward the goal of demonstrating the advantages and limitations of displaying settlement as related to resources on a macro scale.

GIS ANALYSIS

Geographic Information Systems are becoming more and more a boon to archaeologists as data sets are collected and made available to the public, and satellite imaging as found in easy to use programs like Google Earth become clearer and more accessible. For our purposes, distribution of known Maya sites and known cenotes are compared spatially to a variety of geographic data sets including dominant vegetation, pedology, geology and faults, water salinity, water alkalinity, and important consideration of the third dimension through topography and water table. All of these must be considered to understand Maya settlement patterns.

After scrutinizing many maps of the Northern Yucatan composed of the above varieties of data sets and all manner of combinations to search for patterns and trends and anomalies and outliers to these trends, the task fell to use all of the above background knowledge to explain or propose new theories for Maya settlement, and to create new models and ideas to predict the locations, sizes, and other important elements of Maya ruins still undiscovered or still under-examined. An area of about 400 square kilometers consisting of a large stretch of the southwestern Cenote Zone, as defined in Figure 7 and hereafter referred to as the SWCZ, is completely devoid of any known Maya sites of even low ranking status. Brown et al. (2006) have investigated a similar sized area of the Cenote Zone not far to the east of this area, in the region surrounding and just south of Mayapán, prompted by similar inklings, but this area has dozens of lower ranking sites, and upon survey and closer inspection of much of the area, that team found several more large ruins, some indicative of quite large settlements. Perhaps the SWCZ will also turn up such finds upon closer scrutiny, but for now the current data indicates no advanced settlement whatsoever, and begs an explanation. To explain this lack of development,

despite the abundance of water found in cenotes, which heavily covers this region even more than much of the rest of the ring, the above considerations and data were examined to determine if there were insurmountable barriers to ancient Maya habitation or if other reasons based on geographic and environmental data or on cultural and political motivations, could be responsible for this irregularity.
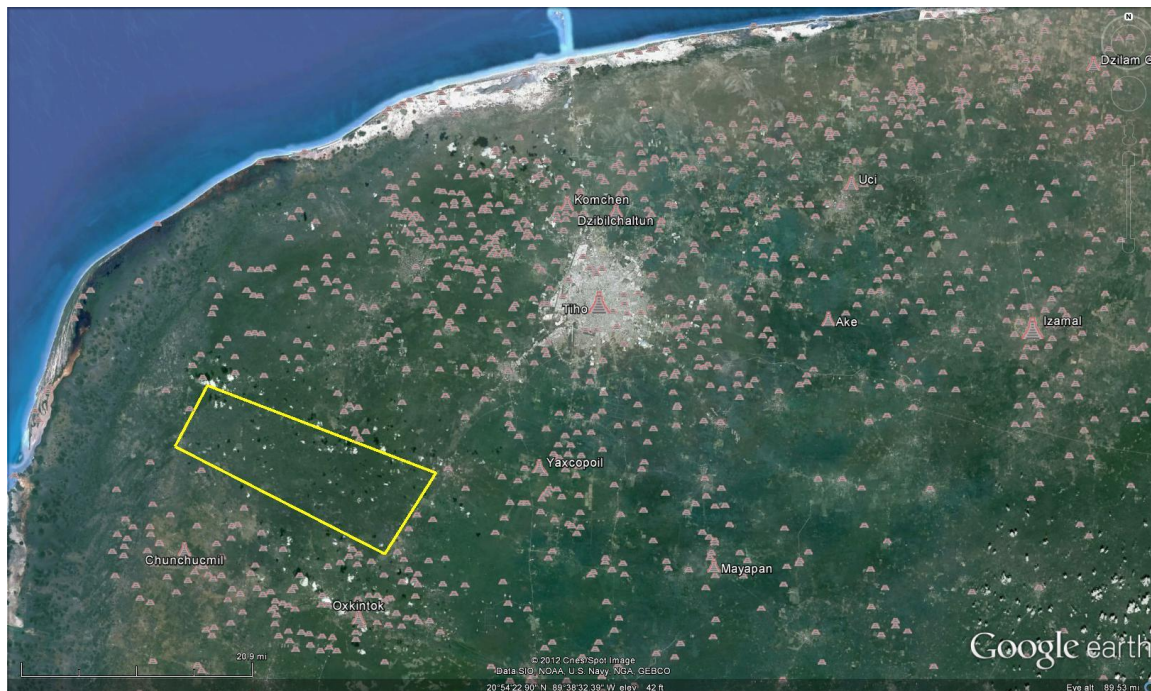
Figure 7: The area within the yellow quadrangle, the SWCZ (southwest Cenote Zone), contains no ancient Maya ruins of even the lowest rank.

