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A Stone Canvas: Interpreting Maya Building Materials and Construction Technology

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A Stone Canvas: Interpreting Maya Building Materials and Construction Technology

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A Stone Canvas: Interpreting Maya Building Materials and Construction Technology

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Supervisor: Fred Valdez Jr.

This dissertation will bring together from disparate sources what is known today about the building materials used by the ancient Maya and the construction technology they used to assemble their remarkable buildings. This knowledge will then be utilized to examine questions regarding Maya technology and specialization from a "bottom up" viewpoint in hopes of pointing out a valuable tool for examining the ancient Maya and delineating gaps in our knowledge.

The study of Maya architecture has long depended on works on engineering and architecture that were written in the 1930's and 40's. While excellent for their time these works were in many cases speculative or incomplete and do not compare with modern materials research or archaeological method. Studies and knowledge, from both within and without the archaeological community, are gathered together in the first part of this work to examine what is known about the materials and technology used in building the Maya centers.

The second half takes this knowledge and utilizes to examine two current scientific questions in Mesoamerica. The first is wholly practical and utilizes the

knowledge of technology and procedure to look at Maya lime burning. The specific question is whether or not the ancient Maya possessed kiln technologies beyond that of open heap burning. If they were able to use more fuel and temperature-efficient methods this would have broad implications for the reconstruction of the Maya environment as well as the Maya use of labor.

The second is theoretical and takes what we know of the practical crafts and characteristics and applies that information to an examination of specialization among the ancient Maya, specifically whether or not Maya monumental buildings were planned or constructed by architects. The assumption to date has been that Maya architects existed which again holds implications for the ancient use of labor, social hierarchies and knowledge base.

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Chapter One

Introduction

> *The archaeologist is better able to establish the probable form of the early buildings he excavates if he can identify the few remaining material fragments, for each material has its own message, and upon the character of each depended the type of building that could have been erected, and its method of construction* (Davey 1961: Preface).

Ancient Maya architecture has fascinated the public since their 'rediscovery' in the eighteenth century (Galindo 1834; Stephens and Catherwood 1841; Waldeck 1838). Since those early accounts much has been written about Maya structures and sites, and a tremendous amount of scientific fieldwork has been accomplished. Yet archaeologists working with the architecture still depend heavily on early works in the field for basic references. One such work often cited is Lawrence Roys 1934 monograph, *The Engineering Knowledge of the Maya*. Experts in many fields have since conducted elaborate studies of many Maya materials and methods and we now have a much better understanding of Maya technology. Compendiums of such knowledge for Roman and Egyptian architecture have proven valuable both for understanding construction techniques as well as for making inferences drawn from the materials themselves (Adam 1994; Clarke and Engelbach 1990; Nicholson and Shaw 2000; Taylor 2003). In recent years demands on archaeologists posed by consolidation for ecotourism have pointed need for more work in this area (Houston 1998b).

This work has two distinct elements. The first is a wholly practical study of the materials, forms and construction practices of the ancient Maya. Knowledge from a number of fields and on different facets of architecture and construction will be brought to bear on Maya construction technology. Much of this is a synthesis of works, published and unpublished, interwoven with experimental archaeology and knowledge from field experiences. The synthesis is designed to act as a reference as well as an outline to help determine where future work is needed or perhaps where work unknown to the author can be integrated.

The second part will look at how knowledge of the materials and technology can imply practical hypotheses for field-testing, in this case looking at lime-burning technology, and offer another way to examine theoretical questions such as specialization. The first example will build on knowledge of limestone and quicklime manufacturing to suggest conclusions different than most currently being derived from the field data; that the Maya possessed kiln tecgnologies more efficient than heap burning. The test case points out the difficulties we, as archaeologists, face when interpreting data often outside our professional expertise and illustrates a methodology to avoid some of these difficulties.

A good illustration of these pitfalls was provided by Donald Sanders, president of Learning Sites Inc., at the 66th Society for American Anthropology Annual Meeting. Dr. Sander's company specializes in archaeological digital models and his presentation involved a reconstruction of the Throne Room of the Northwest Palace of Ashur-nasir-pal II at Nimrud that had been excavated by Henry Layard in the mid-nineteenth century (see illustrations at www.learningsites.com). Using a "bottom-up" technique of starting with the materials and methods, and utilizing the archaeological data of many expeditions to Nimrud, Learning Sites Inc. was able to construct a model that met strict archaeological scrutiny. One by-product of this methodology was the discovery that many aspects of the original archaeological renderings were technically impossible. The renderings which have been reproduced countless times had elements, such as a roof with no means of support, which knowledge of materials and techniques known to the Assyrians made glaringly obvious (Sanders 2001). This dissertation uses a similar method of utilizing data on Maya methods and materials to examine assumptions about Maya construction.

The second example will expand on one particular theoretical implication of the material and methods data taken as a whole. An examination of specialization in the building trades and the place of the architect in Maya society in light of the construction data will focus on role assumptions. Recent work has demonstrated that, in all probability, it took fewer laborers a shorter length of time to erect the Maya monumental architecture than was estimated in the past (Abrams 1994; Carreli 1997; Webster and Kirker 1995). Similarly, this dissertation will examine the assumption of a number of building trade specialists including the presence of Maya architects. The contention that the technology required special knowledge does not hold up under examination and, as many average Maya farmers would possess the skills required, the architecture can be called a monumental vernacular style.

Maya archaeologists utilize the words architect and engineer with abandon when describing the cities and structures. Modern definitions of both terms stress the continuous nature of an architect or engineer's involvement in the building process from design through construction. If these terms are to be used at all, a new definition must be devised with the emphasis on the artistic side of designing. Ample proofs exist for the above hypotheses to, if not convince, then at least spark a healthy debate about these topics.

Scope

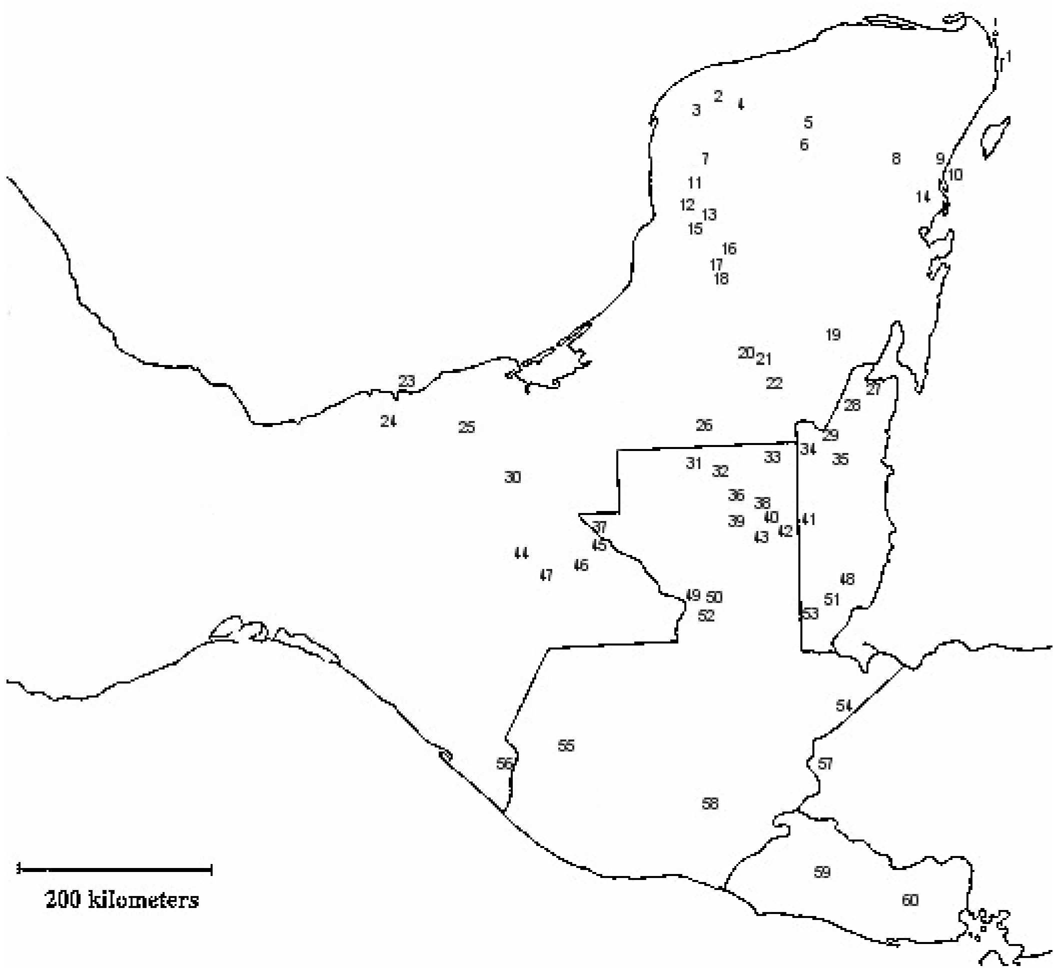
The subject matter tackled here is voluminous and no pretense is made of even attempting an encyclopedic study. The material studies and technology discussions strive to be understandable to archaeologists rather than structural engineers or chemists. While not attempted here, a future study would be to expand this outline through the use of individual subject experts.

This work is primarily a study of building materials and construction technology as they apply to monumental Maya architecture. Residential vernacular architecture, long-served by Wauchope's (1938) monograph, is a worthy subject for an entire dissertation (or book), and will only be discussed where the technologies overlap with those of monumental architecture. The style of monumental architecture, the subject of numerous learned treatises, will also only be touched on where technologies intersect (Andrews 1995; Andrews 1997; Gendrop 1998; Pollock 1980). Lastly, this study will not deal with Maya civil engineering (bridges, waterworks, sacbeob etc.). Maya engineering, especially hydraulic, appears to have been much more advanced than the comparable construction knowledge and is currently the focus of much attention (Scarborough and Isaac 1993; Scarborough 2003).

Maya chronological periods, as defined by archaeology will be used to discuss changes in architectural features and methods through time. Though there are alternate schemes this study will use a chronological framework of four stages; the Archaic, PreClassic, Classic, and Post-Classic. These stages are often subdivided into small periods (early, middle, late, terminal) for greater chronological control. Appendix A is a chart of the Maya eras used in this study.

