

From Calakmul to the Sea: The Historical Ecology of a Classic Maya City That Controlled the Candelaria/Champoton Watersheds

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Abstract:

The Candelaria River watershed of Campeche, Mexico, and Peten, Guatemala, has shaped millennia of Maya, perhaps from their beginnings and generations of archaeologists. This chapter reviews efforts to understand Candelaria historical ecology over the past four decades, mostly in the northern branch, the Candelaria-El Caribe-Tomatillal system, as it relates to the cities of Calakmul and Uxul. Additional investigations stem from the river system farther north, the Champoton-Desempeño watershed, which also approaches Calakmul at its headwaters. Four other projects (Oxpemul, Yaxnohcah, Naachtun, Uxul) have emerged in the southern branches of the Candelaria and Desempeño in recent years, in addition to a long-standing project at El Mirador. Methods utilized range over global-local climate teleconnections, geology, ethnoecology, soil formation and transformation, geochemistry, pollen, and phytolith sampling. Brief but key statements of results for each method are reported as they contribute to a holistic perspective on the evolution and the death of Calakmul. Key interests that guided the research are the commercial location of the city and watershed in the Maya urban system, the way the watershed shaped the human settlement pattern in the west central Maya Lowlands, the socio-ecological adaptations over time, and its utility as a middle-level unit of study in links between human and Earth system changes. Finally, a nutrient flow model unifies the results into a concept that may yield deeper insights into the narrative and simulation modelling of Maya social evolution.

Keywords: Candelaria River | Watershed | Pollen | Sediments | Maya | Campeche | Calakmul | Hydrography

Article:

Introduction

As Euro-American history opens on the western Maya Lowlands, Hernan Cortez is reported marching an army from Mexico City to cross the Yucatan Peninsula as a show of force. At Comalcalco, in the delta of the Usumacinta River, he inquired as to the means of crossing the peninsula, to which the men of the city told him that he should push on to Acalan on the Candelaria to be advised by the Chontal who headquartered there and traded with the east coast of the peninsula. At Acalan, Cortez found the thriving city of Itzamkanac/El Tigre (Fig. 11.1). Their king, Paxbolonacha, offered him 600 porters, after which the journey began from the middle reaches of the Candelaria eastward to the vicinity of Lake Misteri6sa and then southeast toward Lake Chichen Itza and then on to Honduras (Gunn 2018; Scholes and Roys 1968). On the way out of Acalan territory, Cortez encountered a couple of traders, which he appropriated as guides. Following this route, he would have passed near Calakmul, El Mirador, Nakbe, Tintal, Ceibal, and Caracol, some of the oldest and most important cities in the long Mayan occupation of the region. Most likely he would have been unaware of the rich past of these inland ruins. He only saw the thriving west coastal cities that by then carried the bulk of the international trade of the Yucatan Peninsula's native provinces. Landa in the 1500s, however, reported that the old cities were used as concentration points for goods to be exported to the coasts, a custom that continued into the twentieth century for exporting chicle, lumber, white pepper, textiles, and other products of the interior (Avila Chi 2009).

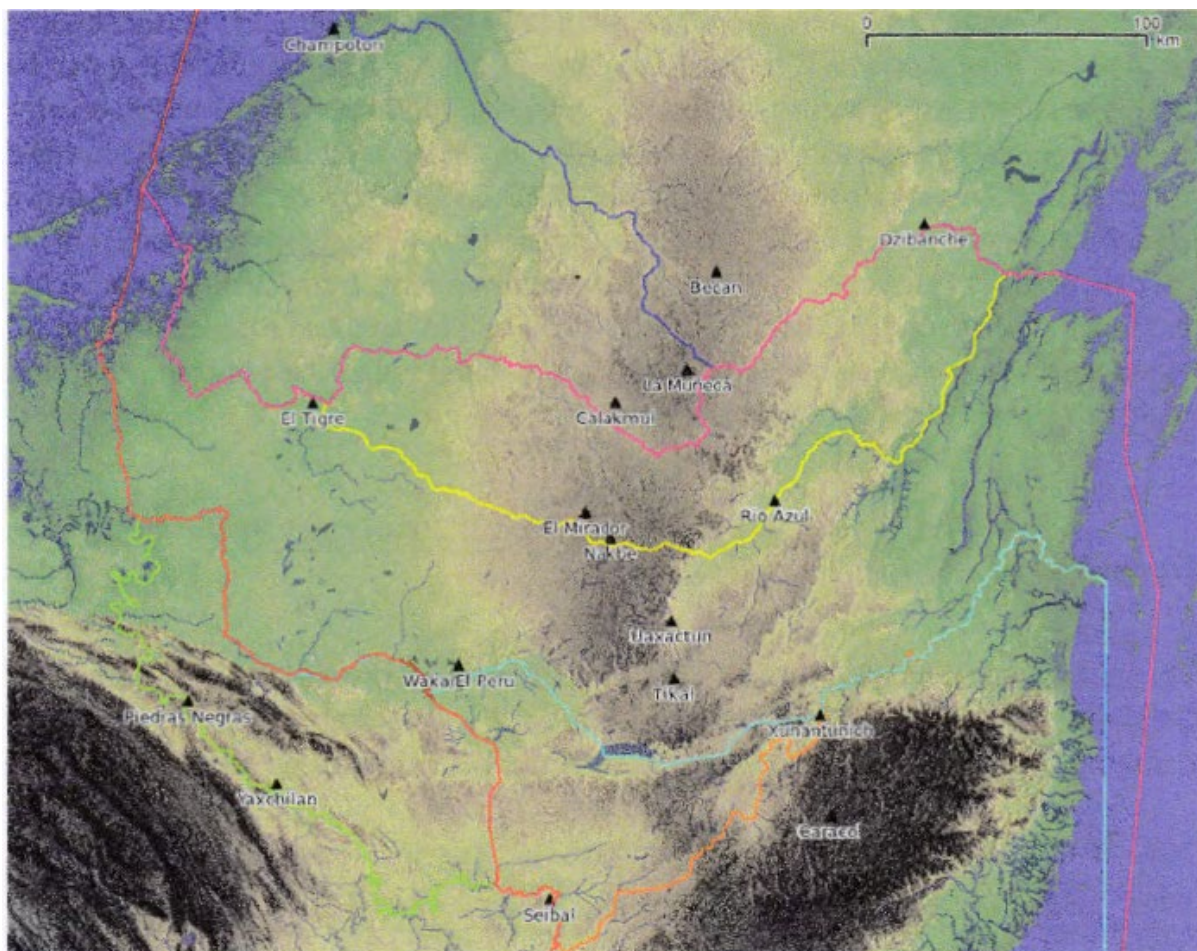


Fig. 11.1. Central Maya Lowlands water routes, Candelaria-El Caribe-Tomatillo (through Calakmul) and La Esperanza (through El Mirador). (Adapted from Volta and Gunn 2012, 2016)

Three hundred years later (1839), Stephens and Catherwood returned to some of the same trails to catalog and describe the still-mysterious, old interior cities, to be tagged a century later as the "Old Empire" by Morley. Over the twentieth century, the idea of an Old Empire was constructed and deconstructed and, now in the twenty-first century, thanks to gaining the ability to read ancient Maya scripts, reconstructed again. As ancient social relations begin to emerge from Maya written records (Martin and Grube 2008), the Old Empire is being somewhat rebuilt, though as hegemonic blocks. Such "empires" are not uncommon in world history, and in the Maya Classic Period (300--900 CE), an alliance between Calakmul and Caracol (approximately 500--700 CE) came the closest of any to establishing imperial hegemony in the southern Maya Lowlands (Gunn et al. 2014a; Gunn et al. 2017).

Even with the ability to read scripts prepared by scribes of ancient kings, much remains to be reconstructed of those distant lifeways. In this article we review through the methods of historical ecology (Crumley 1994) the surroundings and internal functions of the society that once flourished in the region. To constrain the boundaries of our research, we have focused on the flow of water, nutrients, information, goods, and geological residues down the Candelaria River watershed into the sea, the Gulf of Mexico. Within this landscape, we endeavor to detect the landscape modification that ensued from the evolution of Maya society as it moved from hunter-gatherer bands, to trading villages, to great cities of astonishing scope and reach. Even with reading and reconstruction, we will never know precisely the structure of those ancient societies. We can, however, read the outputs of their daily activities collected under structures, at the bottom of hill slopes, artificial lakes, and the Candelaria River delta.

To examine these outputs, we will first overview the findings of Project Candelaria. Then we will add some details to these findings by offering additional information from cores and test excavations that move us toward a broader understanding of the watershed's social evolution. We will conclude by offering a unified understanding of what has been discovered so far in the form of a flow structure model that can be interpreted from the point of view human nutrients, but in parallel to water, energy, information, ecosystem services, sustainability, or all six simultaneously (Gunn and Folan 2018; Gunn and Members of the ESCHER Workshop 2019). We find that a limited number of geochemical indicators (magnesium, potassium, phosphate) are the critical variables that measure the vitality these flows have for sustaining human life and that the Maya of the Candelaria watershed seem to have had a clever scheme for recycling them to the top of the watershed even though their desalinization process tended to move them down the watershed to the sea.

Overview of Project Candelaria

This is the fourth decade (Table 11.1) of an effort to understand the environment of Calakmul, Campeche, through environmental archaeology and ethnoecology. Calakmul has two apparent access routes to the Gulf Coast, one to the west along the Candelaria-El Caribe-Tomatillal system and the other through the Champoton-Desempeño system to the northwest. The study was set initially in the context of the Candelaria River watershed (Gunn et al. 1995) (Fig. 11.2). Aside from the fact that watersheds are excellent units of study for understanding part or whole of human settlement patterns, they also comprise middle-scale (mesoscale) segments of

landscapes that can be linked to global environmental change through their water volumes per unit of time (Gunn et al. 2019; Gunn et al. 1995). In addition to water, river systems collect environmental data and deposit it in deltas. To examine these accumulated sediments for the watershed narrative we are building, we have cored the Candelaria River delta at Panlao (near Ciudad del Carmen) where we found evidence that the Classic Period Maya were profoundly modifying watershed landscape to manage agricultural production (Gunn et al. 2009a; Gunn et al. 2013; Siemens 2009; Torrescano-Valle et al. 2012). No doubt this accounts for the millennium-long history of Calakmul's sustainability (Folan et al. 2012; Gunn et al. 2013).

Table 11.1. Candelaria watershed research timeline

1972	Siemens and Puleston characterize semi-karst rivers (Siemens and Puleston 1972)
1980s	Background research, tour, ethnography (Faust 1988, 1998), excavations start (Folan 1983)
1981	GCM study of climate change characteristics (Gunn and Adams 1981)
1983	Historic background of climate and social organization (Folan et al. 1983; Hoggarth et al. 2017)
1989	Siemens published <i>Tierra Configurada</i> (Siemens 1989)
1991	Model mesoscale global climate interactions (Gunn 1991)
1992	Organize biosphere reserve (Folan et al. 1992)
1994	Historical Ecology: Global Climate and Regional Biocultural Diversity (Gunn 1994)
1994	Model past Candelaria discharge from modern 1958 to 1990 data (Gunn et al. 1994)
1995	LIA Calakmul excavations, SW ML hydrological response surface (Joel Gunn et al. 1995)
1996	Tres Rios and Global Change (Gunn and Folan 1996)
2000	Model global climate sensitivity of discharge for adjoining rivers (Usumacinta, Champoton, Grijalva) (Gunn and Folan 2000)
2002	Bajo sediments and Calakmul water system (Gunn et al. 2002)
	Dams on the Candelaria (Siemens et al. 2002)
2008	Panlao core published, Conditions of Interior, Sustainable Urbanism (Gunn et al. 2009a; Torrescano-Valle et al. 2012)
2008	Geovannini Rain Harvesting published (Geovannini-Acufia 2008)
2009	Rosario test pits published (Gunn et al. 2009b)
2009	Candelaria landscape profile (see Fig 11.3) presented to first IHOPE-Maya workshop (Faust et al. 2012) (Gunn 2009 IHOPE)
2009	Siemens reports on pollen cores from Lake Candelaria in lower/middle Candelaria (Siemens 2009)
2013	Nutrient profile published

Siemens and Puleston (1972) gave considerable impetus to the study of watersheds by bringing semi-karst and rivers of the southern Maya Lowlands to archaeologist's attention. A clear vision of rivers and floodplains unsettled an age-old archaeological myth that the Maya Lowlands were a flat, low-lying, uniform tropical jungle in which climate did not change.