One possible answer is water quality. Near the ocean, some cenotes' salt water layers are not as deep and distinct as they are further inland, and along the coastlines one may observe a clear border between the sea and settlements as a result of this phenomena, coupled with impenetrable mangroves allowing sparse population usually only in the form of a trade port or

small settlement that managed to find fresh water. Saltwater may intrude into unconfined aquifers, like that of the Yucatan (Beddows et al. 2007; Gondwe et al. 2010), and the salty seas surrounding the peninsula can encroach as much as 90 kilometers inland. Rather than create brackish water as in inter-coastal waterways, however, the denser seawater lies beneath the water table and forms a blurry halocline barrier separating freshwater from seawater. Nevertheless, saltwater incursions can generate fluctuations in the aquifer and exacerbate conditions that leave the water table vulnerable to contamination. Alkalinity also affects the usefulness of water from these wells, and once again portrays the uniqueness of cenotes in their varied water quality. Some may have poor quality water because of dissolved solids and accumulated salts not from the seas but as a result of high evaporation rates in this hot and arid region, especially through the dry season (Gondwe et al. 2010: 11). In some cases it actually becomes entirely undrinkable, and today is only used for watering livestock as a means to cool them in the hot tropics but not to sustain life. In the area in question, however, water quality and abundance does not seem to be an issue. The water table is deep enough and potable, and is not vulnerable to contamination nor sufficient degradation from dry conditions.

Slight elevation changes in a karst landscape are sufficient to create a gradient capable of directing and inducing greater velocities of water flow through bedrock and water conduits. Usually these conditions literally arise as a product of uplift or folding, often resulting in faulting and, therefore, a series of barriers and conduits to water flow that entirely shape the hydrology of the landscape, especially in an area riddled with them like the Northern Yucatan. We have already seen an example of this in T'ho, and similar relationships between population centers and these minor faults exist throughout the area, but the Cenote Zone itself is essentially a