Data

The Maya architectural data is presented in the first six chapters. The first chapter will deal with the materials utilized by the Maya: stone and its derivatives, clay, and wood. Physical performance data will be presented where appropriate while, at the same time, attempting to avoid for sake of clarity the formulas utilized by modern architects and engineers to analyze materials strengths. In the cases where this is necessary the information will be condensed to a form more accommodating to the archaeological reader. Maya sites discussed in the text are shown on the map in Figure 1.1.



1 Isla Mujeres	16 Santa Rosa Ixtampak	31 El Mirador	46 Lacanha
2 Dzibilchaltun	17 Nocuchich	32 Nakbe	47 Tonina
3 Sibunchen	18 Tabasqueno	33 Rio Azul	48 Nim Li Punit
4 Ake	19 Dzibanche	34 La Milpa	49 Dos Pilas
5 Chichen Itza	20 Becan	35 Lamanai	50 Seibal
6 Yaxuna	21 Xpuhil	36 Uaxactun	51 Lubaantun
7 Muna	22 Rio Bec	37 Piedras Negras	52 Aguateca
8 Coba	23 Bellote	38 Nakum	53 Pusilha
9 Xelha	24 Comalcalco	39 Tikal	54 Quirigua
10 Tulum	25 Jonuta	40 Holmul	55 Zacaleu
11 Uxmal	26 Calakmul	41 El Pilar	56 Izapa
12 Kabah	27 Cerros	42 Naranjo	57 Copan
13 Sayil	28 Cuello	43 Topoxte	58 Kaminaljuyu
14 Muyil	29 Blue Creek	44 Ocosingo	59 Ceren
15 Bolonchen	30 Palenque	45 Yaxchilan	60 Quelapa

Figure 1.1 Maya sites discussed in the text.

Chapter three will cover what we know of Maya architectural preparation and planning. The following chapters, four through six, will discuss specific architectural elements and the information we have on construction techniques. Chapter seven will present what tools the ancient Maya had available to accomplish the tasks covered in the previous five chapters. The final two chapters, as noted above, will examine the question of what the construction and material data can tell us utilizing two examples.

This work is seen as step in a needed direction and not as the compendium of all knowledge regarding Maya construction. Yet, even in this form, it should be clear that there are a number of practical and important uses. First, this information can help many archaeologists in the field better understand structures and features being excavated. The material and construction data are also imperative to anyone working on properly consolidating structures in the field, a process most Central American nations have made compulsory. The use of the wrong materials or methods at this juncture can destroy precious architectural remains (Larios Villalta 2000; Molina-Montes 1982).

A third usage of this dissertation would be in computer reconstruction like the example of the palace at Nimrud. Archaeologists generally try to resist pressures to physically rebuild monuments and new technologies have given archaeology a way to present reconstruction to the public without damaging the archaeological resources (Brigman 1996).

Understanding Maya materials and technology can also lead us to a better understanding of Maya social order and societal priorities. Who built these structures and how much thought and labor they put into them have repercussions throughout Maya society. One glaringly obvious question is why the ancient Maya did not develop more sophisticated architectural forms given the first-rate materials available and the knowledge, particularly mathematical, they possessed. Hopefully this compilation will spur on further studies stemming from the data.

Chapter Two

Environment and Materials

> *Hence I believed it right to treat of the diversity and practical peculiarities of these things as well as of the qualities which they exhibit in buildings, so that persons who are intending to build may understand them and so make no mistake, but may gather materials which are suitable to use in their buildings.* Vitruvius, The Ten Books on Architecture

The Geology and Environment of the Maya Area

The Maya were efficient users of their local environment. The broad availability of good construction resources and the economic and transportation systems of their time made the use of locally available materials mandatory. The primary materials utilized in Maya monumental architecture were drawn from around them; stone, clay, and timber. The study of these materials makes it clear that while material properties did not dictate form, they did narrow the range of architectural possibilities. Although architectural forms remained fairly consistent throughout the Maya area, differences in the availability of materials made substitutions for favored materials and innovations obligatory.

The Maya area can be divided geologically into five areas (Figure 2.1) (West 1964; Weyl 1980). The first, made up of alluvia, sands and marls, is situated in a thin band along the coastline of Belize south of the Belize River, along the Pacific coast of Mexico and Guatemala from the western Chiapas border to the El

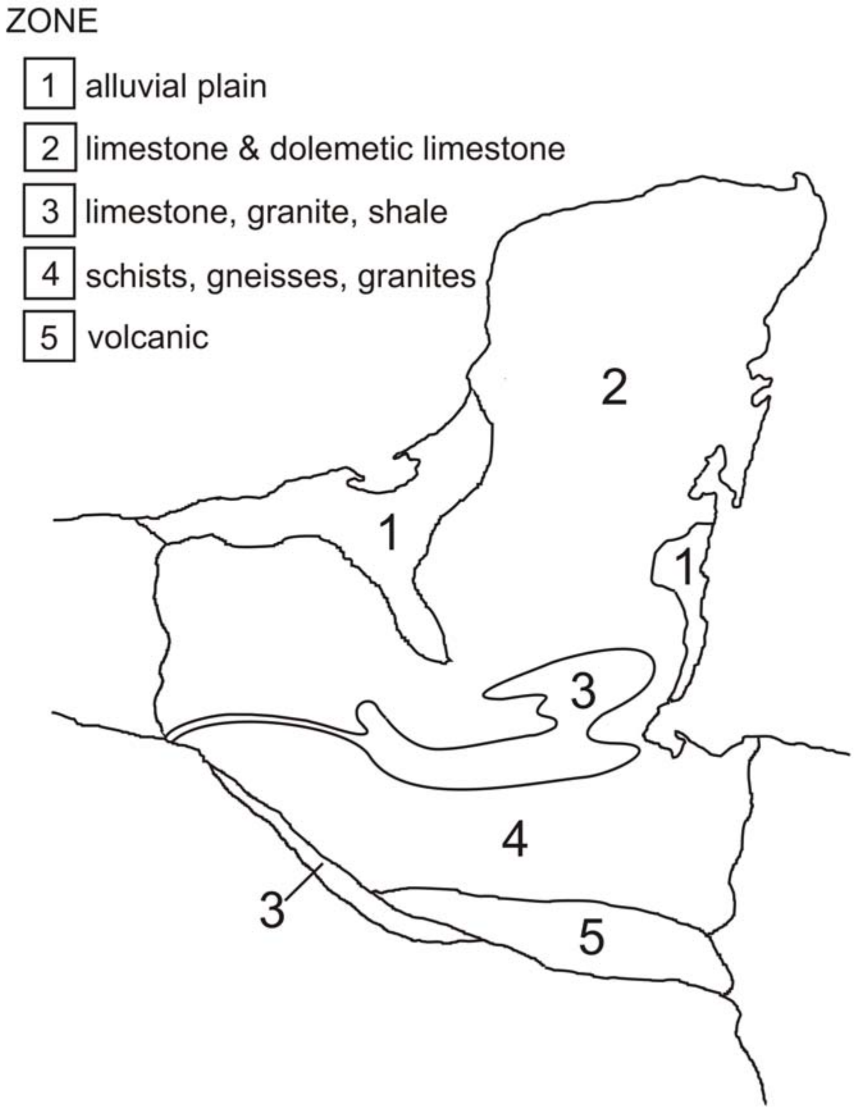


Figure 2.1 geological zones in the Maya area (after West 1964).

Salvadorian border, and in a broad plain surrounding the mouths of the Grijalva and Usumacinta Rivers and the Laguna de Terminos. The other four form bands running parallel to the Pacific coastline, roughly northwest-southeast. From north to south they consist of: 1) the largest area consisting of limestone and marl, 2) a band of limestones, shales and mudstones, 3) a band of schists, gneisses and granite, and, lastly, 4) the band of the volcanics.

The first geological zone along the coastal plains is split among three geographic areas; Tabasco, eastern Belize and of western Guatemala. The Usamacinta River drainage basin in Tabasco is geologically different from the rest of the Maya world, consisting primarily of noncalcareous sediments lying in deep strata (Andrews 1989). The Usamicinta alluvial plain has deeply buried the bedrock in a large area. The coastal plain of Belize (especially southern Belize) and that of western Guatemala also contain alluvial plains but, due to the steep and narrow nature of the river valleys, much of the underlying limestones and shales are exposed (Ower 1928).

The geology of the Yucatan Peninsula is complex and has been divided into as many as 14 physiographic areas (Moseley and Terry 1980). For the purposes of this study, which does not demand such geologic resolution, the Yucatan Peninsula and northern portions of the Petén are lumped together as one. This area is characterized by limestone and dolomitic limestones of increasing age from north to south (Miocene-Pliocene to Cretaceous)(Isphording 1975; Weidie 1985). The limestone is generally “capped” with a hardened crust formed through the processes of repeated dissolution and redeposit. This cap is commonly underlain by a thick layer of saprolitic limestone known locally as “sascab,” a saprolitic limestone (Isphording 1975; Quinones and Allende 1974). This zone covers much of Yucatan, the Petén, and lowland Chiapas.

The third zone is a narrow band roughly equivalent to the northern half of Weyl's Central Guatemalan Cordillera (Weyl 1980). This zone is primarily made up of gently folded Cretaceous and Oligocene limestones anchored by an outcropping of Paleozoic rocks (the Maya Mountains) and the Toledo series of shales, mudstones and sandstone in the east (Powers 1918; Ower 1928).

South of this zone is a belt of mountains paralleling the volcanic belt and forming a broad sweeping arc from Chiapas to the Gulf of Honduras. Schists, gneisses and granites are the primary geological components in this area (Powers 1918; Weyl 1980). Lastly, the volcanic belt stretches parallel to the Pacific coast from the Mexico-Guatemala border down through El Salvador (Weyl 1980).

This rapid sketch of the geology of the Maya area outlines the availability of construction materials in each area. Stone was the single most-utilized resource for major construction and, due to its weight and the lack of energy-efficient transport; structures were generally built out of the closest material at hand. While stone was often transported some distance via human effort this generally did not exceed a distance of ten kilometers (Sidrys 1978). The assumption that architectural materials were obtained locally has even been used to identify sites previously known only from their artifacts utilizing petrographic analyses to match stela with architectural stone (Hayward 2000).