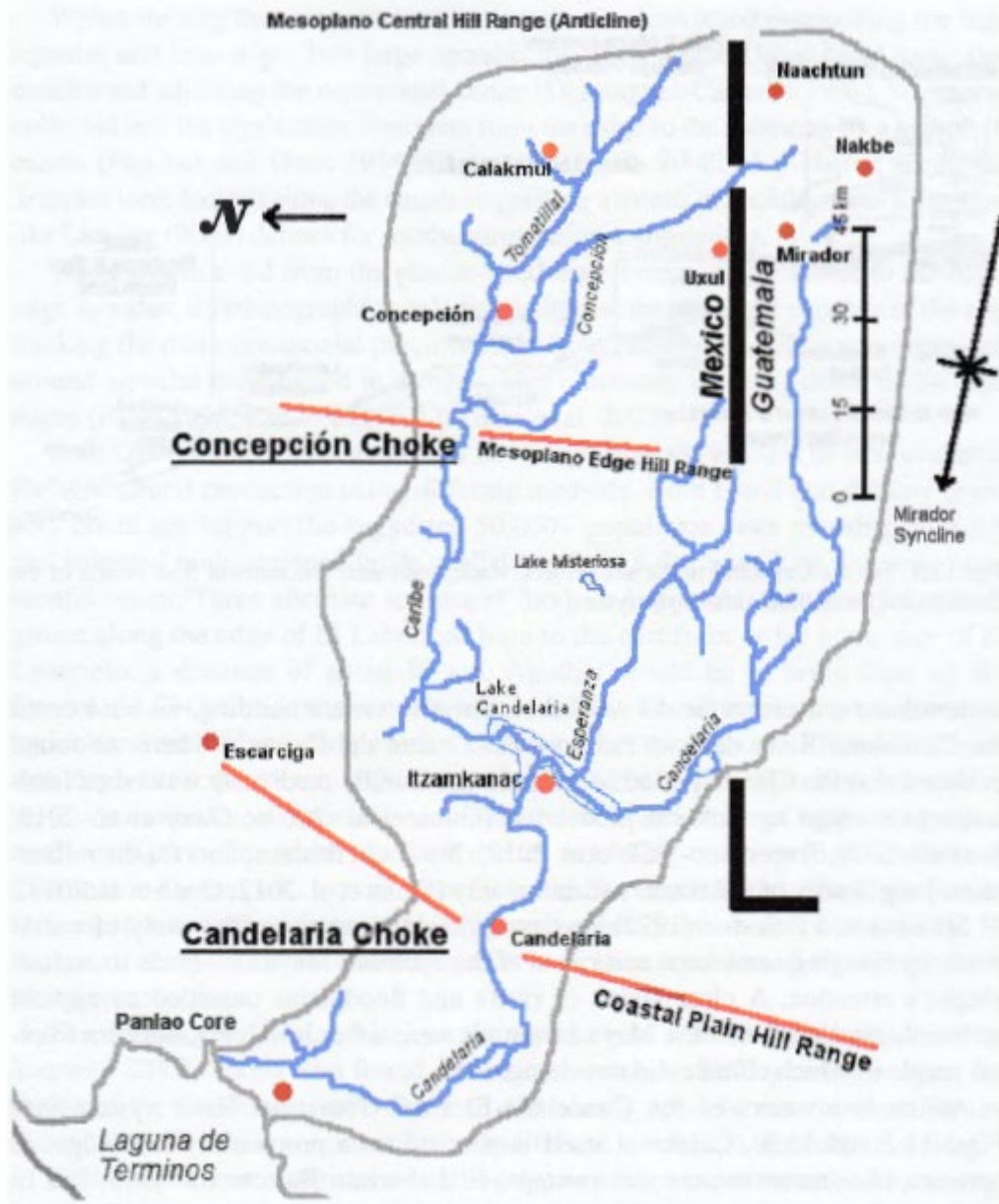


Fig. 11.2. Candelaria River watershed. Note: North is to the left

At the headwaters of the Candelaria-El Carib-Tomatillal River system (see Figs. 11.2 and 11.3), Calakmul itself is perched on a promontory and ridgeline between two immense seasonal swamps, El Laberinto Bajo to the south and El Ramonal Bajo to the north. The ridge line approximately halves the Calakmul Basin of the Mesopiano, an elevated interior hill and valley system comprising the central spine of the southern Yucatan Peninsula (Dunning et al. 2012; Folan et al. 2016; Gunn et al. 1995; Volta and Gunn 2016). To address Calakmul's use of their immediate environment, we have cored both seasonal swamps and found that after an initial collapsing of vegetation on the bajo sides in the Preclassic, they began to use the kilometer-wide bajo edges as agricultural lands (Gunn et al. 2002). These capabilities were augmented by construction of reservoirs (or aguadas) in El Laberinto Bajo below the city, one being the largest

in the lowlands (Dominguez-Carrasco and Folan 1996; Gunn et al. 2002). Canals and other water distributary elements were also devised (Fletcher and Gann 1994; Geovannini-Acuña 2008).

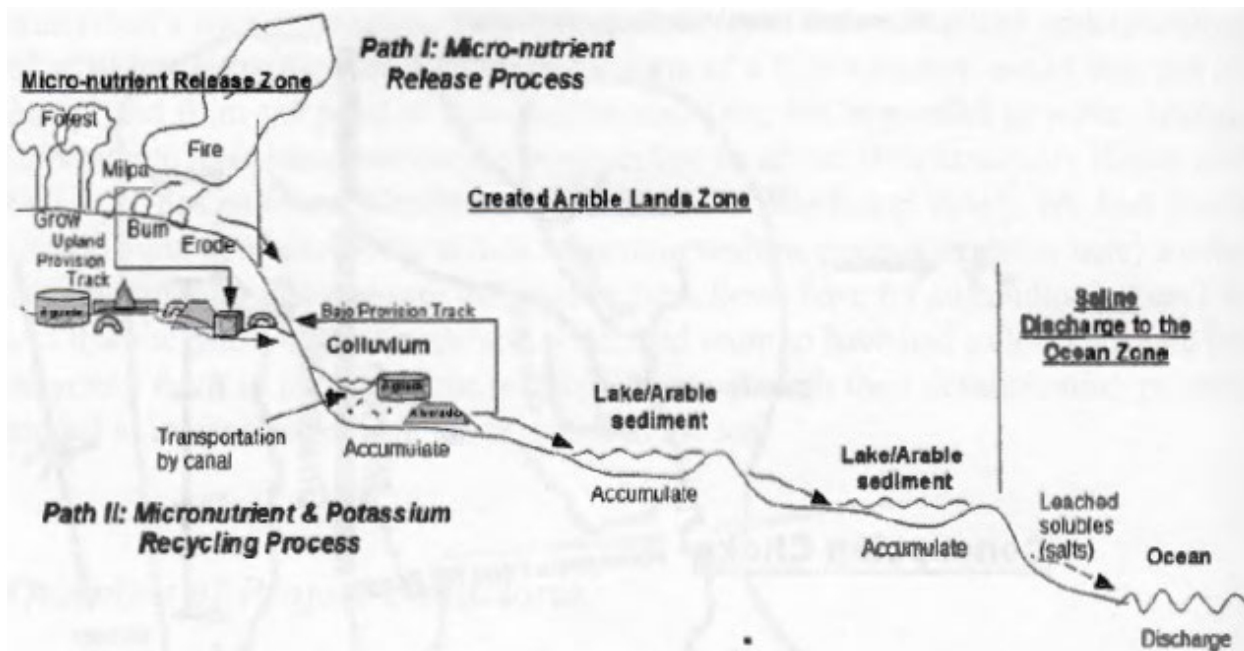


Fig. 11.3. For the Calakmul to the sea project, water, sediment, and nutrient flow profile of the Candelaria-Caribe-Tomatillal River system

Within the city the main ceremonial center was constructed overlooking the bajo aguadas and bajo edge. Two large aguadas joined by a stone lined canal were also constructed adjoining the ceremonial center (Dominguez-Carrasco 1991). Water was collected into the city's main reservoirs from the ridge to the southeast by a system of canals (Fletcher and Gann 1994; Geovannini-Acuña 2008; May-Hau et al. 1990). Temples were located along the canals suggesting a means of social control somewhat like Lansing (2003) defines for southeastern Asian communities.

Water was drained from the plaster-lined main ceremonial precinct to the bajo-edge aguadas. By ethnographic analogy we suggest that the great expanse of the city flanking the main ceremonial precinct away from El Laberinto Bajo was organized around aguadas constructed in arroyos, also ultimately draining down to the bajo edges (Faust 1998; Faust et al. 2012; Gunn et al. 2002).

Both Geovannini-Acuña and Gunn have calculated the amount of land available for agricultural production using differing methods. Both found that the city probably could not support the suggested 50,000+ population even by using both dry and irrigated multi-cropped lands available within a day's walk of the main ceremonial center. Three alternate sources of food are suggested. One is to bring food grown along the edge of El Laberinto Bajo to the east from as far as the city of El Laberinto, a distance of about 12 km. Another would be to bring food up the Candelaria-El Caribe from the coastal plain at Itzamkanak where a very substantial agricultural and fishery component was observed in the Historical Period (Scholes and Roys 1968; Siemens 1989; Vargas-Pacheco 2012). The Spanish explorers of the Cortez expedition reported encountering canals and crops as well as organized canal transport of produce. A third option would be to

bring food south from Champoton-Desempeño system from Edzna via its Grand Canal. The Champoton- Desempeño watershed has not been as well studied, but it supported a city, El Ramonal, along its banks and might also have been a means of transportation if reengineered.

The Itzamkanac/Acalan slackwater regime (see below) has been cored by Siemens (2002, 2009) who found its rudiments date to 7000 years ago when the shoals of the Candelaria were dammed and nearby uplands were cleared. By the Classic Period sediment accumulation had turned it into vast agricultural fields.

Either of the three solutions would involve extensive canalization and damming, especially of the 10-km-wide El Laberinto Bajo that stretches across most of the Yucatan Peninsula Mesoplano east to west or by the Desempeño drainage. Brown (personal communication, email of October 21, 2011) has made preliminary observation from aerial imagery and found suggestions that such may be the case; LIDAR scans of the bajo are currently ongoing and/or planned that may support these contentions. In any event, El Laberinto Bajo remains the widest, most engineerable passage across the peninsula (Volta and Gunn 2012, 2016). This characteristic may account for the location of Calakmul overlooking El Laberinto Bajo, a situation similar to that of Tikal that overlooks the Holmul watershed (Fialko 2005).

To unify these diverse data, we generated a watershed-long profile from the upper end of El Laberinto and the central spine of the Mesoplano to the Gulf of Mexico and the Laguna de Terminos, a distance of some 161 km air (Fig. 11.4) (Faust et al. 2010; Gunn et al. 2013; Gunn et al. 2009b). The profile could be contemplated in any number of perspectives: nutrition, hydrological, travel, and informational. As a flow of nutrients discussed extensively in a later section on modeling the erosion of phosphorus, potassium, and magnesium that figure as key variables. It might also represent commerce and information flow as river systems and portages were the main routes of communication and commerce for most of Maya history (Gunn 2018; Volta and Gunn 2012). Watersheds could also be the context in which the impact of global climate change on the local watershed is measured (Gunn et al. 1994, 1995).

The northwest Maya Lowlands, basically the Mexican state of Campeche and the NW Guatemalan Peten, has emerged as a grander player in the overall picture of the cultural area than would have been suspected from the previous Tikal-centric perspective. This shift in the center of gravity brings with it certain obvious liabilities in terms of understanding the whole of the lowlands nature-culture system. Calakmul, the capital city of a large part of the region, was only identified as a major player in the 1980s. Thirty square kilometers of the city have been mapped (Folan et al. 1990b). Research on understanding the overall picture of its extent, support network, and social structure have begun by examining sites along the Conhuas-Calakmul road (see Morales-L6pez et al. 2017), sorting out the elite social relations between Calakmul and other cities using ceramics (Dominguez-Carrasco et al. 2000; Gunn et al. 2017; Reents-Budet et al. 2011), and detailed investigations of the regional settlement patterns (Šprajc and Grube 2008). We will, therefore, discuss investigations carried out in the last few years that lay out some of the basic groundwork bringing to light the landscape of the western Classic Maya subsystem.

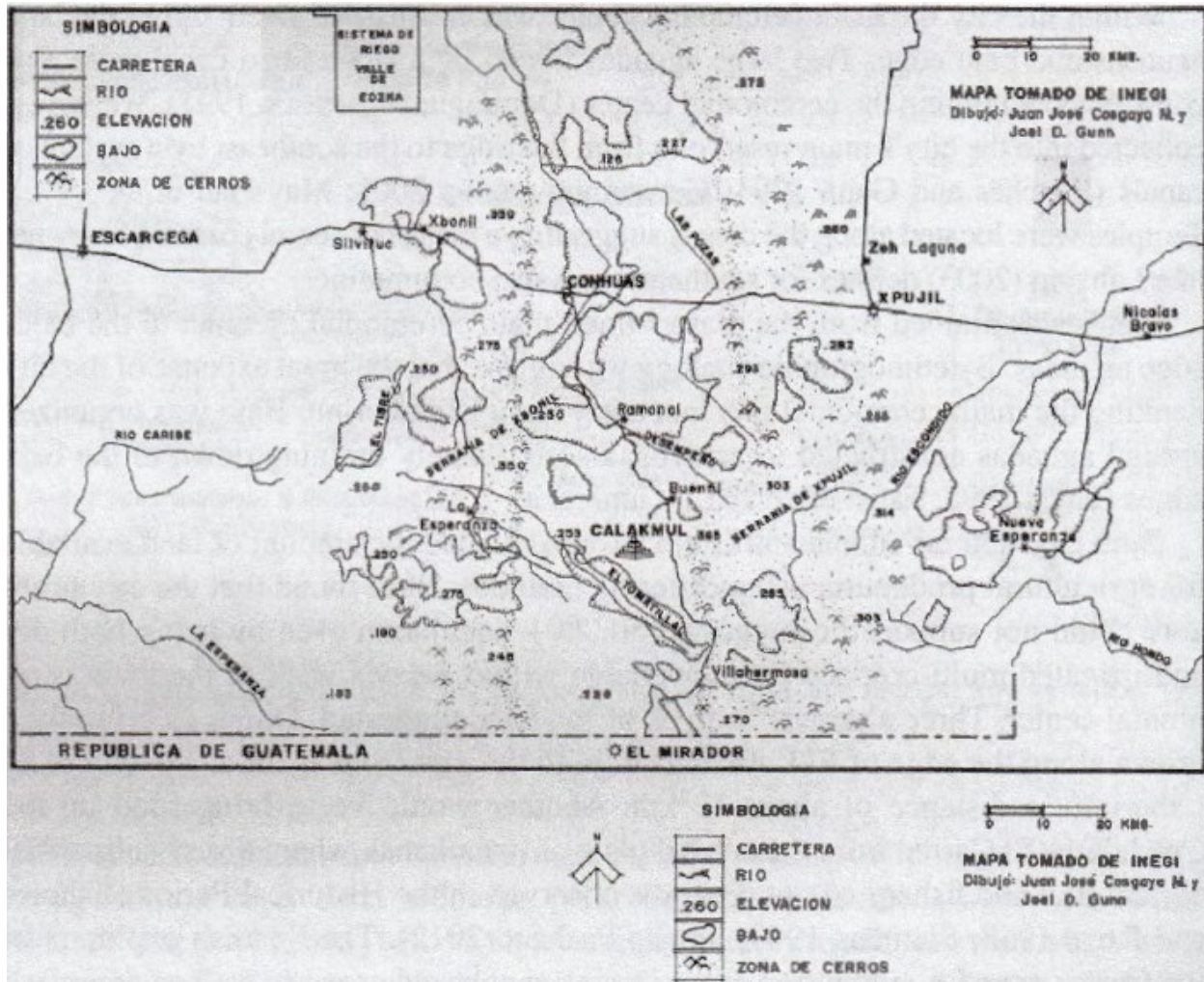


Fig. 11.4. Calakmul Basin and El Laberinto and El Ramona! bajos. (Gunn et al. 2002)