massive fault and, therefore, a massive barrier to water flow. In fact the Chicxulub crater rim created a nearly continual ring fault, directing all water flow along its pathways rather than allowing any to cross through it and creating a thick region of water concentration and table depth greater than the surrounding areas (Pope and Ocampo 1996). Not only does this account for the high concentration of cenotes from an increase of hollowed out areas and therefore roof collapse, it also provides ample supplies of water throughout the year. At first this might sound like a boon to settlers, but it also serves to preclude of the formation of rejolladas and soil conditions suitable for intensive agriculture necessary for denser populations.
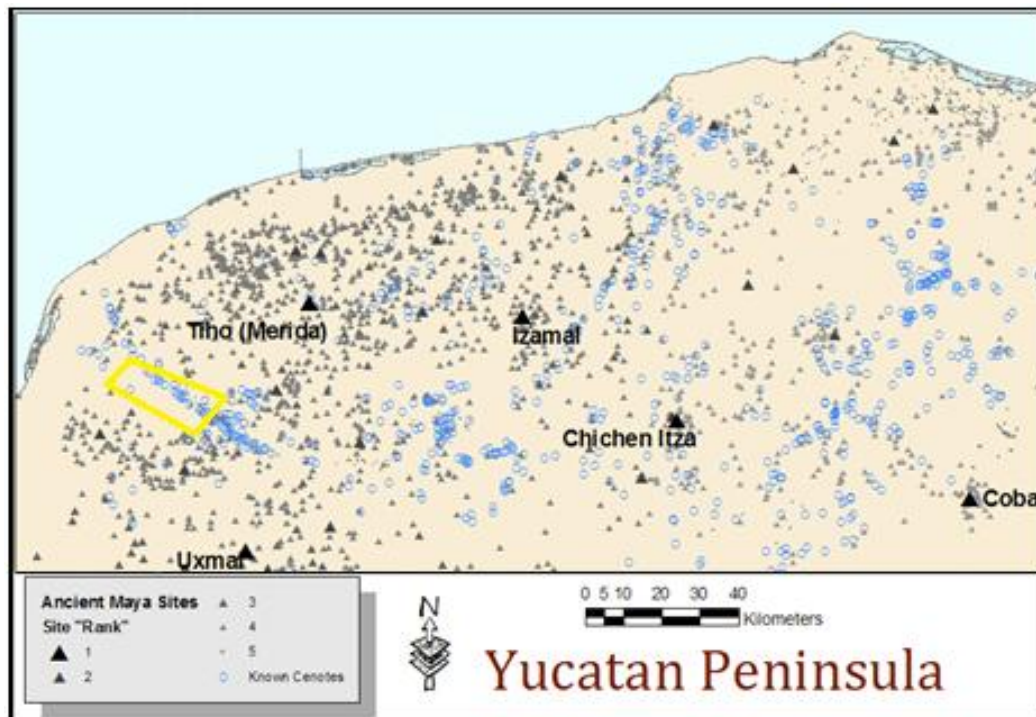
Figure 8: Maya sites cover the Yucatan but are oddly infrequent in some areas with high concentrations of cenotes.

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Other large sections of the Cenote Zone are sparsely settled as well (Figure 8). Some researchers, noticing these discrepancies, have surveyed an area of the central southern trough of the Cenote Ring around Mayapán; however, here they found a considerable number of additional sites to add to the database and were unable to draw too many conclusions (Witschey and Brown 2006). Is this a similar conundrum to Cara Blanca in Belize with its possible poor soil quality, or is there something else going on? Certainly political struggles cannot be ruled out and competition for control of water sources may have been a reality.