The vegetation patterns progress from low canopy to high canopy and from subhumid to perhumid (the wettest type of climate with a humidity index of +100) as you progress from North to South (Hartshorn 1988; Rice 1991). Most of the Maya area, with the exception of montane pine forests in Guatemala, Honduras, and Belize, is made up of lowland tropical and sub-tropical broadleaf forest (Figure 2.2) (Hartshorn 1988). These forests are predominately broad-leafed deciduous forests and are incredibly species rich with up to 200 tree species per hectare (ParksWatch 2001). One guide to usable Central American timber lists the characteristics of 109 species (Echenique-Manrique and Plumptre 1990). Although vegetation survey work in Mesoamerica is still in its infancy it is estimated that there are more than 24,000 vascular plants in the area (D'Arcy 1977; Mittermeier et al. 1997). Quite a large number of plants were used in the construction of buildings for construction and scaffold timber, cordage, thatch and construction additives.

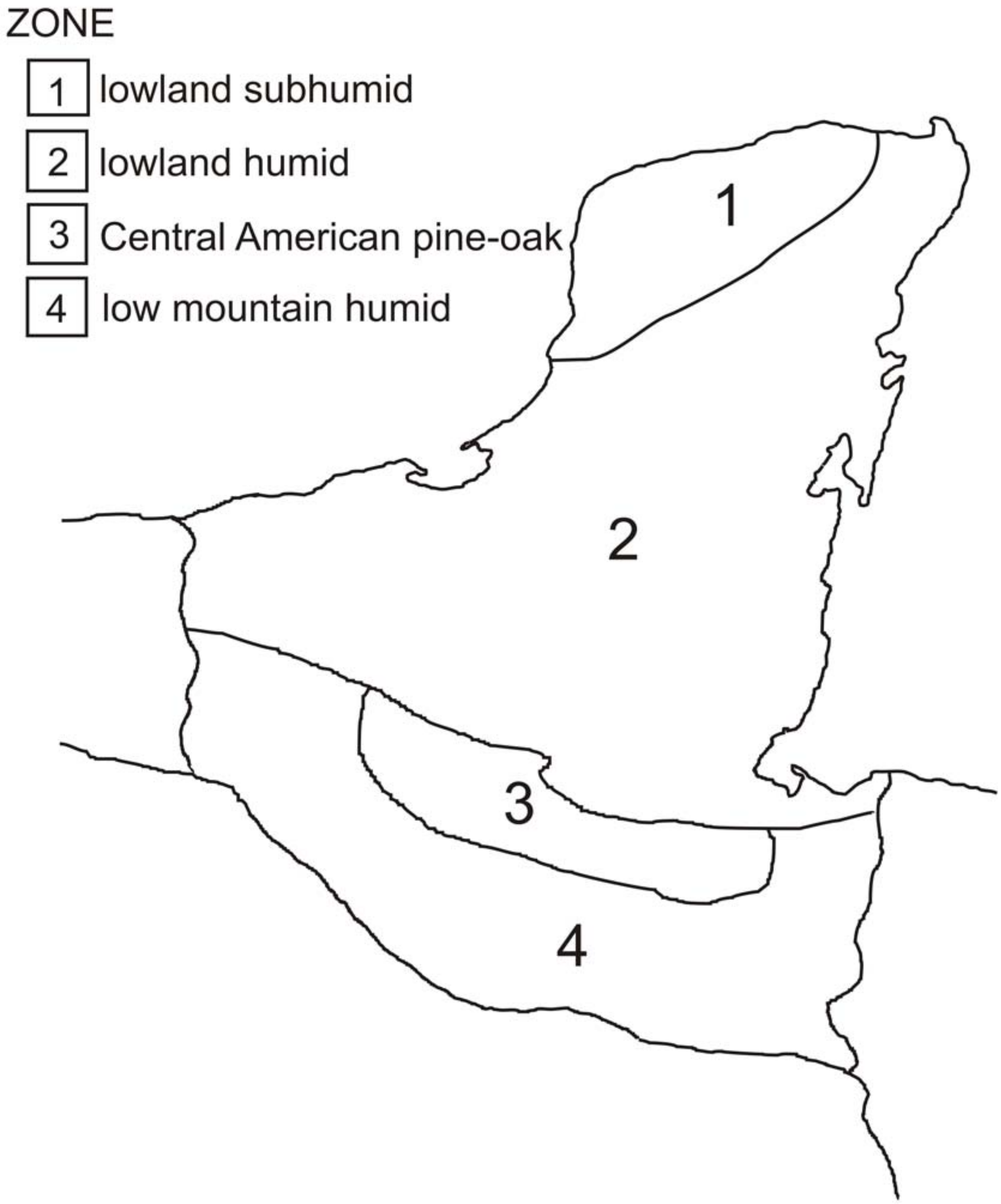


Figure 2.2 Map of Maya environmental zones (after Hartshorn 1988)

Stone

Since the Maya generally built with the materials closest to hand we find that most stone structures in the Yucatan and northern Petén are made of limestone. South of Peten Itza the materials differ as the geological zones previously defined change. Thus we find some “pumice” at Seibal (Smith 1982), siltstones and sandstones at Lubaantun (Hammond 1975); sandstone, rhyolite, and marble at Quirigua (Sharer 1990); trachyte at Copan (Robicsek 1972), and “talpetate,” a volcanic tuff, at Quelapa in El Salvador (Andrews V 1976).

Limestone is a sedimentary rock made up of calcium carbonate or a double carbonate of calcium and magnesium, or it can be a combination of the two (Hornbostel 1991). Stone consistency throughout Central America varies widely (Mathews 2002). Edwin Littman (1966) defined a hierarchy of limestone types based on the percentage of dolomite, a mineral form of calcium-magnesium carbonate. Generally speaking, the higher the percentage of dolomite the harder (4-6 on the Mohs scale) the limestone.

The Mohs scale can serve as a rough descriptive analog for more complex stone properties. The Mohs scale specifically measures resistance to abrasion, but also reflects the atomic structure of a material. On a scale of one to ten, with a diamond representing the high end of the scale, most limestones are a three to four. Sandstones, shale, and other siltstones would also rank four, equivalent to the hardness of a modern iron nail. Dolomitic limestone and schist are somewhat stronger at five and a true dolomite would rate six. Trachyte, rhyolite and chert would range between a seven and nine on the Mohs scale.

Most of the stone utilized by the Maya is relatively soft and easy to work (Figure 2.3). Due to the addition of magnesium to many limestones it can have a compressive strength that varies widely, from 4,000 to 20,000 psi (Hornbostel 1991; Rosen 1985). The physical characteristics of limestone vary region to region by texture, porosity, hardness, strength, and degree of moisture. Most are fine-grained stones that are easily worked and easily acquired (Hornbostel 1991). The properties that make limestone such an easy building material can also be liabilities. Limestone is soft when quarried and highly soluble (it can be as low as 1 on the Mohs scale before exposure to air) (Hunt 1994). Some limestone may harden with exposure to air or develop a “crust” due to weathering or biological agents but has little internal cohesion (Garcia de Miguel, et al. 1995; Hunt 1994). Even the act of working the stone may weaken it further but long-term durability does not seem to have been a high priority for the builders, coats of plaster and constant maintenance could keep a structure viable for years (Hunt 1994).

When choosing dimension building stone (known as ashlars) for modern construction purposes there are four major criteria. The first criterion considered is structural strength (compressive and tensile strength) which we know can be consistently high for many limestones found in Central America. The second criterion is that of durability or how the stone will stand up to forces such as water, thermal stress, and efflorescence. We will address this in more depth later on in this dissertation but the Maya recognized limestone's low tolerance for water in particular and worked around it. Ease of quarrying and dressing is the next guideline, and limestone is near ideal in this respect. The last, and easiest criterion to judge in this case, is availability (Prentice 1990).

Stone Acquisition and Transport

The author is aware of few systematic archaeological investigations of building quarries. Most notable are the excavation and experimentation done at Tikal and Nakbe (Ruiz A. 1985; Woods and Titmus 1996) and the examination of sascaberas at Coba (Folan 1982). Folan's work, in particular, makes it clear that a number of different materials were taken from the same quarries. Not only did the Maya excavate ashlar building stones but also rock suitable for quicklime manufacture, aggregate, and the fine limestone (sascab) often used as a consolidant or mortar substitute.

Quarrying appears to have been generally organized on a very local level. Due to the appearance of small-scale quarries in proximity to household groups, it has been suggested that quarrying was primarily a cottage industry (Folan 1982; Ruiz A. 1985). While a majority of quarries may have operated on a small-scale there are instances of large-scale community-based quarrying often serving multiple purposes. Folan (1983) has suggested that quarrying activities may have formed the lakes at Coba and aguadas (reservoirs) at the site of El Pilar and Tikal may have been quarried for building materials as well (Ford and Wernecke 2002; Scarborough 1993). It has been generally accepted that quarries, if not designed as reservoirs from the start, were at least converted to water storage (Haug et al. 2003).

Quarrying was done with rudimentary tools and the methods employed are marked by an extraordinary conservatism through time and place (Forbes 1966; Ward-Perkins 1971). The limestone's being quarried by the Maya are incredibly soft when first exposed (1-2 on the Mohs scale) and harden only on exposure to the air. Quarry excavation was apparently done primarily with digging sticks or long-handled picks, stone axes and levers (Holmes 1897; Outwater 1957a; Ruiz A. 1985; Woods and Titmus 1997). Quarrying marks have been found in ancient quarries that can be easily replicated utilizing stone picks (Holmes 1897; Folan 1982; Morley and Brainerd 1983; Ruiz A. 1985; Woods and Titmus 1997; Hammond, et al. 2000).

Quarrying methodology was very simple and is still often used when blocks are needed for restoration work (Figure 2.3). A checkerboard of grooves was dug utilizing digging sticks or picks (Figure 2.4). The grooves are dug wide enough to insert timber levers into and as deep as they are needed to be for the preferred size

Figure 2.3 Workers at El Pilar trimming limestone blocks for consolidation work. Note the hatchet they use (on top of block to the right).