Calakmul: Top of the Candelaria Watershed

Organizing the City in Its Social and Physical Setting

The Candelaria watershed drains about 13,000 km² (Gunn et al. 1995) in the southern part of the Mexican state of Campeche and small portions of northwestern Guatemala (Brant et al. (2010) estimated an area of 5670 km² but they did not include El Laberinto Bajo) (Robadue et al. (2004) report 7160 km² citing another source, but they do not appear to include Guatemala or El Laberinto, p43). On the coastal plain, the Candelaria River divides into three branches, the Caribe River to the north, La Esperanza (INEGI 1:250,000 Carmen, Las Golondrinas in other maps) in the middle, and the Candelaria main stream to the south that goes into Guatemala (according to Brant et al. 2010). In the headwaters of these branches are the major interior settlements of Calakmul on the Tomatillal, Naachtun (Philippe Nondedeu) and Yaxnohcah (Brewer et al. 2017; Reese-Taylor et al. 2012) on La Esperanza, and El Mirador on the Candelaria branch (Hansen 2004). Calakmul and El Mirador, the two mega-centers of Maya population in the Late Preclassic and Early Classic, appear to have co-evolved in the early period of Maya cultural development (Folan et al. 1995; Gunn et al. 2014b). It is not impossible that the

decline in population of El Mirador, though not abandonment, was associated with the Kaan dynasty moving its headquarters to Calakmul (Gunn et al. 2014b), a thought reinforced by the transformation of El Mirador into a pilgrimage site in the Classic Period (Hansen 2004).

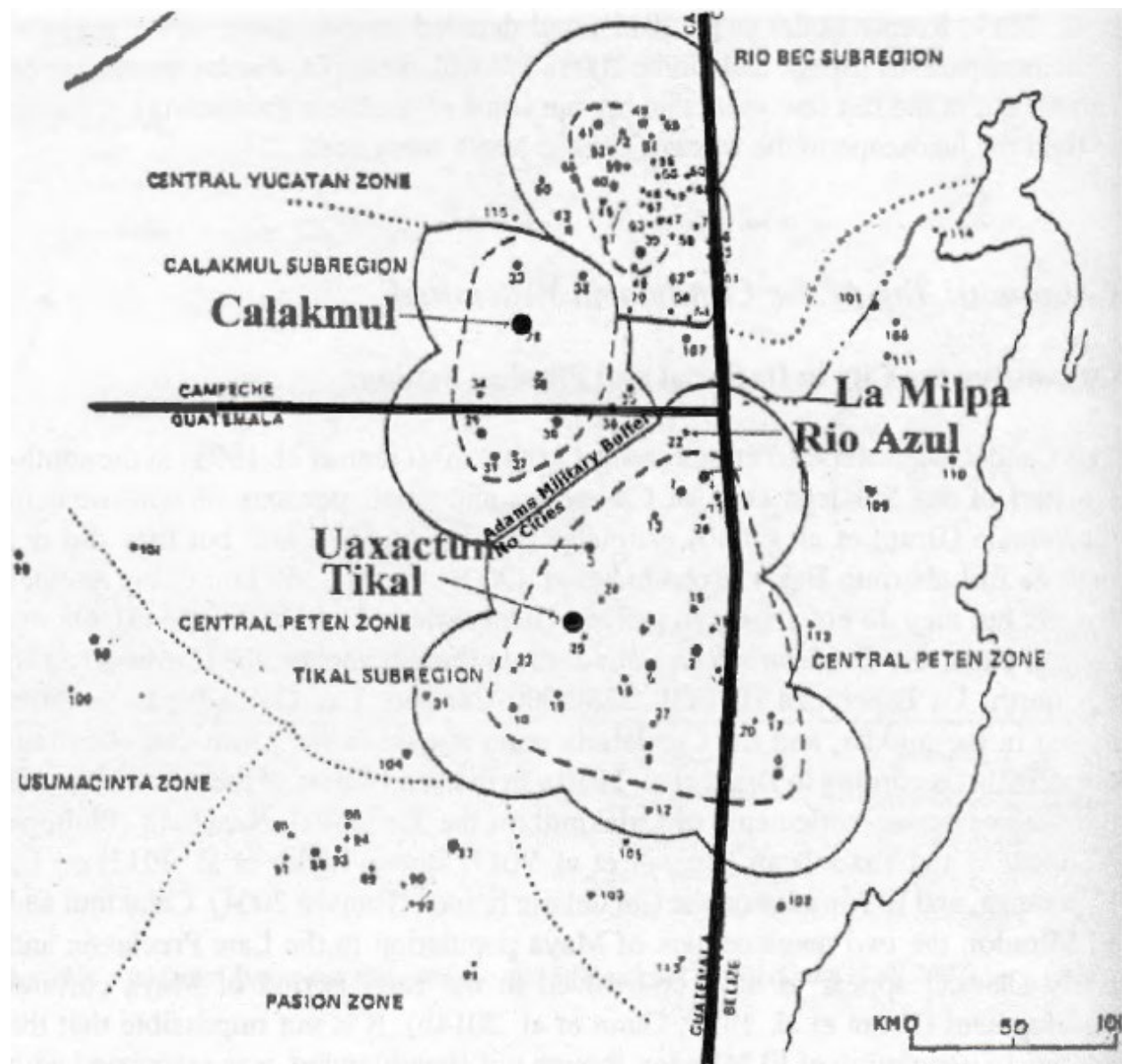


Fig. 11.5. Calakmul-Tikal Buffer. (Adapted from Adams 2005: 174)

In the second and third centuries CE, El Mirador greatly diminished in size and political power (Dahlin et al. 1980; Hansen et al. 2002; Matheny and Matheny n.d.). At least two influences are candidates for contributing to this decline. First, a severe drought (Dahlin et al. 1980, p. 80; Gunn et al. 1994, 1995; Wahl et al. 2006) transpired for which the city was ill-equipped to cope. A cause or co-cause may be that during the Classic Period, it fell within a space thought by R.E.W. Adams to be a buffer zone between Tikal and Calakmul (Adams 2005). The most likely portages across the peninsula (Volta and Gunn 2012, 2016), in fact, suggest that Calakmul and Tikal (Fig. 11.5) may have been struggling for control of waterways, especially in Calakmul's SE

sector within which Adam's buffer zone and available river-ways inscribe perpendicular lines across the Mesoplano between the cities (see Fig. 11.1). The buffer zone would have blocked Calakmul's access to the Rio Azul-Hondo but allowed it access to the Escondido River and Dzibanche (Gunn et al. 2014b). Together the two processes suggest that El Mirador's dimming star was due to a realignment of economic powers during a time of inopportune environmental conditions for maintaining large, interior urban populations, which perhaps relied on trans-peninsular trade. Calakmul recovered from the drought and went on to flourish as one of the great urban centers of the Classic Period in Mesoamerica.

Coring the Bajos Around Calakmul

Calakmul is located in an interior basin of the Mesoplano between two north-south trending ranges of hills with elevations up to 300-400 m (see Fig. 11.4). Within the basin, it is situated on a transverse ridge with large seasonal swamps (bajos) to the north and south. A project was launched with the help of the National Geographic Society to collect and analyze cores from within and on the margins of the bajos to determine the role they played during the lifetime of Calakmul (Gunn et al. 2002). The results from El Laberinto Bajo south of Calakmul suggest, as do similar findings in other locations such as at Nakbe in the Candelaria branch (Jacob 1995), and on the eastern side of the peninsula (Beach et al. 2008; Dunning and Beach 2010), an initial period of sedimentation following 4000 BCE. In El Laberinto Bajo, this period was marked by heavy metals indicating a well-developed weathering horizon in place for a considerable period of time, probably since the beginning of the Late Holocene (Gunn et al. 2002). Subsequent land clearance released additional sediments into low-lying areas during the Middle Preclassic about 1000 BCE. Such activities may have resulted in unintended consequences, as suggested by Hansen's and Jacob's (Hansen 1998b; Jacob 1995) findings discussed below. Or, they may have been, at least in part, intentional and fruitful as it is possible to see in the bajo investigations around Calakmul where these new lands overlay seasonal swamps poisoned by gypsum salts (Gunn et al. 2002, 2013; Perry et al. 2011). At Naachtun Purdue (2018) found similar uses of soils slumped into aguadas that continued after the Preclassic.

Low-lying walls on these bajo foot slopes below Calakmul indicate raised platforms and a field in one case, in the new bajo space. Masonry-lined reservoirs imply that it was a struggle to keep seasonal rainwater free of underlying gypsum contaminants. The underlying sediments were salty enough to be lethal to plants.

Parallel ethnographic studies in the region imply that Calakmul's monstrous size can be accounted for as a patchwork of aguada-based communities extending along a large part of the transverse ridge (Gunn et al. 2002). C. Brown has found 153 aguadas associated with the El Laberinto Bajo detected in aerial images (Brown, personal communication, email of 2008). Brewer et al. (2017) have developed a LIDAR methodology that could be used to test these observations.

In the Esperanza branch of the Candelaria in and around El Mirador, Hansen has conducted extensive research into farming techniques and architectural design. Jacob's (1995) work at Nakbe near El Mirador suggests that there were also negative consequences to slumping sediments there. They covered sources of carbon-rich mud from the bottoms of lakes making

them inaccessible for used to fertilize terrace farms. However, this area featured an aquatic environment, sometimes referred to as the "Lake District." The lakes provide a different dynamic from that of the more elevated and dryer Calakmul 37 km to the north where seasonal swamps replace lakes.

Hansen (1998a) also found that during the Preclassic, in addition to clearing land for agriculture, the inhabitants in NW Guatemala were profligate in the destruction of woodlands for incinerating limestone to make lime for plaster. A key ingredient of which is quick lime, created by heating limestone rocks over burning logs. The early pyramids at Nakbe exhibit thick layers of plaster. Later architecture is less liberally plastered, apparently in an effort to conserve woodlands or large trees that were simply no longer available. This also points out the different dynamics of the moist lowlands and the high interior as at Calakmul. It may have been a dynamic that propelled the rulers of the Calakmul state to move their headquarters to Calakmul in the Early Classic (Gunn 2018; Gunn et al. 2014b). It cautions that very different sourcing and timing may characterize the arms of the Candelaria system, a topic we will return to later.

Geovannini-Acuña (2008) excavated a pattern of test pits in the area of the central ceremonial center and found the site footprint to be confined to that area in the Preclassic but expanded in the Early Classic. Test pit excavations in 1984 in El Laberinto Bajo by Dominguez Carrasco (Dominguez-Carrasco et al. 1998; Gunn et al. 2009b) below the ceremonial center of the city revealed Early Classic sherds but no Late Classic sherds suggesting that the footprint of the city contracted following the volcanic eruptions associated with the AD 536/541 global cooling event (Gunn 2000; see Toohey et al. 2016).

Pollen and Geochemistry of the Upper Candelaria-Champoton Systems

Torrescano-Valle (Torrescano-Valle et al. 2009, 2012; Torrescano-Valle and Islebe 2015) investigated several pollen and/or geochemical sites in the Candelaria and Champoton watersheds. Among them is Lake Silvituc. It is a large, freshwater body at the back edge of the coastal plain (see Fig. 11.4). The water is kept pure by a clay lining formed from volcanic dust (Perry et al. 2011; Tankersley et al. 2011) It was included in a study with Lake Chichen Itza pollen determinations that showed a high correlation with it. Lakes Silvituc and Chichen Itza pollen sequence represent the impact of humans on interior vegetation (Gunn et al. 2017).

Figure 11.6 shows the trends of the four most common trees in the Silvituc core and grasses to represent disturbance vegetation. In the Classic Period, there is a distinct decline in Moraceae, a family of trees related to figs. *Brosimum* is a genus in the Moraceae family that bears an edible nut (ramon). It is of interest that *Brosimum* shows a slight increase during the Late Classic, while the Moraceae family shows a sharp decline. This suggests that *Brosimum* was being cultivated for some purpose, quite likely food (Puleston 1978), while Moraceae as a family were being removed en masse. Whether this was for land clearance or whether it served another purpose is worth investigating. It is not currently considered a good wood for construction (0. Silvario Gallegos, personal communication, May 2018).