Most of the Cenote Zone not only lies within this markedly poor soil area (Figure 11), but the previously discussed geologic nature of the underground moat practically precludes the ring from any possibility of forming rejolladas, because all of the cenotes are part of this underground river system in some way or another, thus giving no opportunity for cenotes to "die" or dry up and form rejolladas. Perhaps this is why sites like Mayapán and Izamal lie on the edge or just beyond the periphery of the Cenote Zone, so that they may still enjoy the abundant fresh water supply provided in the dry season while still benefiting from rejolladas and proximity to regions of higher quality soil that they might transport toward the site as they did water from the opposite direction.
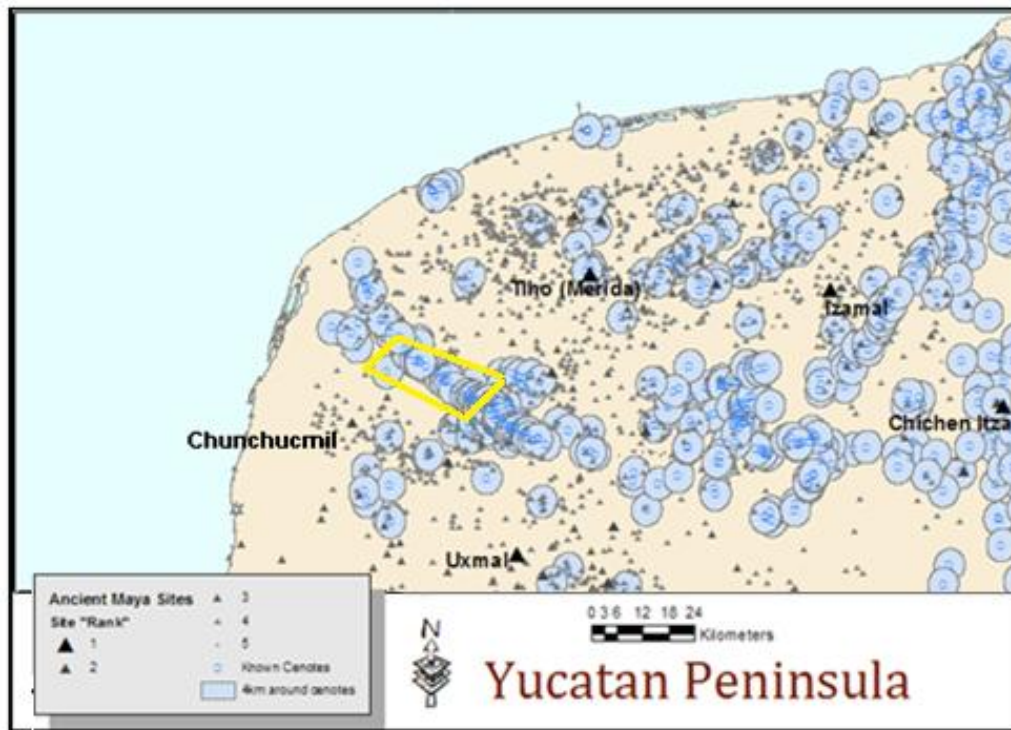