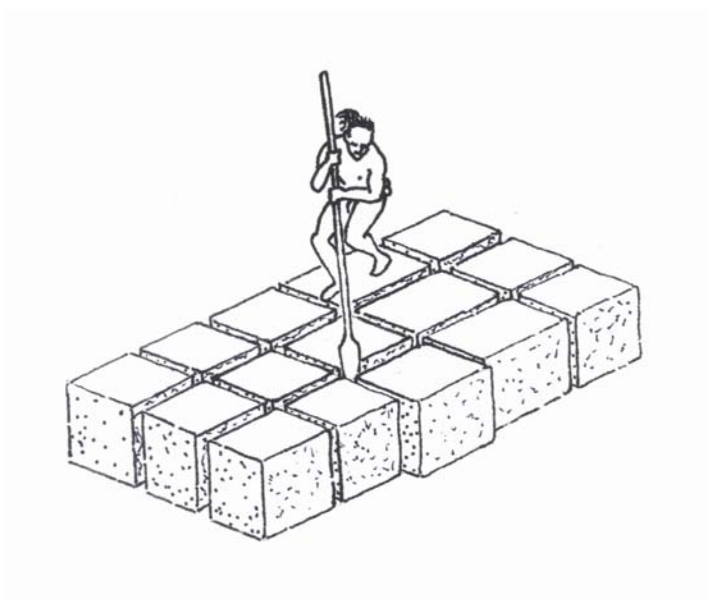


Figure 2.4 Maya quarrying methods.

ashlar. Once the channels are dug, levers can be inserted and large stone blocks broken loose of the bedrock. Once removed from the parent bedrock a stone can be shaped to the rough size needed. The Maya appeared to have utilized a system of cutting unit-sized stones for some projects and, at others, the stones are randomly sized. Since quarrying and shaping debris were typically used as construction fill it is difficult to determine whether he stones were cut and shaped “to order” or if builders made use of a random assortment being produced and transported to the site.

For modern restoration work, experiments at Nakbe and El Pilar have shown that it is more efficient for masons to order the specific sizes needed (Woods and Titmus 1997). In larger scale projects stones may be cut and transported to the size before being shaped by on-site masons (Ruiz A. 1985). Just as in modern stone masonry, both methods were probably used dependent on the circumstances.

Transport was by hand, but the Maya often quarried materials very close to the structure being built or just off of a causeway or trail leading to it making transport easier (Cobos and Winemiller 2001; Hansen et al. 2002; Winemiller 1997). The load carrying capacity of humans is often grossly understated and this has lead to many theories of the “mysterious” origin of megalithic monuments in particular. A number of studies were conducted, for instance, in the twentieth century to determine the optimum load for infantrymen and, although they found the best load (for long term effectiveness) was fairly light, the historical studies found that the load packed by the average infantryman often greatly exceeded his weight (Ezell 1992). Sherpas often carry 140 or more pounds for mountaineering expeditions (Baker 1980). Modern archaeologists have moved stones of up to two tons using litters and slings (Heizer 1966). The crew at Nakbe moved several stones of 700+ pounds utilizing a litter and eight bearers (James Woods, personal communication). Archaeologists preparing a NOVA program, "Secrets of Easter Island," moved a 14 ton Moai statue using a sledge and 40 people (Van Tilburg and Ralston 1999). Some stones may have been moved via water on rafts but the ubiquitous nature of the building materials seldom made this necessary (Pollock 1965). An easy solution was found, if materials could not be found ready-at-hand different materials were used.

Sascab

Sascab (a.k.a. sah kab, sachab, white lime and lime marl) is an unconsolidated saprolitic limestone (Quinones and Allende 1974; Isphording 1976). This material lies beneath a lithified carapace and is probably formed by the deep weathering of the underlying limestone (Darch and Furley 1983). Sascab was a very important material to the ancient Maya and it is crucial that it's strengths and limitations be understood.

Sascab's strength lies in its simplicity. It can be easily quarried (you can dig it with your hands) and, after moistening, it dries quickly to a concrete-like hardness. The weakness of the material is that it has relatively little abrasion resistance or moisture resistance. If it is wet again it turns into a fine sticky paste.

Sascab has been used extensively as a flooring material, both in residences and public buildings as well as for surfaces such as causeways (Wauchope 1938) (Von Falkenhausen 1985; Hansen 1998). It is also, mixed with vegetal materials, used for constructing wattle and daub structures. Sascab was probably the "whitewash" mentioned in Landa (1937). More importantly, sascab is very effectively used for consolidating structure fill (Von Falkenhausen 1985; Garcia de Miguel, et al. 1995; Benavides C. 2004).

Sascab is often mistaken for mortar or cement and it is important to make a distinction between these three. Archaeologists use these terms in a much looser way than those involved in the building trades. Mortar can be any material having cementitious properties (plasticity, cohesive, and adhesive) and may or may not contain real cements. Sascab has been used as a structural mortar both externally (Trik 1939; Andrews and Andrews V 1980) and internally as a consolidant as mentioned above.

The term cement is generally limited to references to materials made from hydrated lime, itself the product of burning limestone. Since the process of calcination is dependent on air flow around the stone (preferably fist-sized) powdery sascab cannot be burned to manufacture lime and therefore cannot be made into a true cement. While sascab can be very effective as a substitute for cement in those places where it will not be exposed to moisture or abrasive forces. It was and is also used as an aggregate, the inert material mixed with lime to manufacture true mortars and cements (Hyman 1970; Folan 1982). Experiments in the field have found sascab an excellent aggregate used in a three to one ratio with hydrated lime (Morris 1931).

Lime Cements, Mortars, Plasters, and Stuccos

Imperative to understanding the materials is a good definition of the materials used. Many terms in the construction and building materials industries have numerous local and even international variants and some terms are used only as vague group signifiers. In addition, the definitions can change depending on the professional perspective of the researcher – Hyman (1970) points out that some terms can mean diametrically opposed things depending on one's professional background. Cement is one of these vague terms. It can be used to denote almost anything having adhesive, bonding qualities (roofing cement, rubber cement etc.) as well as often being vernacularly used as the equivalent of concrete.

In order to reduce confusion the following definitions of materials will be used throughout this composition.

Cement: in this context this is lime cement manufactured by calcining limestone or shell.

Mortar: although the Maya are known to have used sascab or clay in some instances, mortar is a product of slaked lime (from limestone or shell), a fine aggregate and water.

Stucco: stucco and plaster can often be used nearly interchangeably though stucco is usually thought of as a rougher mixture of lime, aggregate and water than plaster. Stucco is primarily used on the exterior of structures and is made in a stiffer mixture that retains enough plasticity to enable it to be molded. In the Maya context it is often used for architectural sculpture.

Plaster: a finer mixture of lime, aggregate and water utilized primarily in the interior of structures for walls, floors and molding purposes.

The lime used in these materials is manufactured from limestone or shell deposits. Lime, or calcium carbonate $CaCO_3$, is heated, or calcined, to separate and drive off the carbon dioxide (CO_2) leaving calcium oxide (CaO) (Figure 2.5). The lime used by the Maya was apparently burned at fairly low temperatures, 1652°F or 900°C, which retains the highest reactive properties of the lime. In contrast, modern lime is burned greater than 2000°F temperatures that allow for more efficient burns but at some loss of material strength (Holes and Wingate 1997; Wingate 1985).

Calcium oxide (CaO) is popularly known as quicklime or caustic lime. It is a highly corrosive material difficult to handle. Water is added to quicklime to make usable hydrated lime. Approximately 23% water is added in a process known as "slaking" to create calcium hydroxide, $Ca(OH)_2$. A great deal of heat is given off in this process and, if the proper amount of water is added, it results in a fine white powder. If excess water is added a plastic mass known as “lime putty” is formed which, when aged, is significantly improved in quality (plasticity, workability and water retention)(Cazalla, et al. 2000).

When hydrated lime is mixed with an aggregate and water or lime putty is exposed to air it begins a process of reabsorption of CO_2 that will eventually change it back into calcium carbonate, $CaCO_3$. Depending on the mix of aggregate and water hydrated lime can be used to manufacture a lime concrete, mortar, plaster or stucco (see Figure 2.5).

The manufacturing process is relatively simple. The most important variables are the temperature at which the limestone is burned and the length of time the stone or shell is kept at the calcining temperature. In both cases, practical experience readily substitutes for instrumentation and calculations. Even on a first attempt you are bound to get lime produced but with experience you can minimize the firing time and maximize output without overburning and reducing quality. Limestone, depending on exact composition, begins calcining at 1490-1652°F (810-900°C) and

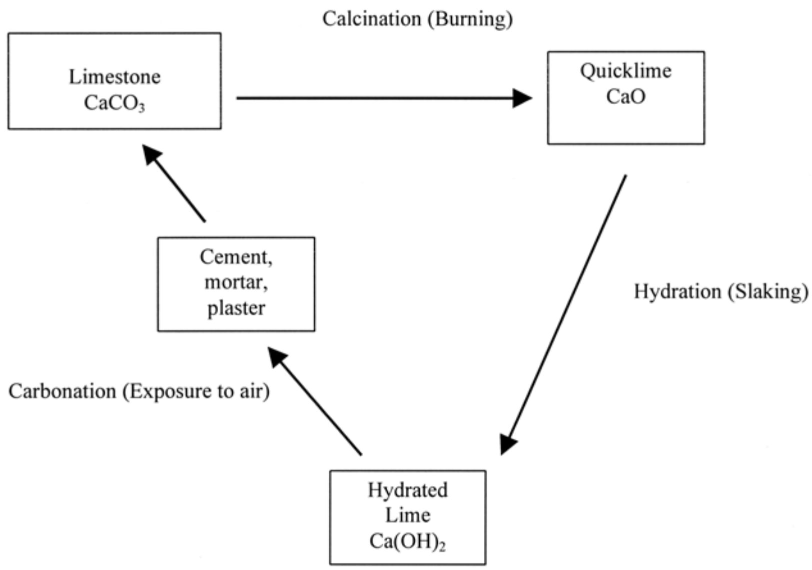


Figure 2.5 The Lime manufacturing cycle.

reaches optimum calcination when the entire mass being burned reaches 2000-2200°F (1093-1204°C) (Harrington 2000; Rehder 2000; Spiropoulos 1985).

The easiest production methods to use are heap burning or pit burning. In heap burning a pile of alternating layers of limestone and fuel (usually wood) is constructed, lit, and allowed to burn down (Figure 2.6). This process is easy but inefficient in both usages of fuel and usable lime output. Experiments in the field have resulted in fuel to stone ratios as high as 3:1 (Bury 1996; Crepaldi Affonso and Pemicka 1996).