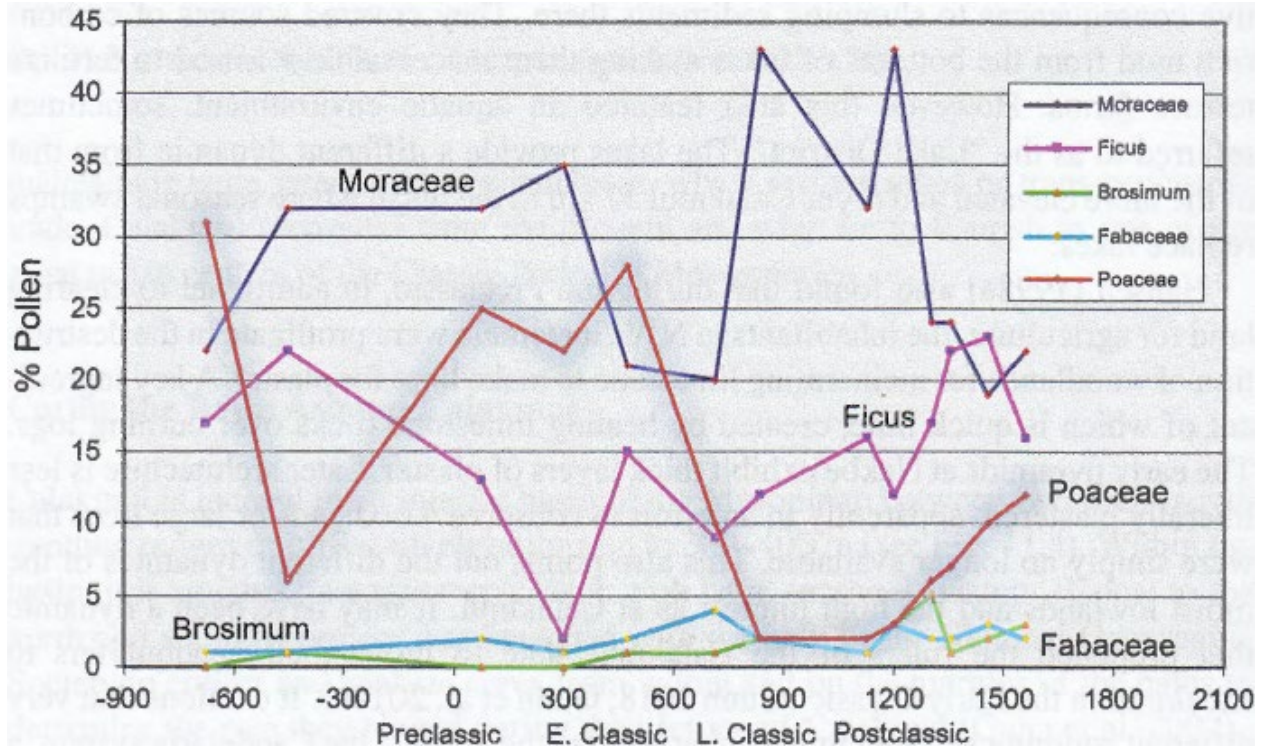


Fig. 11.6. Four most commonly identified tree families/genera/species in the Silvituc pollen core along with grasses (Poaceae). (PolenAnalysis.xls)

Grasses (Poaceae, glowing diamonds), disturbance vegetation, move in opposition to Moraceae. Grasses taken to represent the introduction of agriculture indicate that agriculture appeared around 900 BCE, retreated for the mid first millennium BCE, and then surged again through the Late Preclassic and Early Classic. Silvituc is the most northerly of the pollen sequences analyzed by Torrescano-Valle. This pattern of disturbance vegetation is repeated in the most southerly of her cores at Chumpich (see below). If grasses represent the arrival of agriculture, it appears that agriculture appeared across the south-to-north range of the Candelaria and Champoton drainages simultaneously with the appearance of external trade goods such as obsidian and jade around 900 BCE (Lohse 2010) and then fell into retreat until the Late Preclassic. A similar pattern was also observed by Wahl et al. (2006) in the northern Peten at Lago Puerto Arturo. It suggests that after the notable, sudden spread of trade, ceramics, and agriculture across the lowlands at least as far north as Silvituc, there was some sort of calamity that reversed the initial introduction of agriculture.

Ficus (squares), which was valued for paper making, and is valued still today for shade, suffered a devastating decline in the Late Preclassic/Early Classic but was restored to its Preclassic values in the Late Classic. That *Ficus* declines in the interlude between the Preclassic and Oassic suggests the drought in that period was involved. It declines a bit in the Late Classic that also ended in extended droughts. Moraceae (diamonds) family, including *Brosimum* (triangles), ramon nut, now considered to be a famine food, was also restored in the Late Classic implying forest management under drought conditions, perhaps replacement by orchards. It might have been before the value of shade to preserve reservoir water a prominent need in the Late Classic,

or the introduction of the use of paper, or other reasons. Whichever, it was not being managed at the Preclassic scale until after the late Early Classic.

Fabaceae, which Lentz et al. (2014) catalogs as useful for construction, was only weakly present. It, however, shows a slight increase during the Late Classic suggesting again that it was being managed, as was suggested for Tikal by Lentz, and perhaps managed in the teeth of increasingly frequent, extended droughts.

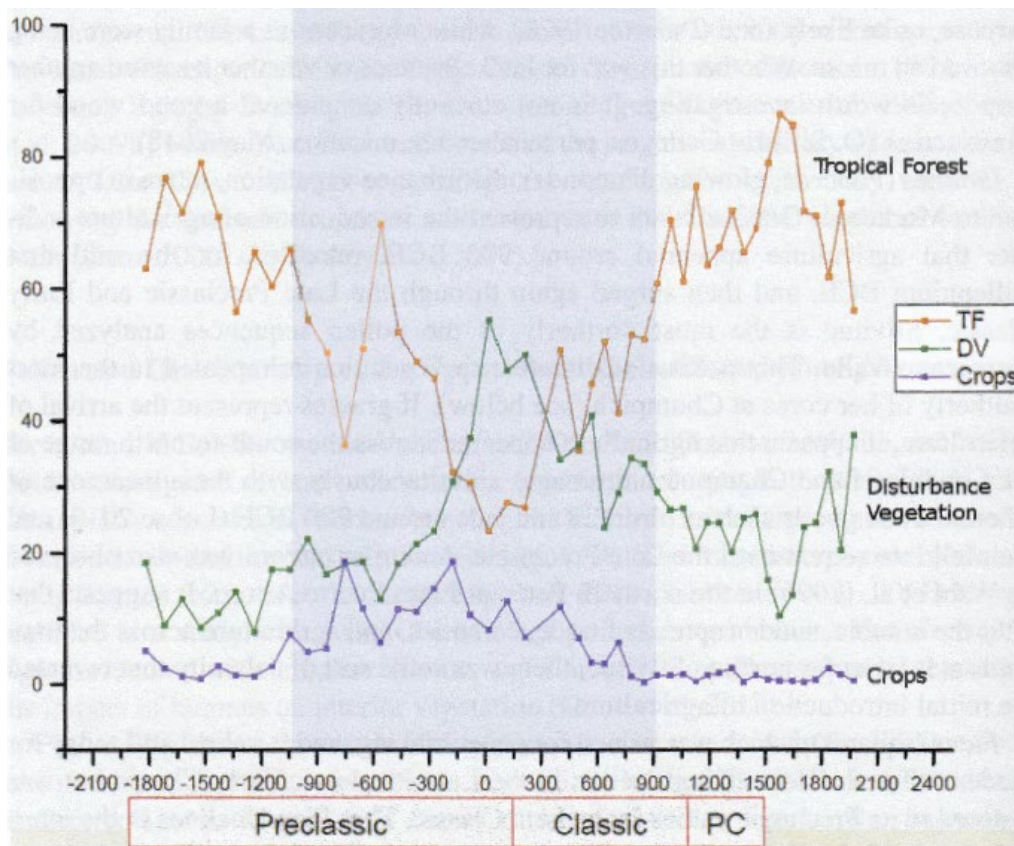


Fig. 11.7. Chumpich vegetation sequence from near Uxul. (Adapted from Torrescano-Valle et al. 2016, slide 13)

In another core near Uxul (Grube et al. 2013) from Lake Chumpich, parallel research in the Esperanza branch of the Candelaria (Torrescano-Valle et al. 2016) to the south of Calakmul, tropical vegetation plunges in favor of increases in disturbance vegetation in the early first millennium BCE (Fig. 11.7), the Middle Preclassic around 900 BCE. It recovers briefly in the late first millennium BCE and declines greatly again in the last first millennium (Late Preclassic), recovers modestly in the Classic, and returns to Early Preclassic levels in the Postclassic. This implies that the Uxul/Esperanza watershed area near El Mirador was involved in the Middle Preclassic spread of agriculture across the Lake District around 900 BCE, lost this status for a while, and then joined in the great El Mirador explosion of the Late Preclassic from around 300 BCE to 200 CE. During the Classic, the landscape was managed to balance tropical forest and disturbance vegetation. Tiris control was lost around 900 CE and the area returned to tropical forest. Comparing the Silvituc and Chumpich findings supports a northward spread of

agricultural societies out of the Lake District into the drier bajo district of the Mesoplano in the Late Preclassic after an initial attempt in the early first millennium BCE.

A study of Oxpemul pollen currently underway adds some perspective to the Mesoplano yet further north and inland though still in the Ramona! Baja (see Fig. 11.4). In the left-hand panel (Fig. 11.8), forest (Selva) and disturbance-cultivation vegetation appear to remain constant through the Classic and then drop off in the early part of the Postclassic. This would be a pattern consistent with the rise of Chichen Itza and Mayapan in the north rather than the Classic of the central Maya Lowlands. Further perspective on this will be available when the bottom 100 cm of the core are finished. It should show when agriculture became important in the north of the Ramon al Baja.

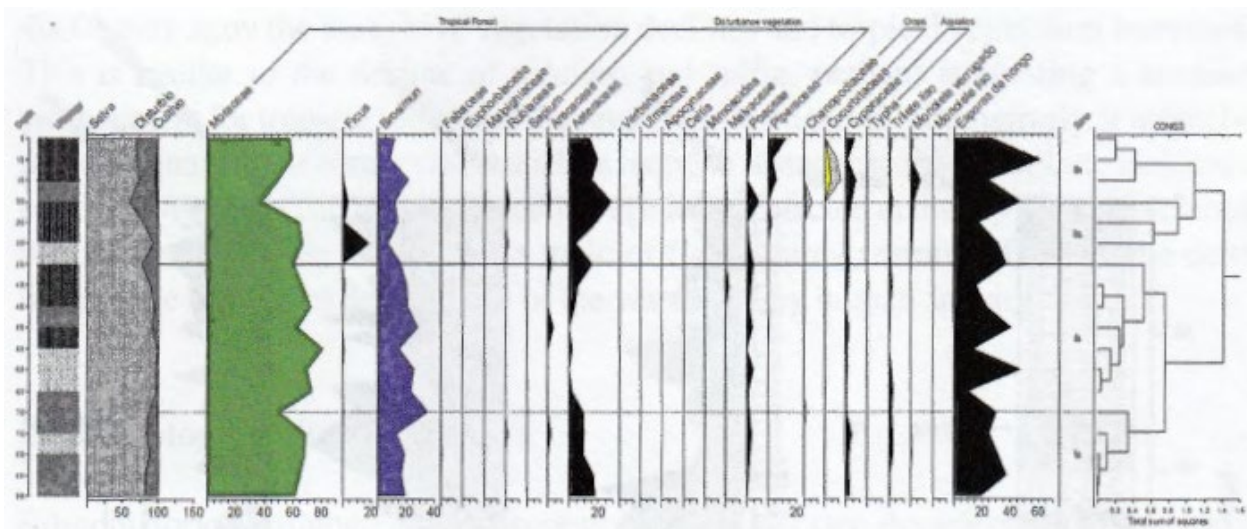


Fig. 11.8. Pollen study from Ramonal Bajo at Oxpemul (Torrescano-Valle in preparation)

Turning downstream to Torrescano-Valle's work in the Candelaria delta (Torrescano-Valle et al. 2012; Torrescano-Valle and Islebe 2015), a core was taken for numerous reasons from an island in the Candelaria delta (see Gunn et al. 2012). It was tested for geochemical, grain size, and pollen characteristics (Fig. 11.9). Keeping in mind that these results represent the whole of the Candelaria watershed from Nakbe to Calakmul, Torrescano et al. report that the pollen shows that the Archaic Period experienced high levels of precipitation, a warmer and more humid climate than now. There was a wide distribution of mangroves and tropical forests. The sediments reveal some stability in discharge and low erosion from human activities. This would include the human activity for the previous 3000 years reported by Siemens (2009) in the middle Candelaria (see below).

During the Preclassic, precipitation conditions change substantially. There are periods of high discharge and some periods of erosion. Considering together both the archaeological and pollen data, human occupation is confirmed. This archaeological and agricultural evidence includes dams, raised fields, terraces, and albarradas: the conditions show management and erosion control.