Figure 9: Buffers used to clarify sites outside of the range of easy access to cenotes.

On the other hand, some Maya sites are well out of range of cenotes (Figure 9). This conundrum, however, is more probably explained both by an absence of complete data on the thousands upon thousands of cenotes, especially in the case of small and easy to overlook openings utilized by the lower level sites that make up the majority of this discrepancy, in addition to the even better hidden sources of water through underwater pools. Larger sites like Uxmal and Chunchucmil are explained by their particular cultural adaptations discussed earlier, the chultunob' of the Puuc to afford abundant water in the former and the economic ingenuity of the latter to supplement poor agricultural conditions.
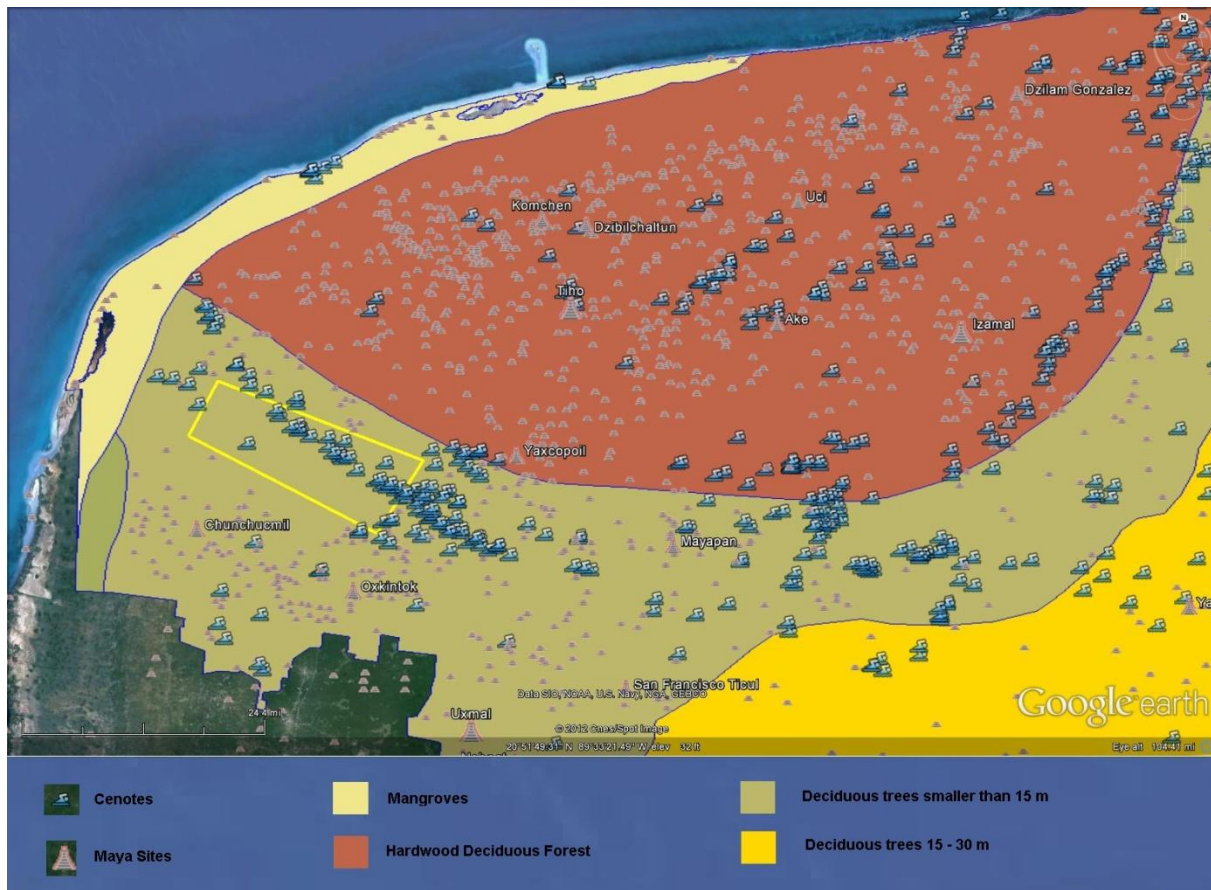
Figure 10: Vegetation trends, edaphology of the Northwest Yucatan