Pit burning is an expedient form of a mixed-feed batch kiln. Layers of fuel and limestone are placed in a pit with a vent excavated to provide air to the bottom of the fire. The pit can burn, covered or uncovered, in the same fashion as heap burning until the fuel is consumed. The heat is better contained in a pit burn so there is a resulting increase in fuel and burn efficiency. In the case of covered pit burning the additional containment of super-heated steam from the burning wood also adds substantially to the efficiency. Though the author has been unable to find any figures on how much of an increase over heap burning could be expected, the literature was unanimous in agreement that it was significant (Harrington 2000; Spiropoulos 1985; Wingate 1985).

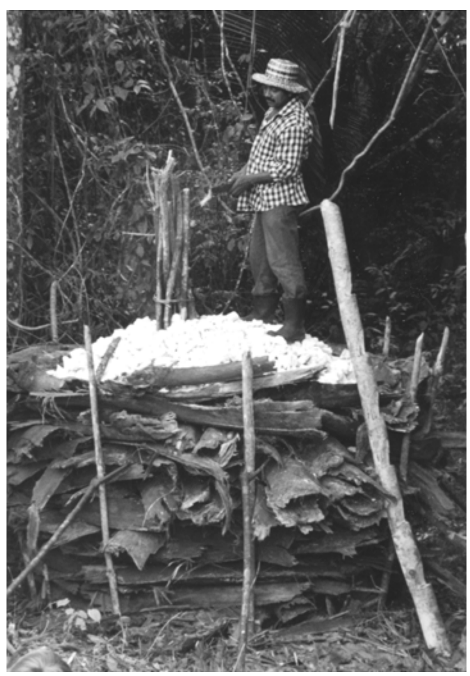


Figure 2.6 An experimental "heap" burn at El Pilar utilizing Corozo palm petioles. It has become an archaeological tradition to regard heap burning as the

method used by the Maya since the ethnographic descriptions of Yucatecan burns by Morris (1931). It is certainly a method still much used today throughout the Maya world for the production of lime for household use (Baer and Merrifield 1971) (MacKinnon and May 1990). There is some evidence for modern usage of small scale “traditional “pit burning as well from Yucatecan families who burn household lime in washtubs (Mathews 2002).

Not all lime produced by the above methods was the same. There were certainly differences in quality and some trace minerals, like magnesium, can make a tremendous difference in the end product (Mathews 2002). More important to this study is the production of hydraulic lime, a material that has tremendous consequences for construction and construction techniques. Lime has long been classified into three categories according to its ability to set underwater (Vicat 1997). “Non-hydraulic to feebly hydraulic” limes are the poorest and do not fare well outdoors unprotected, “feebly to moderately hydraulic” limes are suited for exposure and make excellent building lime, and “moderate to hydraulic” limes will set up underwater. Hydraulic limes have a “pozzalan” , a finely powdered additive like volcanic ash, which reacts chemically with the lime to form a more durable material. Previous research has maintained that hydraulic lime was not in use in Mesoamerica (Hyman 1970).

Pozzalanas, named for the volcanic ash the Romans discovered near Pozzuoli in Italy, are not always added to the mix. Natural pozzalanas, which are siliceous or aluminous, occur with the limestone and can be readily combined to get the proper chemical reactions when fired at the relatively low temperatures (1652-1832°F or 900-1000°C) realized in heap and pit burning (Allen 1992; Gibbons 1997). The technology is simple and intuitive; having been found in Neolithic times in the Middle East (Frierman 1971).Today more than 35 percent of the hydraulic cement production in Mexico utilizes natural pozzalanas. Analyses of lime cements from El Tajin, a Huastec Maya city in eastern Mexico, and the reanalysis of data from Comalcalco have found significantly hydraulic limes (Littmann 1957; Littmann 1958; Rivera-Villarreal and Krayer 1996). A study of burnt-lime technology at Nakbe in Guatemala also found the materials to be semi hydraulic (Hansen et al. 1997).

Chemical as well as mineral admixtures affect material strength. Today the use of additives in cements and concretes is pervasive (a $2.9 billion industry worldwide) and our understanding of the effect of chemistry and physical blending enable modern manufacturers to make a special blend that will meet any need (Freedonia Group 1998; Ramachandran 1996). The Maya also understood that different uses of lime might require different characteristics. What worked great for modeling a stucco sculpture might be a drawback when trying to plaster a wall, for instance. Admixtures could be used to enhance binding characteristics, curing time, workability, hardness, and appearance.

There is ample evidence of sophisticated use of organic admixtures by the

Maya. As with pozzalanas, organic admixtures are neither new nor rare. Sickels (1981) compiled a list of ancient admixtures mentioned in Europe and found 41 different compounds. Another study done in Brazil found that oil, blood and sugar were often used as binding agents and that there was an undoubted beneficial effect on the lime mixtures (Santiago and De Oliveira 1992). There is also historical evidence of the use of admixtures by the Maya. Landa wrote:

> " . . . the terrace, finished with a very hard stucco made with the water from the bark of a certain tree, and there is another tree . . . whose crushed bark they use for polishing walls and hardening them" (Landa 1937: 87, 104).

Morris (1931) was told that a chocom bark infusion was used for polishing building plaster and giving it strength.

A number of scientific tests of samples from Maya archaeological sites have revealed the presence of organic admixtures, but have been unable to determine the origin of the substances (Brainerd 1954; Hyman 1970; Laws 1962; Littmann 1960; Maglioni, et al. 1995). Probably a number of substances were used chosen by availability, local favorites or observation of changes in the physical properties of the mixtures. Experiments have shown that organic admixtures can add stabilization during the curing process, speed curing, and increase strength of lime mixtures (Littmann 1960).

Clay and other soils

The Maya used clays and other soils for numerous construction purposes. Unfortunately the archaeological literature is often unclear as to the exact material used phrases like “lime clay” and “clay mortar” leave one unsure as to whether the material in question is clay, sascab, or burnt lime. Clays were utilized in either an “as is” condition, tempered with other materials for strength and stability, or fired and burned (Clifton and Davis 1979).

Clays are found throughout the traditional Maya area and the different varieties were utilized for construction, ceramics, and even medicines (Arnold and Bohor 1977). Much of the Yucatan and Peten has substantial deposits of montmorillites, palygorskites, smectites, and kaolinites (Bartlett, et al. 2000; Beach 1998; Isphording 1975, 1976, 1984; Wilson 1980) . Although the gathering of clay was probably done primarily on the surface there is also evidence for intensive mining of specific clays (Andrews IV 1970; Arnold and Bohor 1977; Folan 1982).

The bulk of the use of clay soils in Maya architecture is in structural fill that will be detailed in a subsequent chapter. Clay was also used heavily in the prevalent form of residential construction known as “bajareque”, wattle and daub or cob architecture. As the primary focus of this essay is monumental architecture this form will only be touched on as it applies to those subsidiary buildings constructed atop of monumental structures. The best descriptions and archaeological data regarding bajaraque come from the site of Ceren in El Salvador (Sheets 1992).

The earliest monumental Maya architecture is apparently either simple earth platforms, earth with clay plaster, or puddled clay construction (Figure 2.7) (Lowe, et al. 1982; Parsons 1969; Schortman, et al. 1986; Sharer 1978; Shook and Kidder 1952). There is also evidence for the use of burned clay floors (Lowe, et al. 1982; Sheets 1992). Perhaps the most interesting Maya use of clay was in the form of bricks. There are several sites with evidence of the use of adobe bricks or blocks (Copan, Quirigua and Ceren in the south) and a number of sites in and around Comalcalco in the north that used fired bricks (Andrews 1989; Blom and La Farge 1927; Sharer and Sedat 1987; Sharer et al. 1999; Sheets 1992).

Wood

" . . . this valuable material (stone) was not used to the exclusion of wood, and even in the most sumptuous temples and palaces we constantly find lintels and vault-beams of wood covered in rubble," (Lothrup 1924: 27).

The Maya lived in tropical and montane rain forests with an abundance of

Figure 2.7 Early clay structures underneath Structure EP7 at El Pilar. This clay ramp is situated on a Preclassic plaster surface and was exposed in tunneling the structure.

usable woods. Studies of the rainforest have found as many as 200 species of trees per hectare or more than 490 species per acre (P. Adam 1994; ParksWatch 2001). Wood was daily used as firewood with residential construction running a distant second. Residential structures appear to have been either simple stick and thatch structures or bajaraque (wattle-and-daub) (Figure 2.8) (Wauchope 1938; Alcorn 1984). Structures atop monumental constructions were also often built this way (Proskouriakoff 1963).

Figure 2.8 Construction of a traditional *bajareque* structure at El Pilar. The walls are being plastered with a mixture of sascab, grass, and water.

Monumental stone architecture utilized wood in three primary areas; as door lintels, corbel vault beams, and as roof beams in flat roof systems (Pollock 1965). Lintels were important enough to be elaborately carved as well as represented in codices (Figure 2.9). Wood was also used in more unique situations such as a binder in fill at Uaxactun, reinforcement over door lintels and, possible wood doors at Holmul (Merwin and Vaillant 1932; Smith 1950; Andrews, et al. 1985; McAnany 1999). No doubt a tremendous amount of wood was also used temporarily as scaffolding during the construction phase (Loten 1991). Archaeologically, the use of wood can often only be deduced from small remnants or empty wall sockets. At Palenque, for instance, it is thought that more than 800 beams were used in the central

Figure 2.9 Carved chicozapote lintel.

monumental district and yet none remain today.