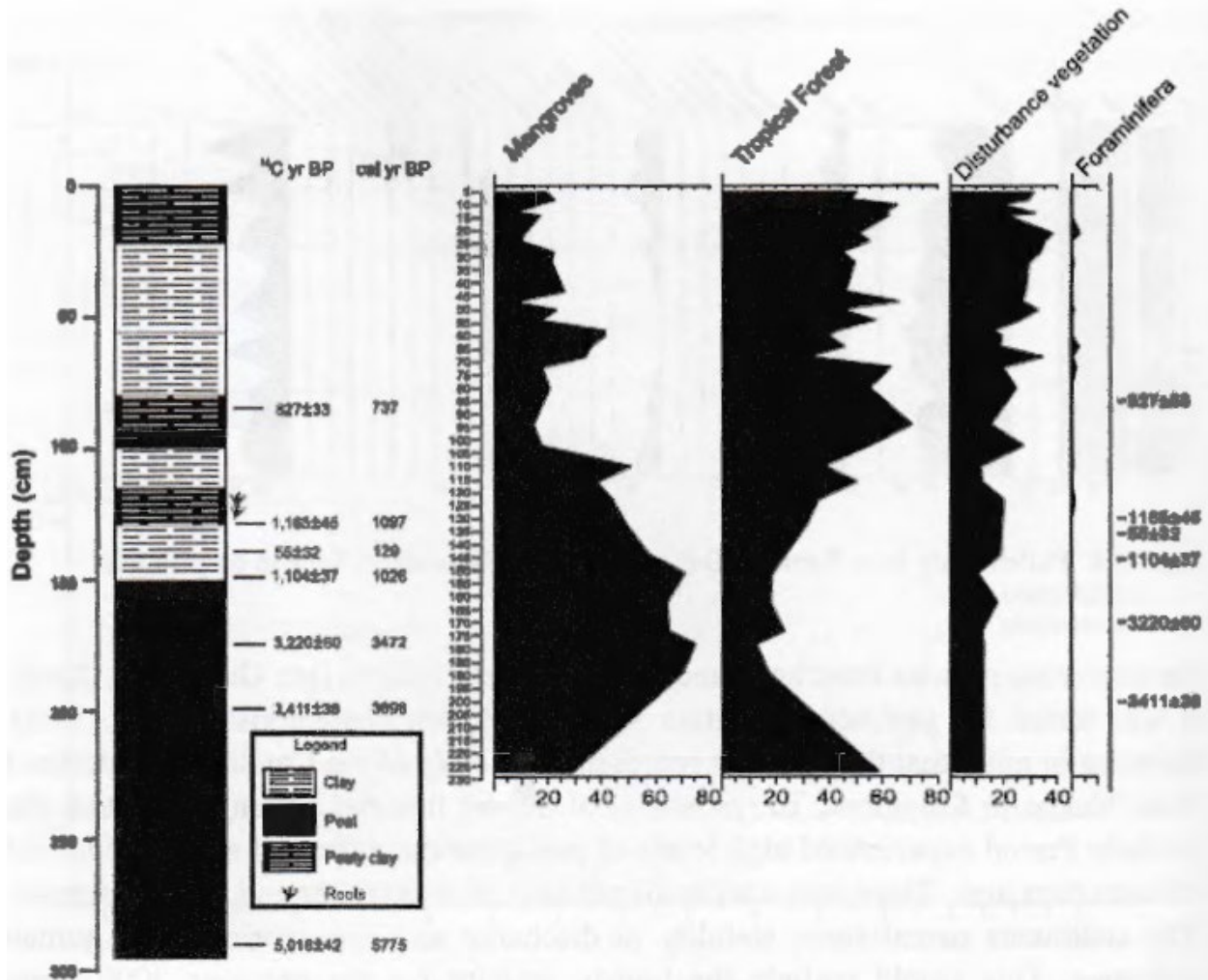


Fig. 11.9. Panlao core pollen and sediments. (Adapted from Torrescano-Valle et al. 2012)

The Classic Period sediments reveal erosion due to deforestation, elements of vegetation of disturbance and increase. The magnitude of the annual cycle decreases, and there is a decline of tropical forest and mangrove vegetation during the ninth century.

The Terminal Classic pollen analysis agrees with the physical and chemical data on the sediments (see below); it is likely that several centers such as Calakmul exercised no further control over erosion during the Terminal Classic Period. The palynological data are not bracketed by high-resolution dating during this period but indicate a drastic decline in all taxa implying a strong drought event.

In the Postclassic tropical forest vegetation recovered, savannahs, moist lowlands, and low deciduous jungles appear. Rainfall levels return but it is not comparable to that of the Archaic Period. After the conquest, repopulation fosters high deforestation and erosion.

Taken as a whole, the Panlao core sediments should present an average of all of the tributary input proportioned according to their average volume of input to the delta. As can be seen in the geochemical and pollen diagram (Fig. 11.10), after about 4000 years ago the mangrove

vegetation declines and tropical vegetation increases. This is similar to the decline of calcium and sulfur, perhaps suggesting a healthier environment for tropical forest and the reverse for mangrove. Alternatively, it might be more a signal for the core location such as increase distance to the sea or Late Holocene cooling over time. The human signal in vegetation detected at the top of the watershed is obscured for some reason and a topic of forthcoming research. Perhaps the delta records the long-term degradation of the watershed by human activity.

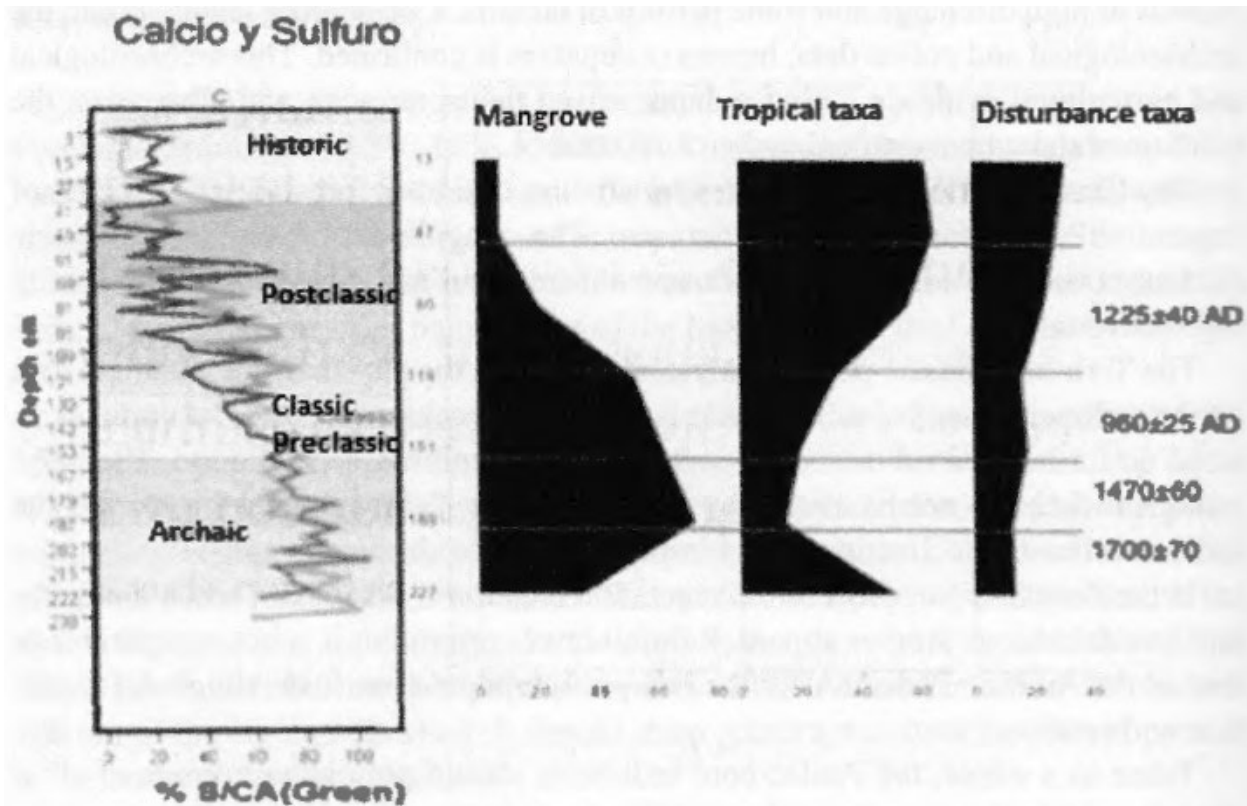


Fig. 11.10. Pollen and geochemical determinations from Panlao (Gunn et al. 2012; Adapted from Torrescano-Valle et al. 2012)

Ethnoecology of the Watersheds

Ethnohistorical/ethnoecological research in the last two decades in nearby towns add some insights into possible habits of residents of the city of Calakmul during the Classic. The research has mostly been carried out along the Champoton-Desempeño watershed and the adjoining Edzna Valley, especially in the communities of Pich and Cauich (Faust 1998, 2010; Faust et al. 2012). Following the patterns of these ethnographic population, residents may have lived in Calakmul part of the year, and each farm family may have spent half or more of the year in a hamlet of associated families near a remote reservoir (aguada) and returned during the dry season to town to do construction work on temples, road building, making pottery, weaving cloth, socializing, etc. (Folan et al. 2000; Lutz et al. 2000; Zetina-Gutiérrez and Faust 2011). Zetina Gutiérrez and Faust report interview data from Pich concerning the pattern of life before the 1970s. While living in the agricultural hamlet, the farmers dispersed to farms, while the women and children stayed closer to the homes where they cared for fruit trees, pigs, chickens, and

turkeys and sometimes adopted baby deer whose mother had been shot. The domestic animals were raised to be sold, while the families ate primarily deer, wild pig, and wild turkey for meat.

According to interviews with older people who had lived in these hamlets, every 14 years or so all the families of the hamlet would abandon them and move to another area known to them from previous occupations of their parents or grandparents. The men had continued to visit these sites on hunting expeditions; sometimes women also went and collected medicinal plants, firewood, etc. It has been hypothesized by Zetina and Faust, on the basis of historical reports of persecution by colonial authorities, that in colonial times, these hamlets were intentionally made to look like they were temporary shelters to avoid persecution, a tactic that might well have applied occasionally in the days of the kings as well.

Interview data concerning observations of nearby stone foundations of houses or ruined stone buildings indicate that in Prehispanic times these settlements were more substantial. The hamlet locations probably belonged to lineages, along with the aguada that provided the homes with water. This would indicate that each family during its life cycle maintained a home in town and one in each of two or three hamlet sites. Then each family would have been responsible for three or four houses. Population estimates based on counting remnants of house foundations would therefore need to be divided by three, at least.

Since other crops would rot in the bajo, corn may have been grown there (Silverio, personal communication, August 2018). If so, that was why there was so many dental issues. They could grow a lot of corn because the bajos were extensive and probably reliably moist. The uplands would only produce when the rains were of the correct magnitude and seasonal distribution, 1/2 dry season and 1/2 wet season. However, if the bajos were producing a lot of corn, should there be fewer carries and tartar in the Classic the way there is less porotic hyperostosis?

Camote are grown on slopes near the bajos. The older people formerly took camote into the field to eat; carbs gave them a lot of energy. Beans are grown on slopes, and farther down slope near the bajo the camote, squash, and Macal where they get moisture but the roots do not rot. On the other hand, corn in bajos resists moisture and corn roots do not rot.

Reporting to Lynda Folan, her Comadre (personal communication, 2018) had a traditional lifestyle in her Pueblo, planted and weeded and gathered corn, squash, etc. She remembers the beans were cooked with stones. Her father would bring home fresh ibis (small white beans) from the milpa and her mother would boil them until cooked. She then drained the beans and threw away the water. Also she would cut the stems of small green onions into small pieces and fry them with pepita de calabaza (ground squash seeds). This was added to the cooked. white beans and stirred together, and they were put in a pan. Meanwhile her mother found three stones about the size of a fist. She washed and rinsed them well and placed them in the fire until they are red hot. Then she placed them in the pan with the beans, green onion stems, and squash seed powder. This she covered with a cloth for 1 hour. She said the beans are so delicious and they have a flavor of being cooked in the ground. The dish is called Tokzel. She also says she misses eating camote her father always prepared them in the ground.

Hydrography of the Middle Reaches of the Candelaria Basin

A second impediment to sediment travel to the Candelaria delta is being researched by Siemens et al. (2002; Siemens 2009) and Vargas-Pacheco (2012). The middle Candelaria is taken to be the Candelaria system from the first shoals of the river 70 km inland from the Laguna de Terminos to the back side of the coastal plain marked by the edge of the elevated interior, the Xbonil Hills (see Fig. 11.4). About 70 km up the Candelaria (Fig. 11.11), the river passes through a ridge of resistant limestone (dashed lines). The elevations on either side of the river rise to over 60 m amsl. The river cuts through this ridge (solid limestone) creating some modestly fast water or shoals in the choke. The ridge line accounts for the convergence of the three arms of the Candelaria system (El Caribe, La Esperanza, Candelaria/San Pedro) that span a much wider area than would be expected if each went straight to the sea. Such geological "chokes" (or "narrows") in river floodplains create sediment traps (slack water deposits) into which sediments accumulated during slow, or slack water, episodes during floods as the volume of water is too high to allow for the normal velocities that keep sediments in suspension.



Fig. 11.11. Middle and lower Candelaria in the coastal plain and zone. (Adapted from Siemens 2009)

The middle and lower Candelaria in the coastal plain and zone contain a complex lake/laguna topography (Fig. 11.11). The shoals below Candelaria Town funnel the many branches of the Candelaria River through a single choke. This creates a massive slack water deposit upstream that extends as much as 30 km up the streams. The depth of the deposit and Lake Candelaria were extended by damming the choke in ancient times (Siemens et al. 2002; Vargas 2001, pp. 153-155). Siemens working with local resident Soler-Graham (Siemens et al. 2002; Siemens 2009) found six dams in the narrows. The dams appear to have been made originally of logs, since encrusted by carbonates. Most of the dams that Soler and his people reported, confirmed by

Seimens snorkeling, were constructed of stones manageable by one or two people rather like stone boundary walls. In the abutments were calcium casts of logs that appeared to have served as reinforcements.

An embayment below the choke indicates a Pleistocene-age, low sea level, well-established channel. The embayment (see Fig. 11.11, triangle) suggests a longstanding and stable relationship between the river and its surrounding uplands extending at least into the Pleistocene when sea level was much lower.