From Figure 10 we see how the general vegetation trends are also heavily affected by geomorphology. The map first stands out as yet another legacy of Chicxulub, with scarcer rains combining with fewer cenotes due to the crater rim runoff conduits and the resulting soil formations previously discussed. The implications of Maya settlement and culture, however, are an even more interesting interpretation of the map. Continuing the cultural adaptations of the Puuc line of thought, might the more gradual differences in architectural, ceramic, and other cultural markers between sites like Chichén Itzá and its polity, Mayapán, and T'ho be explained by this landscape? Different types and densities of trees and other vegetation may very well alter

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agricultural adaptations, if not as severely as the Puuc, and soil and precipitation have the same effect, as well as providing diverse local sources for clay and therefore altering the produced pottery. This map however, only shows gradual general trends as seen in vegetation type, and only begins to hint at a possible distinction between various sections of the Cenote Zone. Figure 11 takes another step toward answering the question of why our SWCZ quadrangle remains virtually unsettled while other sites within the Cenote Zone like Mayapán, Izamal, and many other secondary sites were able to prosper.

Winemiller (2003) has established that varied water resources and consequential water management adaptations, whether highly sophisticated or extremely basic, were not responsible for any hierarchy or discrepancy in the distribution of cultural markers of Maya civilization, such as architecture and epicenter layout on the macro level, despite the elite control of such resources on the micro scale as previously discussed. Soil and agricultural strategies, however, may have prompted cultural and political borders, if only through their necessarily geographic isolation.
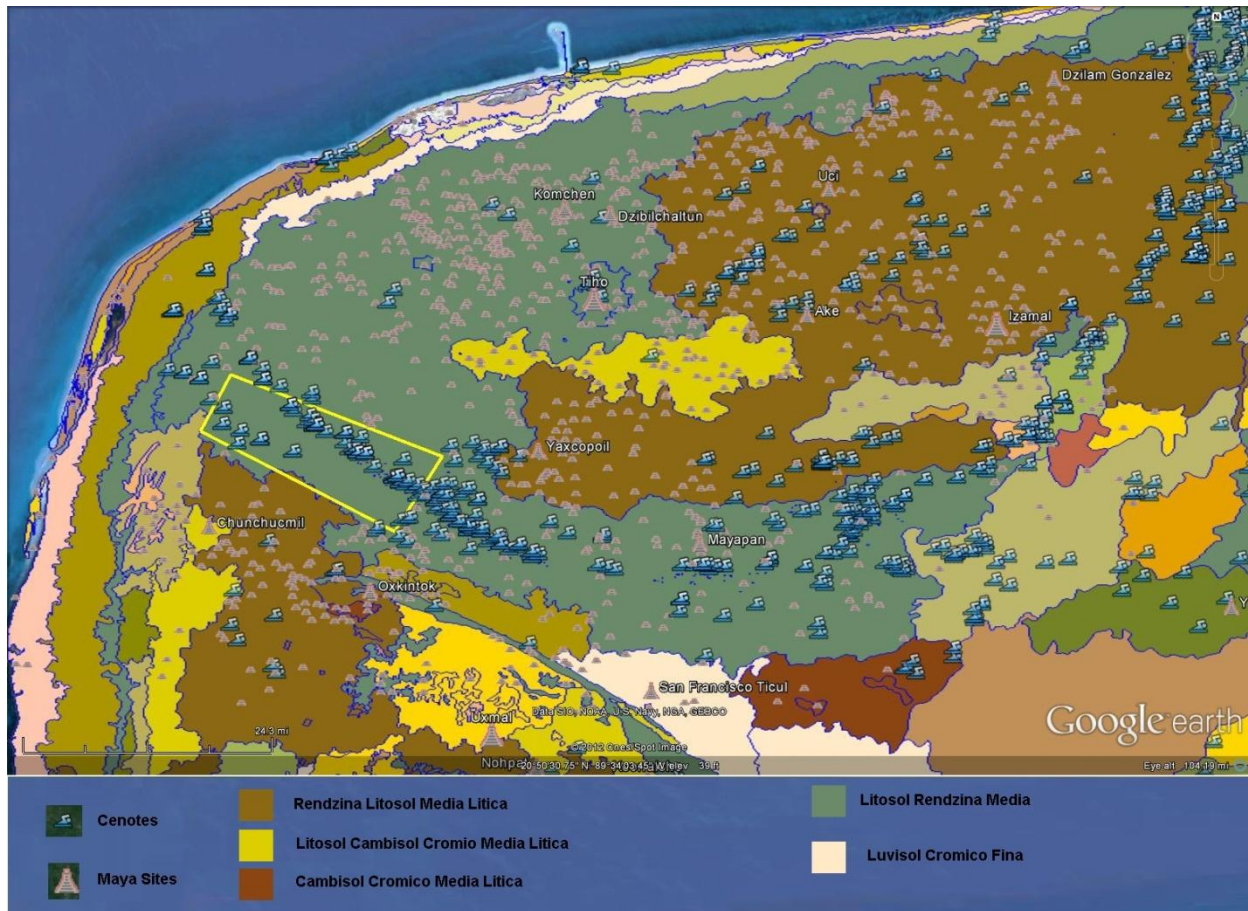
Figure 11: Soil Science defined zones, the pedology of the Northwest Yucatan

Much of the western and southern areas of the Cenote Zone are dominated by Leptosols (Figure 11) so rocky as to limit vegetation and sufficient soil generation. While the rest of the region also falls under the Leptosol taxa, the secondary attributes of much of the rest of the landscape allow for an acceptable buildup of soil in addition to the rejolladas. This broad spectrum of soils allows for a cursory analysis of overarching trends, but the scale of 1:250,000 fails to represent the rejolladas and other features exploited by ancient Maya agriculturists (Fedick, in press). Though Mayapán and T'ho share the same soil description zone as the

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settlement anomaly in Figure 7, they are near the borders of such challenging geography, and in areas with more localized favorable soils. Whether this is a result of geologic and geographic irregularities or from anthropogenic measures might be a consideration of future soil and phosphate testing.