The samples that remain are remarkably homogenous regardless of the location of the site. The ancient Maya seemed to prefer chicozapote (*Manilkara zapota*) over the many other choices (the Oxford Forestry Institute lists 105 species useful for modern structural use) and the fact that many lintels and even more numerous vault beams still exist justify this choice (Echenique-Manrique and Plumptre 1990). Lundell (1937) suggested that the modern density of chicozapote groves may reflect Maya silvicultural practices. Table 2.1 lists identified woods at Maya sites. Chicozapote is an extremely dense hardwood that quickly dulls modern chainsaws. One simple measure of comparative strength used is the specific gravity, the heaviness of a substance in comparison to water. The higher the specific gravity,

Site	Structure	Material	Source
Chichen Itza	general	zapote, cholul, chacte, jabin	Morris et al. 1931
Chichen Itza	Castillo	zapote	Stephens 1843, Holmes 1895-97, Maudslay 1889-1902
Chichen Itza	Casa Colorada	zapote	Maudslay 1889-1902
Chichen Itza	Temple of the Jaguar	zapote	Stephens 1843
Chichen Itza	3C6	zapote	Ruppert 1952
Chichen Itza	3E3	cholol	Ruppert 1952
Dzibanche	Temple VI	quebracho	Site visit
Dzibilchaltun	7 Dolls	subinche	Andrews & Andrews 1980
Kabah	2A2	zapote	Stephens 1843
Mugeres Island	general	zapote	Holmes 1895-97
Muyil	Castillo	zapote	Witschey 1992
Ocosingo		zapote	Stephens & Catherwood 1841
Palenque	Palace	zapote?	Holmes 1895-97
Seibal	general	zapote	Smith 1982
Tikal	10 (5 ea)	zapote	Coe & Shook 1961
Tikal	3 (8 ea)	zapote	Coe & Shook 1961
Tikal	2 (5 ea)	zapote	Coe & Shook 1961
Tikal	4 (13 ea)	zapote	Coe & Shook 1961
Tikal	1 (9 ea)	zapote	Coe & Shook 1961
Tikal	general lintels & beams	logwood	Coe & Shook 1961, Larios
Tonina	Temple of the Wood Lintel	zapote	Marquina 1951
Topoxte		jabin	Bullard 1970 (Galindo 1831)
Tulum	general	zapote, madre de cacao, cirocote	Lothrup 1924
Uaxactun	Str. A-XVIII	zapote	Smith 1937
Uxmal	Pyramid of the Magician	zapote	Holmes 1895-97
Uxmal	House of the Governor	zapote	Stephens 1843
Xelha	Str. 1	ciricote	Lothrup 1924

chacte = *Sweetia panamensis*
cirocote = *Cordia dodecandra*
cholul = *Apoplanesia paniculata*
jabin = *Piscidia piscipula*
logwood = *Haemotoxylon campeachium*
madre de cacao = *Gliricidia sepium*
quebracho = *Schinopsis balansae*
subinche = *Acacia farnesiana*
zapote = *Manilkara zapota*

Table 2.1 Woods identified at Maya Sites the denser the substance and density can be a rough equivalent in many cases for strength. The western softwood species Douglas Fir-Larch, the predominate timber used in modern North American construction, has a specific gravity of 0.45-0.50 compared to 1.05 for chicozapote (Joaquin Rodriguez, personal communication 2000).

A joint project of the Broward County (FL) Archaeological Society and the Institute of Maya Studies led by consulting engineer Joaquin Rodriguez has been examining extent Maya wood lintels. The study uses modern flexural stresses analysis with a goal of determining patterns and variations in the construction techniques and efficiency in the use of materials. The engineering studies look at two important measures of strength; bending stress, the stress induced in a member subject to loads that cause it to bend, and shear stress, the stress longitudinal to the axis. Table 2.2 illustrates information on ten chicozapote lintels from different time periods and Maya regions. The preliminary data seem to indicate that the chicozapote exceeded the strength need for Maya architectural purposes by a wide margin and that it was used inconsistently throughout the region and time. There does appear to be consistency in regards to individual sites and periods of time that argue for some sort of local “customary usage” doctrine covering lintels. Maya builders probably adapted the most conservative building style based on past building failures. The mathematical calculation of stresses was not even possible until the Nineteenth

Site	Bldg.	Location	Period	Type	Span	Depth	Load	L/D	Bending Stress (psi)	Shear Stress (psi)
Caracol	A6	Spine	300 AD	Fixed	79”	6”	76.4	13.2	543	62.5
Tikal	5D23	Spine	350 AD	Fixed	95”	6”	50.5	15.8	600	49.9
Tikal	Temple II	Front	700 AD	Fixed	96”	6”	84	16	896	84
Tikal	5D120	Front	750 AD	Fixed	85”	5”	95	17	1470	101
Xunantunich	A6	Front	750 AD	Fixed	94”	6”	78	3.76	857	76.3
Palenque	Temple of the Inscriptions	Central Span	685 AD	Simple	108”	12”	150	7.66	760	85
Copan	Temple 22	Front	715 AD	Fixed	66”	7.5”	140	8.8	455	77
Uaxactun	Group A3	Spine		Fixed	46”	6.25”	143.6	7.36	324	63.6
Tzikintzakan		Spine		Fixed	94”	5.5”	35	17.1	536	37.4
Uxmal	Palace of the Governor	Front	900 AD	Simple	60”	10”	600	6	1347	225

Table 2.2 Stress Analyses on ten Maya lintels (Rodriguez 2002)

Century and the introduction of advanced materials mechanics theories (especially the theory of elasticity)(Gordon 1978; Timoshenko1983).

Summary

This chapter began with a description of the geologic and environmental setting that the Maya drew their building materials from. The Maya area is replete with large timber and stone resources. In addition the stone and timber available, particularly limestone that is found in a large portion of the study area and tropical hardwoods, are ideal building materials possessing superior structural characteristics.

The stone was readily available, easy to work, and had high compressive strengths. The Maya had the technical ability and labor available to quarry and transport large quantities of ashlars, quarrying debris and soil to the building sites. Large supplies of versatile sascab from the limestone carapace were used for flooring, fill, consolidation, mortar substitute, and as an additive to plasters and mortars. Soils were also utilized as fills and mortars.

Tropical hardwoods were also readily available and possessed the characteristics of superior building materials. The selective use of species by Maya builders also reflects a great deal of knowledge of the different woods mechanical characteristics. Though unable to do formal mechanical engineering, extant Maya structures reveal the adoption of customary rules covering the range of usages acceptable within a sound structure.

The following chapter will begin a odyssey through what is currently known of the Maya building process beginning with the planning process. Organization of the materials and personnel will be addressed before continuing on to look at Maya structures from the ground up beginning with site preparation and foundations.

Chapter 3

Planning and Preparation

> " . . .*the builders worked by slow and laboured means. They followed general rules laid down by revered traditions. Practice in design in later periods was but that to which thoughtful evolution had led from the custom of earlier work. . . . Work was commenced frequently – if not usually – before anything more than a general idea of the ultimate end had been forseen, and constructive problems were attempted in the early days with but little knowledge of what would probably be the final statical result* (Andrews 1999:1)

Planning

The information we have on Maya architectural planning is sketchy at best. Most treatises on Maya architecture avoid this pitfall by simply beginning the narrative with material procurement (as I have also done) and then launching straight into construction. Any evidence for pre-construction planning, however, has major implications for studies of specialization, social order and the process of construction.

Unlike many other cultures with monumental architecture, archaeologists have not yet found any undoubted architectural plans or models that suggest pre-construction planning. There exists a strong tradition of graffiti depicting architecture and even clay and stone models of structures, but many cannot be connected to any realistic depiction of actual nearby structures (Houston 1998a; Laporte and Fialko 1995; Schmidt, et al. 1998).

The confusion of design and artistic intricacy with construction sophistication has led several scholars to conclude that there must have been a formal planning process. Citing work on excellent evidence of planning in the layout of painting and sculpture by the Maya, Vinette (1986) proceeds from art to architecture fluidly. Robicsek (1972: 34) waxes eloquently on the genius of the Maya builders and writes, “judging from the codices, murals and temple graffiti, the Mayas were quite versatile in drawing and it seems logical to suppose they had some kind of architectural sketches.” Pollock (1965: 395) uses similar logic when stating that there is, “ a complexity of structural design and an intricacy of ornamentation, however that make it difficult to believe the builders had no previously perfected guide to go by.” These are but three examples of the prevalent course of logic regarding Maya planning.

The use of spatial planning in artistic design and the use of architectural planning do not, however, naturally follow each other. Both Vinette and Pollock cite evidence for construction lines and marks found in Maya structures as evidence for their contentions (Pollock 1965; Vinette 1986). These marks and others like it (see Morris et al. 1931, Smith 1950, Schele and Mathews 1998 for others) do appear to be undoubted construction guides but, they are no different in appearance or apparent function than the chalk lines used to delineate work by masons and carpenters today. They mark off work areas and tasks to be performed by laborers and do not need the expertise of an architect or master builder to explain them. This does not diminish their importance to understanding the process of Maya construction nor does it preclude the existence of planning but, they also cannot be said to prove the existence of planning.

Though we cannot confirm or deny structural planning it can be said with some certainty that there was site planning. It is difficult to understand how formal this process was, however. There has long been a school of thought that sees Maya structures as astronomically aligned (Aveni 1980; Hartung 1981). The classic example of this is the idea of an astronomical observatory at Group E at Uaxactun. This structural assemblage is found throughout the Maya world and has been named after that at Uaxactun (Figure 3.1). As Ruppert (1940) pointed out early on there is significant variation in alignment between these “E Groups”. While these groups may signify a relationship with the sun or stars they may not have been observatories. Some cases can be more obvious than others, for example, the Palace of the Governor at Uxmal has 350 plus Venus-related glyphs and a perpendicular sightline related to a Venus rising (Figure 3.2). It is doubtful, however, that more than the most important buildings were aligned in this manner. There is also the fact that, without ancient Maya documentary evidence, there is no way to falsify or prove these assertions (Kohler 1991). While the remaining documentary evidence does demonstrate the Mayas close attention to the stars it is difficult to understand why a skilled astronomer

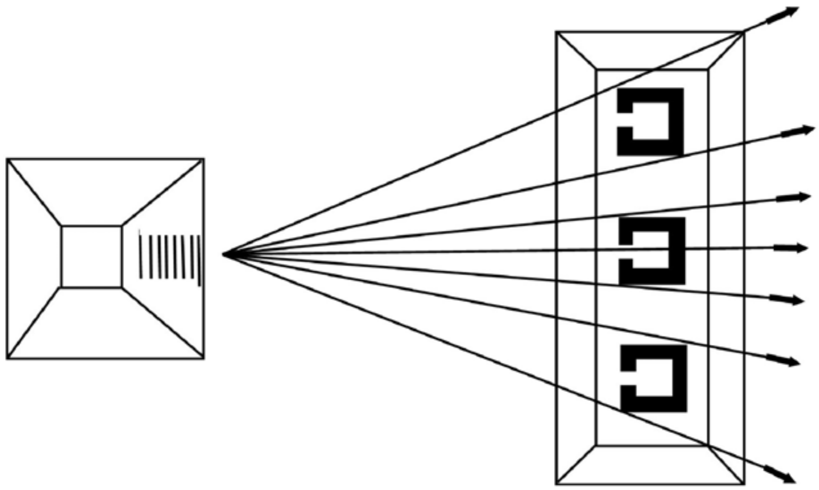


Figure 3.1 Idealized diagram of the Group E structures at Uaxactun (after Ricketson 1928).