Behind the dams and the ridge on which they reside is the 30-km-long artificial lake. Subsequent to 5000 BCE, the lake was formed accompanied by clearing of surrounding uplands of forest vegetation (Siemens 2009). (This occurred at the same time as occupation of the Tabasco coast (Pope et al. 2001).) Upland clearance was surmised from a pollen analysis of a core (El Chilar; see Fig. 11.12). Major disturbance of the surrounding uplands occurred between 5000 and 3100 BCE. After that, lesser disturbances continued in the uplands until 2100 BCE.

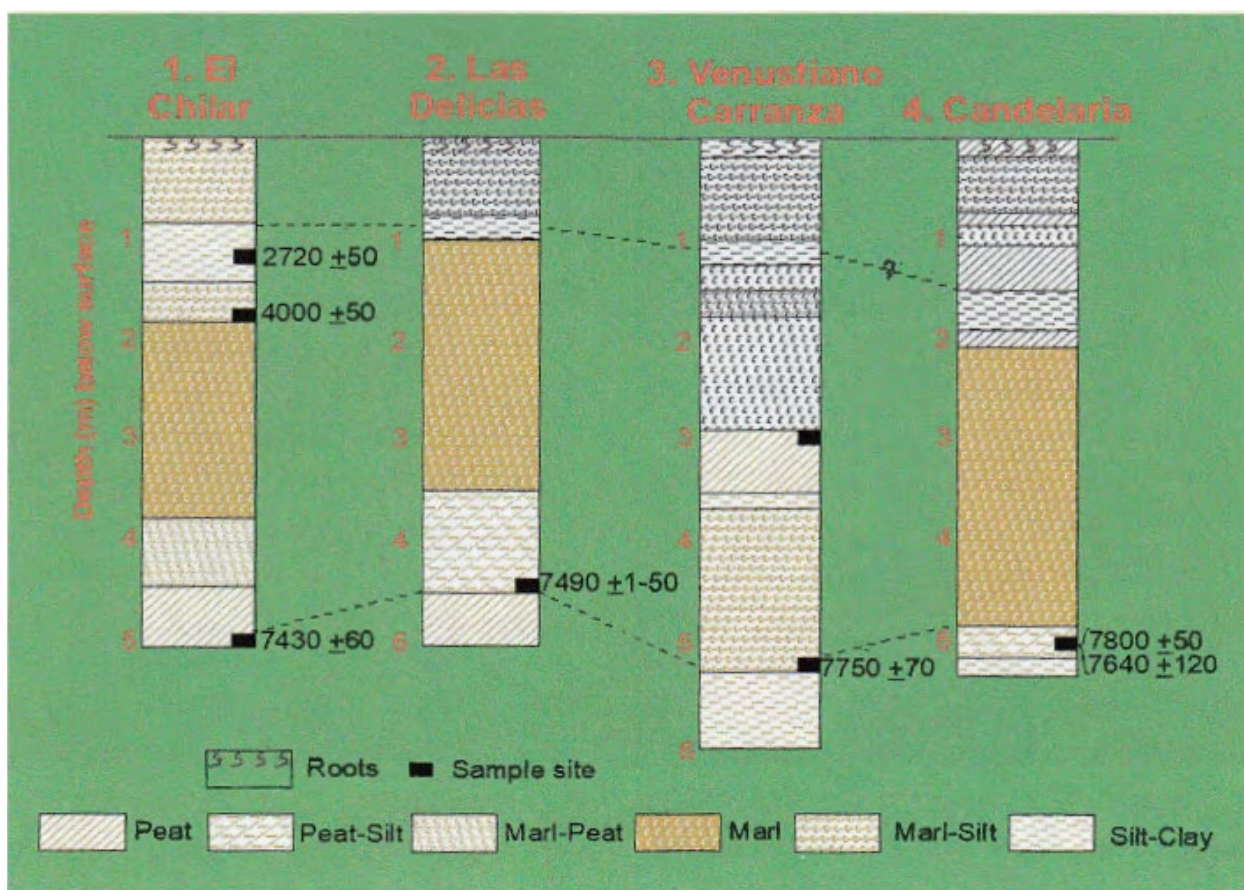


Fig. 11.12. El Chilar core sediment profile. (Adapted from Siemens 2009)

A thick layer of marl within the lake was formed between 4000 and 2000 BCE indicating open water sponsoring a pelagic microfauna (Fig. 11.12). After 2000 BCE the marly regime was replaced by thinner layers of silty marl and clay-silt. The clay-silt sediments indicate that although the lake was full to near capacity, sedimentation continued, apparently from overbank

flooding creating a seasonal lake. This was observed by Cortez during his 1524 visit to the area (Scholes and Roys 1968). Thus, the basin above the Candelaria choke would have continued as a sediment trap even without a permanent lake. Water lilies were introduced into the lake at the beginning and continued until 2100 BCE. Lilies are thought to be a Maya source of fertilizer and a water conservation measure in the dry season as their floating leaves reduce evaporation (Matheny et al. 1983). Their root systems also clean impurities from the water.

The clay-silt in the period between 2100 BCE and 1000 CE replaced the lake by agricultural lagoons and raised fields thought to be proto-chinampas (Siemens 2004). The raised fields were identified in zone b of Siemens heuristic model of floodplain annual microvariations. Area-wise, the raised fields are a minor portion of the whole basin, but functionally key. The agricultural system utilized in this period was probably flood recession agriculture as observed in 1524 by Cortez. This occurred in the zone from the 40 m contour down to a variable annual low of the lake during any given year. Exact measurement of the area of the lake was not attempted. The blue area in Fig. 11.11 was defined by a contour level that seemed a likely possible upper boundary. It is a reasonable approximation of high-water levels. Using a total station, attempts were made to deduce successive water levels from the tops of the remains of stone barriers in the river, but no apparent pattern emerged. The various dams may have been adaptations to varying climate regimes. So far no means of dating them has been devised.

This was/is an extremely complex hydrological situation. It was decided to deduce approximate regimes. This particular regime was based on successive plantings following drops in water level referred to as "fugitive" or "flood recession" agriculture. Raised fields can be thought of as an enhancement of flood recession agriculture by canalizing land so it is exposed more quickly and reliably for cultivation. Rather than a vast monocrop, lagoons would have had some canalization to facilitate transport by watercraft, webs of connections between settlements. These water bodies would not present one vast mirror surface of a lake, but a scrubby, ambiguous waterscape. Some of that was firm enough to build planting platforms, or "proto-chinampas." Siemens observed such a complicated watery landscape immediately after a flood in Central Veracruz.

The El Chilar sediment sequence is largely reproduced at the three other core sites along the lake (see Fig. 11.11). It appears to imply that inhabitants of the area first established a lake in the Middle Holocene (~5000 BCE), a time suggested by Scarborough for early occupation of coastal lowlands (Scarborough 1998). This would have been part of their water control regime, perhaps to facilitate traffic by watercraft, for farming purposes, for fishing, and for spanning the dry season with adequate water resources. During the Late Preclassic and Classic (~400 BCE-800 CE), the lake bed was turned into a farming area with a complex canal system discussed below.

Additional opportunities to trap sediments exist in the Upper Candelaria in the El Tomatillal, which drains El Laberinto Bajo south of the Calakmul transverse ridge. It passes through a narrow gap in the Xbonil Hills (see Fig. 11.4, the Concepción Choke) near La Concepción settlement into the coastal plain swamp. This is about 90 km up the Caribe branch of the watershed. Damming the Concepción Choke in Fig. 11.2 would likewise have provided an extensive sediment trap within the Calakmul Basin that could have been managed using the strategies suggested in Siemens' heuristic model.

In Lake Candelaria, Siemens and Puleston (1972) discovered sequences of canals parallel to the stream channels. These canals appear to be repeated incidents of excavating canals, infilling with sediments and excavating a new canal next to an older canal in some instances only a few meters apart (Siemens 1989, Plate IV-7). This could be interpreted to mean either that (1) for some reason it was easier to excavate new canals than dredge old ones or that (2) the canals were more profitably used for other purposes, perhaps agricultural.

1. In the new canals case, in 2015 Faust visited a canal dug by the Bonfil rice project during the 1970s. It was abandoned by 1990, and 15 years later, large trees had taken over the canal, and water was no longer visible except in one area where a family had cleared the trees. It is possible that if a human population abandoned the area for 15 years due to political or other reasons, it was easier to dig a new canal than remove the roots of large trees fertilized by agricultural activity and open growth areas.
2. In case where the canals were intentionally designed for agriculture use, reflecting on the heuristic model, Siemens proposes that the parallel canals located nearer the river channel may have served to hasten the drainage of water from the upper part of the floodplain recession area early in the growing season (Siemens 2004, p. 349). Later in the growing season when the river level was toward the channel, they would have served to retain water with intervening spaces becoming raised fields. The raised fields would have become the habitat of agriculture during the dry season allowing for multi-cropping. The low water levels would have been relatively reliable because of the Candelaria's semikarstic underground storage of water released slowly through the dry season (Siemens and Puleston 1972). Dry season water levels would also have been maintained by tributary streams emerging from springs. The canals would have additionally provided the routes of a transportation web as observed by Cortez and his recorders at both Acalan and Tenochtitlan and still apparent in Siemens' aerial photographs (Siemens 1989).

In either case, the canals provided another sediment trap explaining the lack of interior sediments during the Classic in the Panlao core. There can be little doubt that the Maya in the Candelaria drainages were busy with canalization for various purposes. These include the canals mapped at Calakmul (Folan et al. 1990a; Folan et al. 2001; Geovannini-Acuña 2008) for potable water storage and watering of crops. Also in the Champoton-Desempeño watershed at Oxpemul (Barnes et al. 2009) and Edzna (Gunn et al. 2002; Matheny et al. 1983), very substantial amounts of water were stored in canals and modified polgars producing by far the largest storage capacity of anywhere in the lowlands (Gunn et al. 2002).

Geochemistry by the Sea: The Laguna de Términos at Panlao

In addition to the pollen, and complementary to coring the bajos, a core was taken from an island in the delta of the Candelaria system in 2004 (Gunn et al. 2009a; Tebbens and van der Borg 2001). It was expected that the Panlao core would lead to an understanding of the impact that settlements in the interior had on sedimentation from the entire Candelaria system as viewed from its terminus (Fig. 11.13). The record of the Panlao core extended back to 4000 BCE. Eight radiocarbon dates were performed to correlate the sediments with the archaeological chronology. Interpreted as they are here, the core seems to indicate relatively rapid sedimentation in the

appears on two of the three subsystems (nutrients, factor 2; volcanism, factor 3). Association with factor 2 indicates some silica is apparently coming down the river with potassium, possibly locked in barium silicates sequestered by plants (phytoliths) and probably a function of human control of sediment exit of the interior. The other silica subsystem is from volcanic events that inject silica without barium. Likewise, potassium is shared between the heavy-light (factor 1) and nutrient subsystems suggesting that potassium comes down the river as a natural matter of course, but human infusions kick part of the potassium allegiance out of the natural orbit in an unrelated pattern with barium. Potassium and silica erosion decline toward the Classic-Preclassic indicating that humans were conserving these elements in the interior (see Fig. 11.13d). A spike in factor 2 deposition at the end of the Classic probably indicates some loss of control of erosion. In terms of number of shared subsystems, barium is the most distributed touching on all three systems. Barium is concentrated in plants so its decline with time in the nature/heavy-light subsystem and decrease in the human/nutrient subsystem during the Preclassic-Classic reflect increasing human control of system-wide vegetation. In factor 3, volcanic injections of silica from volcanoes depress the barium content.

More important than these artifacts of analytical methods are the dynamics of linked systems (Gunn et al. 2017; Gunn et al. 2019). Some variables are shared by more than one subsystem. They tie the system together in one sense. In another they confuse bivariate correlations by apparently diminishing the variance accounted for in subsystems by variables. In mutualistic systems of variables, the fissure lines between subsystems are the lines of disturbance that reveal partial causations. Factoring these systems sorts out the partial causations, or partial correlations, giving some sense of direction in the more usual human need to see cause and effect in binary relationships. This helps to order one's understanding of events in the perceptual sphere. In this analysis, the variable depth (−0.96), or time, points to factor 1 as harboring much that goes on through time such as the decrease in lighter and more soluble sediments and increases in heavy metals. Humans acting on this system probably control the timing of release of heavy metals and plant nutrients in factor 2. Volcanism in factor 3 is also a centrifical force in the system providing another source of silica, though without barium. This suggests that the barium in factor 2 is sequestered in plants as barium silicates, whereas the silica coming in as volcanic debris is barium-free. This is an hypothesis that was tested using XRD (Faust et al. 2010)

Factor		1	2	3	
Element	Variable Symbol	Heavy vs Light	Nutrients/Toxins	Volcanism	Atomic Wt
Heavy/light	Depth (time)	−0.96	0.20	0.07	–
Lead	PPb	0.84	−0.13	0.00	207
Barium	PBa	−0.40	0.72	−0.37	137
Copper	PCu	0.84	0.26	−0.10	64
Iron	PFe	0.85	0.12	−0.07	56
Calcium	PCa	−0.83	0.34	−0.06	40
Potassium	PK	0.68	0.60	−0.06	39
Sulfur	PS	−0.93	0.13	−0.08	32
Phosphorus	PP	0.90	0.22	−0.08	31
Silica	PSi	0.09	0.41	0.90	28
Sodium	PNa	−0.86	−0.04	0.04	23

Positive with factor
 Negative with factor
 Shared elements

A factor analysis of the elements in effect recreates the compounds from which the elements are a part. Compounds are correlated communities of elements. Factor 3 (Table 11.2) contains a strong silica signal indicating volcanic eruptions at the end of the Classic and in the Postclassic (Fig. 11.13e). The mega-spike in the Postclassic is the 1300s CE eruption of El Chichon (Nooren et al. 2009). Beach et al. (2016) point out that there appear to be three episodes of collapse in the Maya chronology but that the correlations of droughts with these changes leave room to question precise cause-and-effect relations. Two of the three silica spikes in the Panlao core strengthen this argument allowing us to step past the cause-and-effect dilemma. Historical observations confirm that the debris of local volcanoes bring troubled times to the lowlands (Dull et al. 2001; Folan et al. 1983; Sheets 1983), especially if they are of sufficient magnitude to bring accompanying droughts rooted in global climate change (Gunn et al. 1995).