Finally, water flow as shaped by elevation, faults, and proximity to the coast takes a northwestern current along the ring fault starting east of our quadrangle but west of the Mayapán area. This has helped shape the Cenote Zone in west into an extremely highly concentrated and dense conduit, producing a denser concentration of cenotes than found anywhere else. The eastern two thirds of the Cenote Zone, though still relatively concentrated compared to the rest of the Yucatan, allows for water to flow into multiple, wider, and less defined and concentrated ring faults, therefore also allowing for rejolladas and soil formation between pockets of heavy cenote concentration. These pockets may be responsible for corresponding pockets of more sparsely dispersed ancient Maya settlements in other stretches of the Cenote Zone, but does not entirely preclude agriculture and therefore settlement, as does the SWCZ. A region of bajos in the Southern Yucatan in the Petén may have a similar issue, as its swampland is too inundated with water for much of the year to be useful for growing crops, and thus explains the lack of Maya settlement in this somewhat parallel area (Winemiller 2003).

In addition, the SWCZ serves as a natural geographic buffer or barrier between Puuc and other styles of architecture, perhaps reinforcing this cultural divide and providing a kind of convenient demilitarized zone. Keeping in mind the separate migrations, separate obsidian sources, practically opposite resource management and subsistence methods, and Late Postclassic rise of Mayapán all discussed in the previous chapter, the southwest portion of the

Cenote Zone was an unlikely candidate for Maya settlement given the political climate of the Terminal Classic. The environmental obstacles of the SWCZ likely made an expedient preclusion to settling in an area within a day's war march of a rival polity. The curious case of Chunchucmil, as the only large site within this warpath range, may indeed have fallen prey to this scenario; something supported by Dahlin (2000) through suggestion of warfare as an explanation of that site's abandonment and impetus for barricade construction.

CONCLUSION AND DISCUSSION

Through GIS analysis of both the wider Northwest Yucatan landscape and important natural and altered features of prominent Maya sites, we uncover a complex picture of ancient Maya settlement. This emergent image, then, challenges the notion of a simple correlation between cenotes and settlement, calls into question any singular factor, such as drought, as an explanation of decline and abandonment of Maya sites, and underscores the importance of small-scale features in the landscape in understanding opportunities and strategies for Maya subsistence and settlement throughout the Northwest Yucatan. The area of little to no settlement of the SWCZ is a glaring example of the natural environment and geography providing too much of a good thing through its abundant fresh water cenotes and presenting the ancient Maya with an insurmountable environmental challenge. Nearby areas like the complex coasts, dry Puuc hills, and poor soil of the Mérida and Itza regions are equally extraordinary instances of triumphs over difficult landscapes, however. By studying the intricacies of this unique Chicxulub scarred land, we better understand the relationship between the Maya and natural features, their adaptations to overcome them, and how their cultural, political, and economic attributes are often directly influenced by geographic factors.

Several times through the course of this paper the author has mentioned suggestions for more detailed and new sets of data to be included if possible in future surveys and data collecting. Not all cenotes and Maya sites have been identified and recorded in order to resolve the questions and issues raised here. Soil maps of the area are increasing in their detail as more research is done. Overcoming these limitations may either overturn or support some of the ideas discussed, but current maps and data are sufficient to propose these initial considerations and

findings, while old maps help us define and correlate settlement pattern theories on the micro site level. "The use of GIS enables integration of maps created over a century ago with data relevant to the study of ancient Maya settlements, giving long-silent mapmakers a new voice and enabling them to contribute to a better understanding of the human/environment interface." (Winemiller and Ochoa-Winemiller 2006: 1) This sophisticated technology of the modern world is helping us to understand the complexities of an ancient one, with more and more data and accessibility to GIS inspiring those curious to uncover and understand forgotten worlds.

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