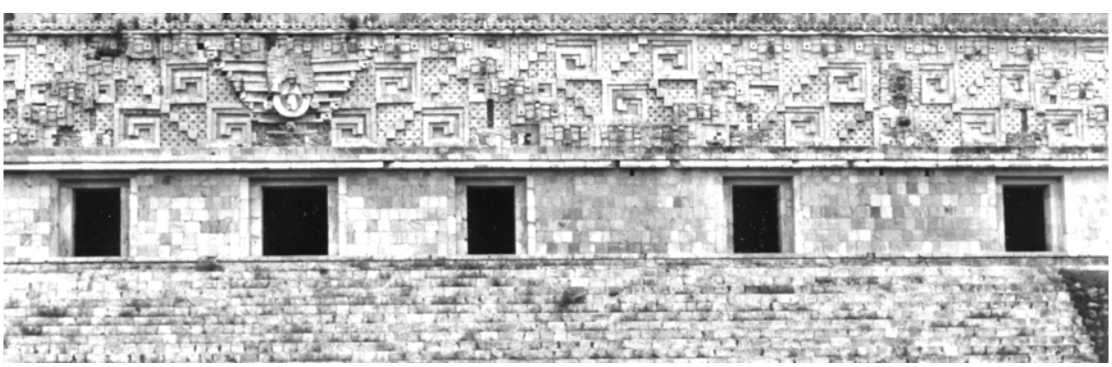


Figure 3.2 The House of the Governor at Uxmal.

or architect would design a structure such that sightings can only be made diagonally through the doors and windows (Thompson 1972; Köhler 1991).

Another method of analyzing building sites and orientations see them as Maya cosmology writ large. Groups of buildings and plazas are thought to use symbolic references to religion, ideology and society in order to influence the ancient public. This train of thought would mean that an ancient builder would have to carefully site a structure to blend in with the overall message to be part of the whole cosmogram (Ashmore 1989; Broda 1982; Guillemin 1968).

Siting could also have a directional component. The clearest evidence of the Maya use of the concept of the cardinal directions comes from what have been interpreted as directional glyphs in a painted tomb at Rio Azul (Figure 3.3)(Adams 1990). There has also been speculation as to the possibility of the Maya possessing a magnetic compass (Carlson 1977; Fuson 1969; Klokocník and Kostelecký 2003). In the absence of a compass it has been suggested that the Maya used an architectural planning concept not unlike the Chinese practice of *feng shui*, or geomancy. Geomancy is a divinatory art for locating the proper site and orientation of a building so as to achieve harmony with perceived cosmic forces. If the Maya possessed a well-developed geomantic art it could explain consistency in orientation of many structures (Carlson 1977; Wheatley 1971).

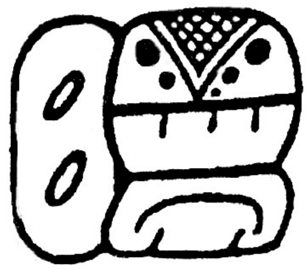


Figure 3.3 Xaman glyph from the Palenque Tablet of the Cross (after Closs 1988).

Many sites and structures may have been simply positioned in response to local topography (Scully 1972). It has long been noted that many Maya sites have strong north-south components and, as a look at a topographic map of the Maya homeland will demonstrate, so does the topography. Accessing any high point in the Peten, for example, reveals views of long north-south rolling green ridges. Caution must be used when examining structure positioning as studies have freely mixed Maya, Aztec, Mixtec, and Teotihaunaco sites as if they were all done by the same builder during the same period (see Aveni and Gibbs 1976 for example).

Structural siting may have been as simple as a response to culturally shared building vocabulary. This is not an uncommon human phenomenon and has been linked to the greater awareness of building traditions in societies where a large part of the population take an active part in construction (Crowe 1995; Fraser 1968; Tuan 1977). Maya construction is evidently very conservative and a structures position may have been a response to strong traditions as to what the “right” spot was. This conservatism and tradition is still evident in the construction of Maya domestic structures (Wauchope 1938; Vogt 1990).

The physical method of laying out the site may have been very simple. Aveni and Hartung (1982) have suggested the use of sight lines utilizing sticks. Recording the shortest shadow from a gnomon at noon is a simple way to find a N/S line. To find an E/W line the shadow is marked sometime in the morning and a circle drawn using the length of the shadow as a radius. In the afternoon, when the shadow reaches the perimeter of the circle it is again marked. A line through the morning and afternoon marks is an E/W direction. Others have suggested cords based on both perceived mathematic evidence as well as ethnography (Aveni and Hartung 1982; Schele and Mathews 1998). The Popul Vuh, a Quiché Maya text outlining their foundation mythology, speaks of the gods creating the world through "measuring, fourfold staking, halving the cord, stretching the cord in the sky, on the earth, the four sides, the four corners" (Tedlock 1985: 72). De Landa (1937: 38) writes of Maya land "measured with a 20-foot rod." The Maya may also have used control points for laying out larger projects as suggested by pecked crosses that seem to correlate with site orientations (Aveni and Hartung 1985).

Regardless of the amount of planning and the exact method, the Maya monumental constructions studied here could not have been a worse design given the climate (Fitch and Branch 1960; Givoni 1997). The large stone buildings did not allow for the cooling (and drying) breezes or light that have led to the modern problem at these sites of dealing with the molds and lichens growing on the ruins (Figure 3.4)(Hale 1984). The climate also created a need for constant maintenance of the structure and, especially, its plaster cover. This is assuming a similar climate to todays. Though surrogate data suggests periods of increasing aridity during the 15+ centuries that this building took place it also suggests large amounts of time (the Middle and Late Preclassic, for instance) when it was as humid if not more humid than today (see Appendix A for Maya chronology)(Curtis et al. 1998; Hodell et al. 2001; Rosenmeier et al. 2002).

Figure 3.4 Maya graffiti on an interior wall at Tikal, the dark surrounding area is mold.

One of the few unmistakable signs of planning are the evident pains taken in many cases of preparing the grade for water removal (Pendergast 1979; Scarborough and Isaac 1993; Ford, et al. 1995). Rain was one of the biggest problems facing Maya construction, as was, in many locations, the supply of drinking water. Preparing large plaster plaza areas to drain to prepared catchments and storage facilities served several important functions at once. The Maya got the water they needed and kept it away from the structures as much as possible.

Mathematics/Geometry

The Maya undoubtedly possessed highly sophisticated mathematics. Their vegisimal (base 20) system of counting included the concept of positional mathematics (the use of zero as a placeholder) that was only developed three other times independently (Kaplan 1999). Their use of this concept did not apparently include multiplication or division, but was almost exclusively used for calendrical notation (Lambert, et al. 1980; Lounsbury 1978; Seidenberg 1986). To be fair, the assumption that higher mathematics was not possible is based only on negative evidence but the one source available that could refute that, the Dresden Codex with its almanacs and astronomical tables, shows no signs of division or multiplication. It is argued that concepts of geometry such as the isoceles triangle, radian and orthagonal axes were utilized in planning, constructing and designing Maya architecture (Aveni and Hartung 1982; Vinette 1986). Harrison (1999) goes so far as to suggest the use of triangulation in planning at Tikal. On the other hand, Maya buildings show a complete disregard for right angles and precision (Prem 1995).

A measurement system of some kind is necessary for construction be it as simple as the length of an arm or as sophisticated as the metric system. The Maya certainly had a measurement system and it appears to have been one based on the human body. A number of researchers have attempted to discern the basis for a measurement system (see Table 3.1). A variety of methods were used but all looked to find a common denominator from amongst multiple measurements. Small measurements (Prado Cobos 1999) as well as large (Sugiyama 1993) were examined.

Researcher	Study Area	English inches	Metric cm	Multiplier	Result cm
Alonso (1984)	Valley of Mexico		60	X2	120
Brinton (1885)	Aztecs	12	30.48	X5	152.4
Canossa (1991)	Sun Stone		4.475	X32	143.2
Cramer (1938)	Uxmal	3	7.62	X20	152.4
Greg (1885)	Aztecs	11.75	29.85	X5	149.25
Harleston (1974)	Teotihuacan		105.9463	X1.5	158.92
O'Brien & Christiansen (1986	Northern Yucatan		140.9-152		141-152
Prado Cobos (1999)	Maya Ceramics		0.36	X400	144
Sugiyama (1993)	Teotihuacan		83	X2	166

Table 3.1 Attempts at determining a Maya unit of measurement. Note the fairly narrow range in the last column.

Each proposed standard measurements, which, for the sake of comparison, have all been converted to metric. In addition a column of multiples is shown which attempts to show a common denominator amongst measurements. The range of this common factor is remarkably close, from 120 to 166 cm. It should be noted that these measurements were developed using data from Maya, Aztec, and Teotihuanaco sources not solely Maya.

One common measurement used throughout the world is that of an arm span. In the English system it was called the fathom and is ca. 182 cm in length. The fathom, however, was devised by a European population of different stature (Krogman and Iscan 1986). A common medical ratio finds that there is a near 1:1 correlation between height and arm span and, interestingly enough, we find that the average stature of the Maya may have been between 155 and 164 cm (Márquez and del Ángel 1997; Steggerda 1941). A recent study puts it at 160.1 cm for Maya men (Danforth 1999).This unit of measurement is used in the Yucatan today and is called a *zapal*. One study looked at measurements of the Castillo at Chichen Itza and possible planning lines at El Mirador and found a striking correlation (Smith and Parmenter 2004). The similarity between these two measures, the Maya arm span and the postulated measures, is intriguing and worthy of further study.

Although still controversial, the Epi-Olmec writings found on the La Mojarra stela and the Tuxtla statuette may provide some confirmation of this. As currently translated both objects have writings that talk about measuring areas in arm or hand-spans (Kaufman and Justeson 2001). The Popol Vuh uses the phrase “stretching the cord” repeatedly which may also be a way of describing measuring with a cord at arms length (Tedlock 1985). Christopher Powell has also described a cord an arm span long and suggested the Maya used the “golden mean” to build proportionate rectangular rooms for a harmonious whole (Schele and Mathews 1998). This type of measurement has the advantage of needing no particular mathematical skill to use but, if the Maya did indeed use this method, they used it inconsistently. If this method was consistently used we should see more 90 degree corners than are evident in Maya construction.