Table 11.2. Factoring of XRF mineral determinations

Factor		1	2	3	
Element	Variable Symbol	Heavy vs Light	Nutrients/Toxins	Volcanism	Atomic Wt
Heavy/light	Depth (time)	-0.96	0.20	0.07	—
Lead	PPb	0.84	-0.13	0.00	207
Barium	PBa	-0.40	0.72	-0.37	137
Copper	PCu	0.84	0.26	-0.10	64
Iron	PFe	0.85	0.12	-0.07	56
Calcium	PCa	-0.83	0.34	-0.06	40
Potassium	PK	0.68	0.60	-0.06	39
Sulfur	PS	-0.93	0.13	-0.08	32
Phosphorus	PP	0.90	0.22	-0.08	31
Silica	PSi	0.09	0.41	0.90	28
Sodium	PNa	-0.86	-0.04	0.04	23

Positive with factor
 Negative with factor
 Shared elements

^a There are a number of reasons that univariate and bivariate analyses under-analyze multivariate systems. They include masking variables in which relationships are hidden by positive and negative correlations between three variables and reduction in variance and therefore statistical significance because of unaccounted for variables (Draper 1981)

The above-described sequence of events at Panlao might arise for a number of reasons: channel changes, sea level/base level changes, or perhaps another interpretation of the radiocarbon dates. However, taking the interpretation offered above suggests that although there is ample evidence for dissipation of sediments in the interior during the period of Maya occupation dating to the period of Maya civilization as suggested by Deevey et al. (1979), these nutrient and metal-bearing sediments did not reach the ocean until the Postclassic. In other words, the Maya were conserving sediments short of the delta.

There are two identifiable reasons that delayed the sediments arrival. One is, as Gunn et al. (2002) suggest, the sediments were intentionally allowed to slump into the edge of the bajos changing otherwise saline and acid bajo bottoms into arable farmland. Secondly, the Maya

would have then constrained these sediments from further erosion and escape to the sea thus accounting for their 1000-year tenure in the Lowlands.

Modeling Nutritional Feedback in the Candelaria Watershed

Continuing the search for key variables, we suggest that in large part, after an initial period of land and sediments modification to create bajo-edge farmland, the Maya gained control of their landscape and retained its fertility by trapping sediments at the base of bajo-edge slopes, canals, lakes, chokes, and other means not discussed here but identified elsewhere: lagoons, terraces, sables, and walled fields. Without such measures, the sustained population of the watershed, perhaps the densest in the lowlands, for the millennium or so of Late Postclassic-Classical Maya fluorescence in the watershed, seems unlikely.

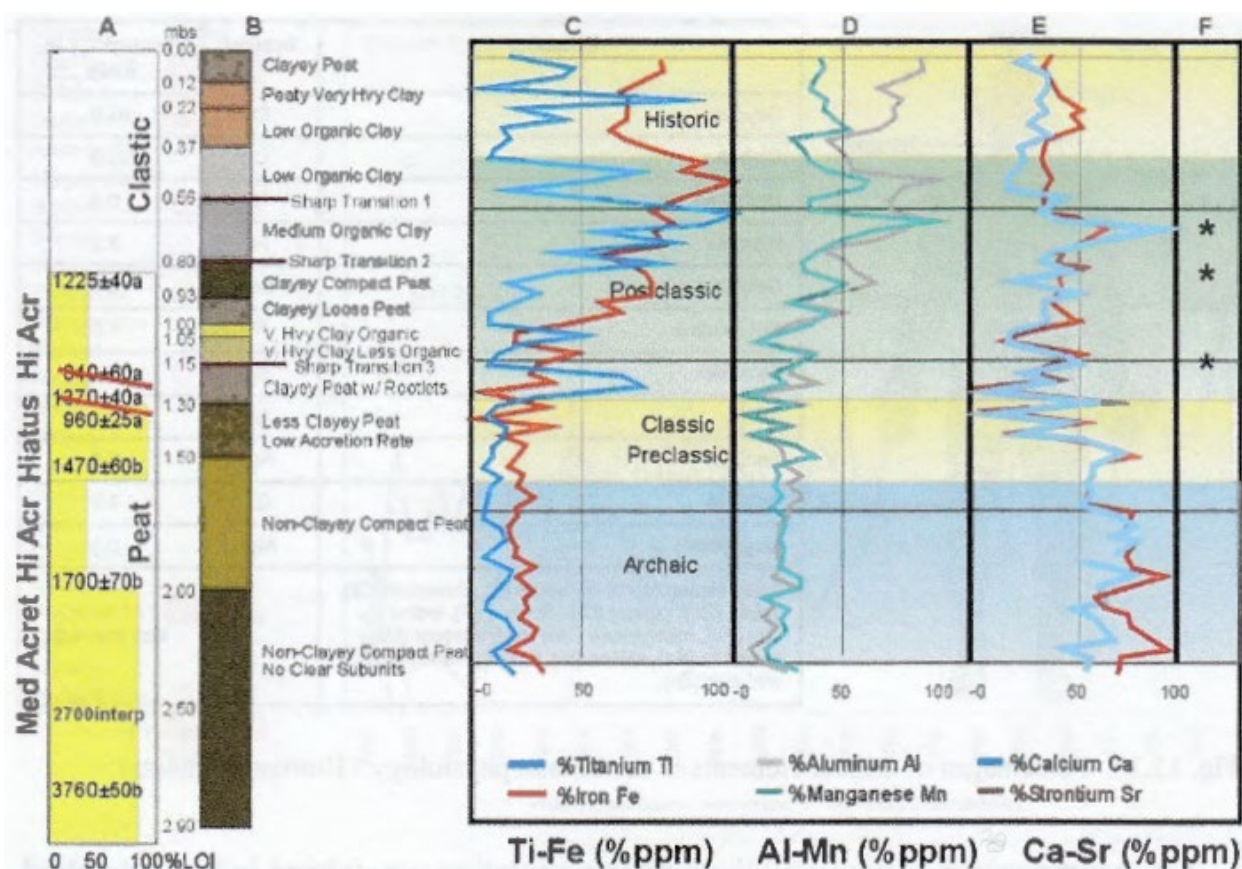


Fig. 11.14. Panlao core 2008 reanalysis is for strontium and five other elements. Low-magnitude oscillation during the Preclassic and Classic suggest some disturbances in the Maya control of erosion. * = lithologic volcano beds. (A) Accretion rate, sediment source and Radiocarbon dates, Depth in m below Surface (mbs), (B) Sediment grain size organics. (C) Titanium-Iron. (D) Aluminum-Manganese. (E) Calcium-Strontium

An additional ICP analysis on the Panlao core in 2008 revealed four interesting, low-magnitude jiggles in the strontium profile (Fig. 11.14e) during the Preclassic-Postclassic Periods (Gunn et al. 2009a). These might result from incidents like the collapse of El Mirador at the end of the Preclassic presaging the grander Postclassic collapse. In addition to the immediate impact of

volcanic ejecta in the region, it would have produced similar droughts that reoccur about every 300 years in the region as a result of the cycling of Earth system variables (Gunn and Folan 2000; Gunn et al. 1995). Thus, the lesser fluxes could be products of disturbance in the Maya sediment world during a time when they were in large part in control of sediments from the interior. They might result from conquest events that temporarily undid the Maya control of their landscape. Since the largest is early during the period, it might prove to correlate with the El Mirador retreat.

Relative to the idea of key variables and the Maya collapse, it is clear that heavy metals inform us that sediments were moving and not just simple rates of sedimentation or other types of sediments such as soluble carbonates (Table 11.2). Lead is especially important because of its great atomic weight. Similar systems appear to be evolving in current conditions on a worldwide basis suggesting to some geologists the naming of a new epoch, the "anthropocene" (Ruddiman 2010; Syvitski et al. 2005). To partially answer our initial question concerning key variables, it would appear that if critical moments in past and present civilizations can be keyed to the constraint and movement of sediments, there is at least enough comparability to begin thinking about a futurology based on the distant past, an IHOPE design (Hibbard et al. 2008), following during some of this research.

Something that might be relevant to the down-functioning of the interior cities in the Terminal Classic is the depletion of minerals in soils critical to human health, a trend that Chew (2007) identifies with collapses of civilizations, or more frequently transformations like the Maya. It might have been the "push" element along with drought in the migration to the coast situation. In a list of the elements in the human body (Fig. 11.15), the first four (oxygen, carbon, hydrogen, nitrogen) are from the atmosphere and not quantified in sediments by our ICP analysis. The next six (calcium C, phosphorus P, potassium K, sulfur S, sodium Na, chlorine Cl, and magnesium Mg) are well understood to enable body functions such as contraction and relaxation of muscles (K Na P), elimination (Mg), cartilage structure (S), brain function (Mg), etc. Since the Yucatan platform is composed largely of limestone (Tankersley et al. 2011), critical elements other than calcium generally arrive from nearby volcanic eruptions and dust blown from Africa on the tropical easterlies. Depletion of these elements could therefore become critical if there was a long period without eruptions or the easterlies were moved toward the equator by a period of global cooling and probably other situations as well.

Since our concern is how well the human population was fairing in the watershed, these critical elements may give us an index of soils and human conditions. In intensively agricultural societies such as the Maya Lowlands, it is not surprising to find that humans can serve as proxies for soils and vice versa. With our ICP analyses, we may have a way to understand how the sediment-human relationships were balanced. Figure 11.16 shows factor 1 and plots of factor 1 scores, which includes the human variables (calcium, phosphorus, potassium, sulfur, sodium, and magnesium; not chlorine) and metals. The calcium-sulfur situation is a little confused because of the veneer of gypsum (calcium sulfate) that overlays the lowlands from the Chicxulub impactor 65 million years ago. There is no shortage of calcium, however, under any circumstances, so it is not very important in terms of sorting out critical variables.

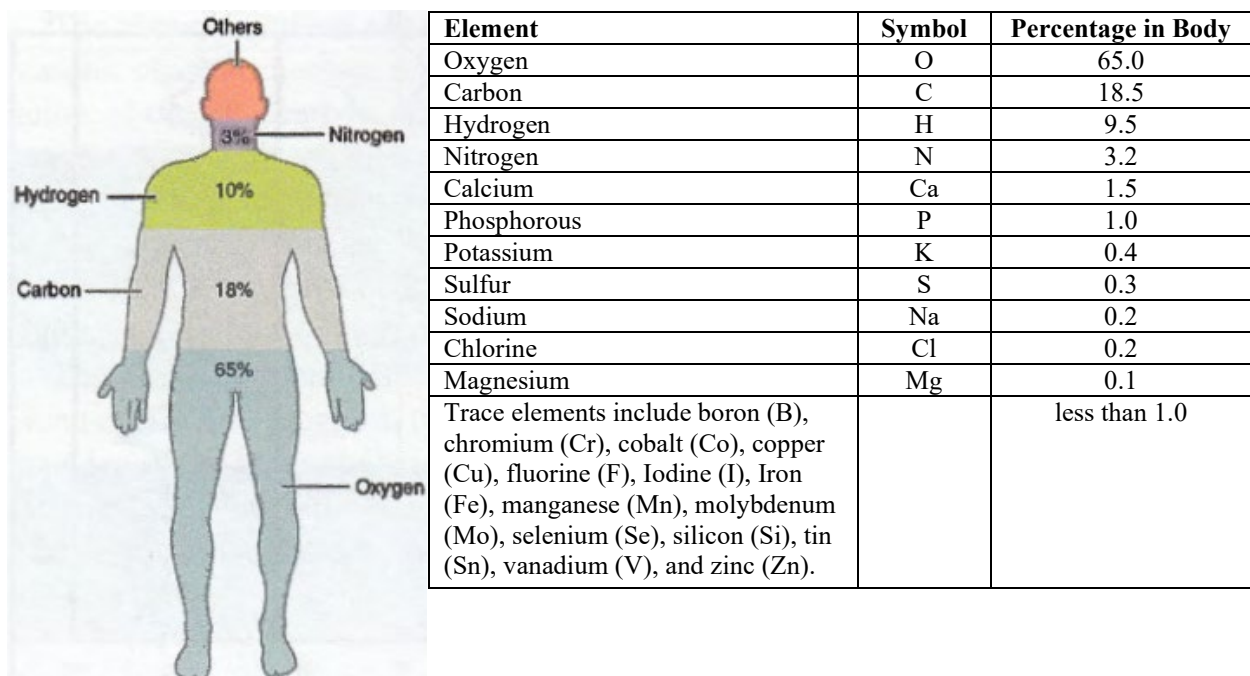


Fig. 11.15. Percentages of critical elements in the human physiology. (Human Elements)

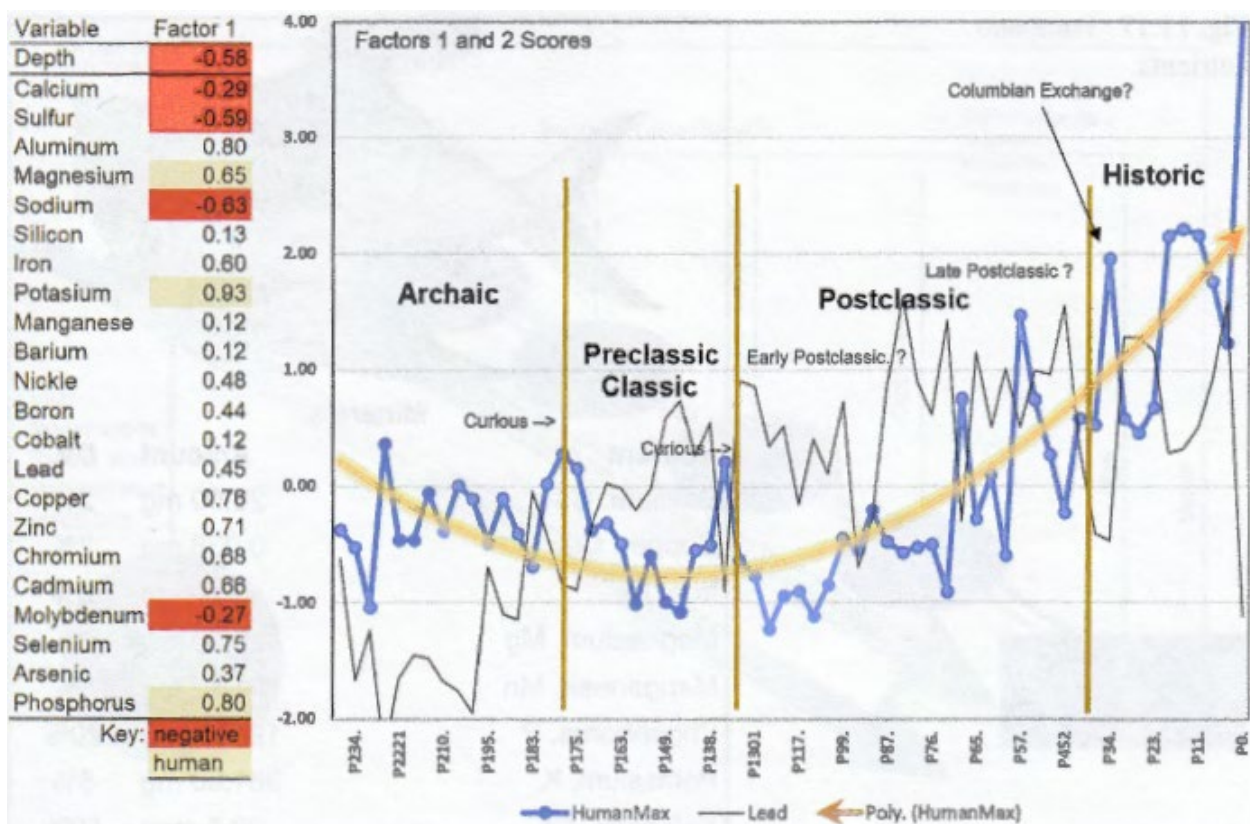


Fig. 11.16. Factor 1 (varimax rotation) and plot of factors 1 and 2 scores from 2008 Panlao core ICP determinations. (FactorAnalyses.xlsx)

What is notable are the key muscle operators, phosphorus, potassium, and magnesium that are strongly present and separable from the general system interaction network: see the factor loadings in the left panel. In the right panel (factor 1 scores), this complex of elements declines through time from the Archaic to the Early Postclassic and then increases to the present. This implies that the key elements were being used at greater rates than replacement by volcanoes and African dust in Classical times. There are curious spikes in factor 1 inputs at the transitions between the periods. This would be spikes in metals, especially lead, indicating that sediments were on the move, i.e., the soil conservation measures lapsed. The essential conservation measures would be to prevent erosion (indicated by lead) while allowing salts (calcium sulfate and sodium) to pass to the sea to prevent salinization. Factor 1 indicates that in large part the conservationists in the Candelaria drainage were successful at desalinization and erosion prevention. Factor 2 scores (light gray line) shows that during the Archaic very little lead was coming into the delta but this increased with time and spiked in the Late Preclassic-Classical Period indicating erosion.

That phosphorus, potassium, and magnesium were also coming into the delta indicates the conundrum that the hydrological and soil conservation engineers faced. Desalinization was also removing critical elements for maintenance of the human bodies. Scherer et al. (2007) have documented that fish were largely essential for healthy life in the interior of the peninsula. At Caracol, there is evidence that the upper class was importing whole, live, marine fish for their meals (A. Chase, personal communication, 2016 email). Without fish, porotic hyperostosis develops, a condition of the bones, so easily spotted in mortuary populations. Tiesler et al. (2017, p. 113) (hyperostosis) reports that 54.5% of inland Yucatecan population from the Classic Period have evidence of hyperostosis, while only 29.9% from the coast show symptoms. This analysis suggests that fish were undoubtedly being brought up from the coast either from Itzamkanac and/or Champoton to replace the critical elements being lost to the desalinization process. Faust reports observations and interview data concerning the continuing weekly importation of fish on ice brought by truck to the inland town of Pich from the Campeche coast and grandparents' memories of small, salted fish being brought by oxcart before the highway was built in the 1970s. The importation of fish from Champoton to interior chiclero stations (Classical cities) was reported during the twentieth century by Tomas Arnabar Gunam to WJF (Folan et al. 2003) that "En las épocas de la chiclerías, en La Montaña se llevaba Pámpano fileteado en capas dentro de barriles sin secarlo pero entre una y otra capa se ponían sal; tal vez como podían haberlo hecho durante tiempos prehispánicos utilizando ollas y/o pacas tal vez forradas con hojas grandes." (Translation: "In the times of the chiclerías in La Montana, pampano was filleted and placed in layers inside barrels without drying it but between one layer and another they put salt; perhaps as they could have done during pre-Hispanic times using pots and/or bales perhaps lined with large leaves.") As can be seen in Fig. 11.17, pámpano contains the necessary magnesium, potassium, and phosphorus (https://www.nutritionvalue.org/Fish%2C_raw%2C_florida%2C_pompano_nutritional_value.html). They also salted saw fish, bass, stingray, lisa, and charales (small minnows that were dried). Salting would have served the double purpose to preserving the fish and replacing the sodium carried away from the interior by the desalinization process.

FIGURE 11.17 IS OMITTED FROM THIS FORMATTED DOCUMENT

Fig. 11.17. Pompano nutrients

ninth century drought came first or if they came simultaneously. There are suggestions by indirect evidence that either is a possibility. Also, we need more cores in the Candelaria delta to ensure that we are seeing the integrated behavior of the drainage system rather than local channel and/or base level changes. A project is underway under the directorship of Nuria Torrescano-Valle to obtain better resolved dating of the Candelaria delta sequence.

Discussion

An integrated, holistic Candelaria-Champoton model can be formulated around the following narrative summary of the above. Outputs from the flow structure of the Candelaria provide insights into Maya watershed-level landscapes, ancient and modern. Outputs are collected in foot slopes, dams, and delta deposits, Calakmul was not agriculturally or hydrologically self-sustaining, so rainwater had to be collected within the city, and additional food had to be transported up to the city. Its social and agricultural network probably extended up the El Laberinto Baja 12 km to the east and 60 km down to the sea through the Candelaria and/or Champoton watersheds to the west. Among the cities of the central Maya Lowlands, Calakmul and Tikal fell into contentious military postures in the Late Classic with Calakmul, in league with Caracol, dominating Tikal until the late Late Classic. El Mirador, once the central feature of trans-peninsular trade between Honduras and Itzamkanac, fell into the military buffer across the elevated districts of the Mesoplano being the zone of confrontation. It was downgraded to a pilgrimage site, while the center of power was moved into the karst at Calakmul. El Laberinto Baja becomes the focus of trans-peninsular travel with a parallel route through the San Pedro system to Tikal.

To augment the agricultural capacities of Calakmul, new lands for planting were created on old salt pans. Processes differ in the Lake District to the south and Karst to the north. Around 900 BCE agriculture appears to have spread across the upper Candelaria-Champoton Systems and then retreated shortly not to reappear until the Late Preclassic. This is obviously in strong contrast to what happened in the Nakbe area where the roots of Maya culture flourished. Since this is a period of worldwide cooling (the Greek Dark Age), which amounts to drought in the Maya Lowlands, it seems likely that agriculturists were cast back to the moister conditions of the Lake District. As in the Mediterranean, the late first millennium BCE witnessed a revitalization most strongly expressed at El Mirador. El Mirador represents an early stage of development of hydrological engineering in the form of damming of drainages. This was followed in the Classic by advanced hydrological engineering capable of supporting large cities somewhat sustainably on karstic promontories such as those occupied by Calakmul and Tikal. This process would have required substantial rainfall both to water the system and flush out harmful concentrations of salts. The latter may account for the unusually precipitous dependence of the Central Lowlands on substantial rainfall.

Pollen and geochemistry of the Candelaria delta show that in the Candelaria watershed taken as a whole, tropical forests declined beginning late in the Archaic and remained in a diminished state until the end of the Early Postclassic. Through this time there was a decline in calcium and sulfur deposition indicating soil conservation efforts were evolving upstream. Since disturbance taxa do not decline in the Postclassic, it seems likely that agriculture continued somewhere in the watershed through the whole of the post Archaic occupation. Where it was practiced appears to

have shifted from one area of the watershed to others. The primary shift in this period was from the elevated interior to the coastal plain sites such as Itzamkanak and Edzna where it continued on through the Postclassic. There may also have been shifts between branches during the Classic, including but not limited to the shift from El Mirador to Calakmul.

Since Calakmul lacked the soil resources to supply itself with food by rainfed horticulture within a day's walk, it seems likely that some part of the population of the city dispersed to the urban hinterlands during the rainy season to raise milpa crops. Dispersed, seasonal homesteads may account in part for the enormous footprint of Calakmul. A survey along the road north from Calakmul indicates that the whole landscape was occupied, terraced, walled, etc. There were undoubtedly intense house gardens as well, both in the city and in the homesteads.

In the middle Candelaria reach, lillies were introduced into the Lake Candelaria before 4000 years ago suggesting that water quality and evaporation control were being monitored and practiced before that time. By Classical times the deposition of sediments was sufficient to turn the floodplain into agricultural fields and canals into fish nurseries. In the Candelaria delta the Panlao core indicates that in spite of erosion upstream, the sediments input during the Classic Period were limited. Apparently intentionally, and perhaps dating from as early as 7000 years ago, the inhabitants of the Candelaria system were welcoming sediments in Lake Candelaria and ultimately used them to support a substantial agricultural enterprise. The scale of this enterprise may help explain how agriculturally impoverished Calakmul could sustain itself. Such an enterprise would have required reliable transportation of food good up the system. A series of dams, lakes, and canals would have been necessary to catch vital resources such as potassium, phosphorus, magnesium, and sodium in crops and fish and return them to the city. Reserved of these elements would also have been replenished by harvesting fish from the Laguna de Terminus and the Campeche Bank off Champoton.

Conclusions

The geophysical and pollen determinations from the Candelaria watershed provide insights into several issues of interest to the culture history of the western Central Maya Lowlands region. Since the Candelaria watershed spans on the divide between the Lake District and the elevated interior karst, it shows that the ability to cope on the karst in terms of agriculture began in the Middle Preclassic around 900 BCE. Hydrological engineering providing for sustainable urban areas developed in the Preclassic and probably explains the timing of urban migration to the elevated interior for both Calakmul and Tikal. It might also explain in its absence why an earlier attempt to establish agriculture and urbanism in the karst failed. There are a number of reasons the Lowland Maya might have wanted to live in the margins of the karst. Living in elevated circumstances would have avoided the health issues inherent in moist lowlands where tropical biology would have quickly festered among dense urban population into disease. As long as there were sufficient wet season rainfall, the elevated cities were cleansed annually. On the other hand, it also allowed cities both to increase the information densities and sustainabilities important for information-based commerce and to command important trade routes across the peninsula.

Across the panoply of developments, both through time and across the branches of the Candelaria and Champoton watersheds, geochemistry shows that the road to urbanization was not smooth but rather travelled in cyclical patterns that reflected volcanic and global climate disruptions. The disruptive events are marked by spikes in metals appearing in the Candelaria delta indicating that somewhere upstream, some or all of the soil conservationists and hydrologists have lost control of their complex systems of water control and erosion retardation. This system bore its own liabilities. Along with refreshing the landscape by desalinization, it removed some of the elements critical to creation and operation of the human body. These elements (magnesium, potassium, phosphate, and sodium) had to be cycled and recycled up the drainage to maintain the elevated cities in the interior. The overall indications from the delta core are that from the Archaic to Early Postclassic, these elements were being depleted or slightly in balance periodically, thanks to volcanic and dust inputs and/or recycling.

Evidence from the middle Candelaria indicates that the shoals of the river were blocked by log dams about 7000 years ago as the adjacent uplands were cleared. Accumulation of sediments eventually turned a large artificial lake of lagoons into intermittent farmlands and fish farms whose use continued into the historic period. This highly productive nexus was, or eventually became, the headquarters of the Chontal Maya who after 3000 years ago facilitated movement of goods across the peninsula, around it, and between the Mexican Highlands and the Caribbean archipelago. Lake Candelaria would have been a major recycling point for key nutrients coming down the Candelaria through crops and fish. Similar recycling may have been processed through the Champoton-Desempeño system with Edzna being the Itzamkanac-equivalent. Also, fish and salt are known historically to have been cycled inland from the sea. Xicalango/Carmen downstream from Itzamkanac on the Laguna de Terminos may have served similar purposes through the Candelaria. Today, coastal fisheries still supply inland towns with fish.

Of special importance to human operation is water, though in a managed environment so as to not foster tropical pathogens and to store it in sufficient purity and quantities to span the dry seasons. Ultimately this key variable proved to be the undoing of the elevated cities when extended droughts in the ninth century brought the horns of the pathogenic-hydrologic dilemma crashing together.

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