Labor Organization

Once the decision of where and what to build have been made then the next logical step is to line up the labor to procure materials and start construction. The archaeological study of labor in construction has come a long ways in recent years. Archaeologists had long believed, and to a certain extant this is still the prevalent popular belief, that Maya pyramids must have required thousands of workers to construct. Morris (1931: 240), for example, said that "it is quite impossible to form an adequate conception of the amount of labor expended in the construction of one of the ancient buildings." This has many implications including that there had to have been a high degree of specialization in Maya society to cope with organizations this large.

We can probably thank Herodotus for these beliefs. Writing 2,000 years after the fact, Herodotus described the manpower required to build the Egyptian pyramid of Kheops at Giza. "They worked in gangs of a hundred thousand men, each gang for three months. . . . The pyramid itself was twenty years in the making "(Herodotus 1920: 2.124.1-5). Recent archaeological work on the Giza Plateau has found that the Egyptians were not quite as profligate with labor as previously believed (Troy 2002).

In a similar vein, recent work on architectural energetics and Maya pyramid building has found that far fewer workers were needed than previously believed (Abrams 1994, 1999; Abrams and Bolland 1999; Carreli 1997; Webster and Kirker 1995). Looking at one of the largest structures at Copan, 10L-22, Abrams found that no more than 411 workers would have been necessary over three months and that a large number of these would only be needed to procure the materials (Abrams 1987). Most monumental Maya structures were conglomerations of previous structures built one on top the other and would take significantly fewer people to modify than it would take to build from scratch.

Another question regarding labor deals with how the workers were "drafted" and organized. Abrams has assumed that the costs of construction are mirrored in the complexity of organization of construction personnel (Abrams 1987). He has gone on to propose two models for labor, a "festive custodial" system in which labor is given in return for a party or feast upon completion, and a low-level corvée system of labor coercively owed to the state (Abrams 1994). Other researchers have proposed systems involving less bureaucracy. Kurtz and Nunley (1993), writing about Teotihuacan, proposed that labor was voluntarily given due to religious beliefs or social constructs of a work ethic. Food for thought also is a point made by David Webster (1985: 389) that cautions against a form of circular reasoning: ". . . we *know* that the Classic Maya were a complex society; hence we interpret unusual concentrations of artifacts as indicating more complex economic behavior than they warrant on their merits alone."

Based on the evidence at hand we cannot do more than speculate about the organization of construction labor by the ancient Maya. What we do know is that the work could have been done with fairly small numbers of laborers and that a group of this size does not necessitate specialized administrative positions nor demands a particular method of labor recruitment.

Ground Preparation and Foundations

There is little evidence that the Maya considered structural factors when choosing a building site. Building placement appears to have been completely subservient to their urban planning principles (Pendergast 1990; Wernecke 1993). This was just one of many signs of indifference to the engineering of structures. It may be that the common practice of superposition, building new structures over old structures, kept Maya builders from thinking in the long term when it came to structural design (Figure 3.5).

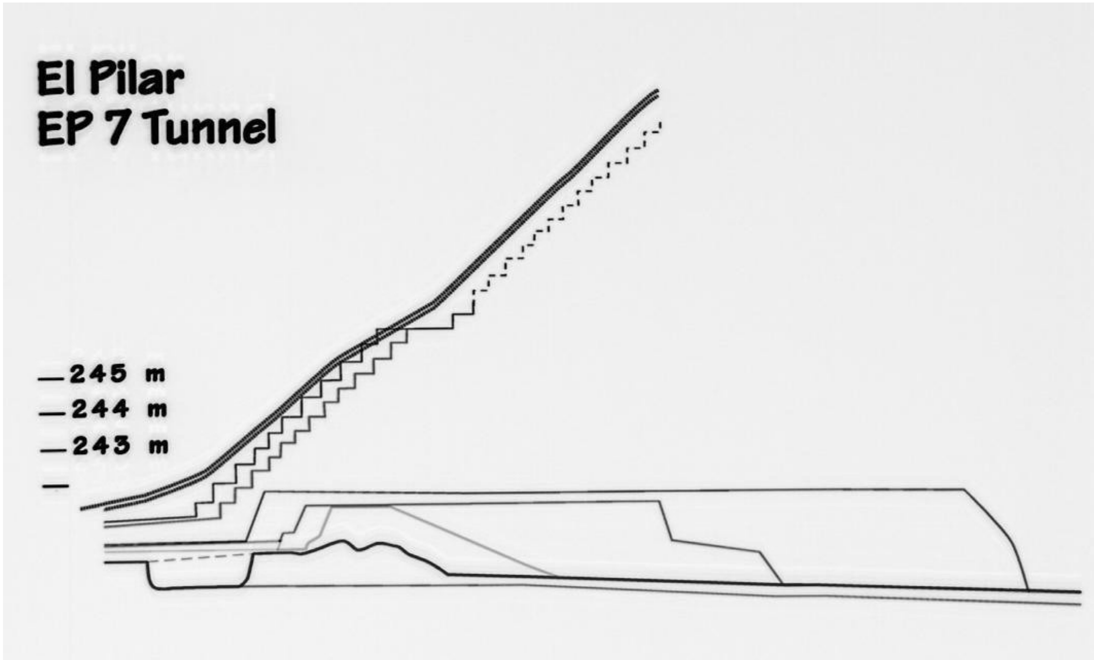


Figure 3.5 Superposition of Maya structures as illustrated in structure EP7 at El Pilar.

Preparation of the building site also commonly got short shrift. In some instances the soil was cleared to bedrock before construction began though this may have had more to do with the reuse of the soil as fill or in agriculture than in seeking a sound footing (Ford, et al. 1995; Sharer and Sedat 1987). The antipode was also true, often large amounts of fill were brought in to level the ground before construction (Houston and Escobedo 1997; Morris 1931; Stierman and Brady 1999). This could often add up to a considerable project by itself - it is estimated that 440,000 metric tons of fill was deposited in the Great Plaza at Chichen Itza, for example (Desmond, et al. 1994).

Another form of preparation took the form of extensive landscape modification in hilly areas. Terracing, retaining walls and large amounts of fill were used to enable the construction of structures on otherwise impossible sites. This technique was used extensively at sites such as, Palenque, Copan, Tonina, Yaxchilan, and Piedras Negras (Andrews 1975; Ferguson and Rohn 1990; Hooke 2000; Schubart and Carpenter 2001).

"Foundation" is another architectural term that has been used in various ways among Maya scholars. It is used to signify a beginning, "foundation caches" for instance, or to designate any low architectural remains. It is also frequently used in regard to building platforms (Andrews 1984; Tourtellot, et al. 1989; Masson 1997). None of these are, strictly speaking, architectural foundations. The foundation is "any part of a structure that serves to transmit the load to the earth or rock (Harris 1993)." Usually the foundation is below ground level and serves to transmit the load to a *stable* stratum of earth or rock. A successful foundation is safe against sheer failure in soil (slippage) as well as ensuring equal displacement or settlement of the structure.

Maya structures appeared to rarely have a prepared foundation (Morris 1931; Prem 1995). This is a fundamental engineering problem that is one of the principal causes of the poor preservation of Maya structures. The Maya relied heavily on the construction of platforms as foundations below both their domestic and monumental constructions. These do not show any signs of compaction to make them stable foundations and they are usually constructed out of disparate materials (Pendergast

1990). There are exceptions; however the attempts do not often go beyond a single stretch of rock slabs (Schortman 1993).

There are practical methods that can reduce the incidence of structural failure due to settlement or sheer failure. One of the easiest to adopt is to simply construct the building in stages in over a long period of time, waiting for the components to settle before continuing on. This method was used by the Babylonians to build their ziggurats and is also suggested as the reason for the long completion time allotted to the Aztecs Templo Mayor (Kerisel 1987). The practice of superposition also contributed in this direction as part of the substructure would consist of an older structure that had completed any major settlement. In many cases the Maya may have just shrugged off the inevitable building failures. The ancient Egyptians did not begin to utilize proper below grade foundations until 1800 years after they began to build monumental stone structures and seemed to take failures in stride (Clarke and Engelbach 1990).

Platforms

One of the two fundamental units of Maya architecture was the platform. Together with the stone vaulted room, combinations of these two units make up most monumental Maya constructions. Platforms range from the rudimentary raised floor in the simplest residential buildings to constructions as large as the basal platform of the Danta group at El Mirador, a platform measuring 300 by 300 meters and seven meters tall (Matheny 1980)(Figure 3.6). Platforms are used singly or stacked to make up pyramids.

Figure 3.6 The North Acropolis at Tikal, essentially an 80 X 100 meter platform.

Clearly, as noted in Chapter 2, availability, topography, and other factors will impact method. The building methods used were simple. Any description of building methods must generalize to a certain extent but this should not be interpreted as evolutionary or universal. The earliest platforms were generally constructed of earth or clay with a waterproof coating of clay or simple stone retaining walls (Hammond and Gerhardt 1990; Lowe et al. 1982; Shook and Kidder 1952). A method that produced a more stable platform was to puddle the clay and mix it with grass to create a form of adobe (Sharer and Sedat 1987; Shook and Kidder 1952). Clay retaining walls would often be painted as well which added some additional protection from the weather. Plaster and burnt clay also make an early appearance on Maya platforms with mixtures exhibiting technical tinkering through time (Hansen et al. 1997; Wauchope 1948). Due to their exposure to extremes of temperature and moisture, Maya platforms probably required almost daily maintenance to ensure the structural integrity.

Starting with the simple river cobble walls on early platforms, Maya stonework also changed through time (Sharer, et al. 1999). Gradually ashlar stonework began to appear and some regional patterns can be read in this. The central Peten shows large, rough blocks in the Preclassic, giving way to "unit" blocks (meaning stones in uniform sizes rather like modern bricks), changing gradually to rough, more randomly sized ashlars often with chinking (Figure 3.7, 3.8). In many areas this construction gives way to a veneered block construction leaning more heavily on mortars and cement fill. As platform size increases so is there a change in construction methodology. Where small, simple platforms could be easily built out of earth or clay piles, larger constructions had to be divided up both for efficient labor organization as well as structural engineering reasons.

This is most evident in the repeated use of construction "cells" noted in large-scale Maya monuments (Figure 3.9) (Ford et al. 1995; Freidel 1986; Hansen 1998;

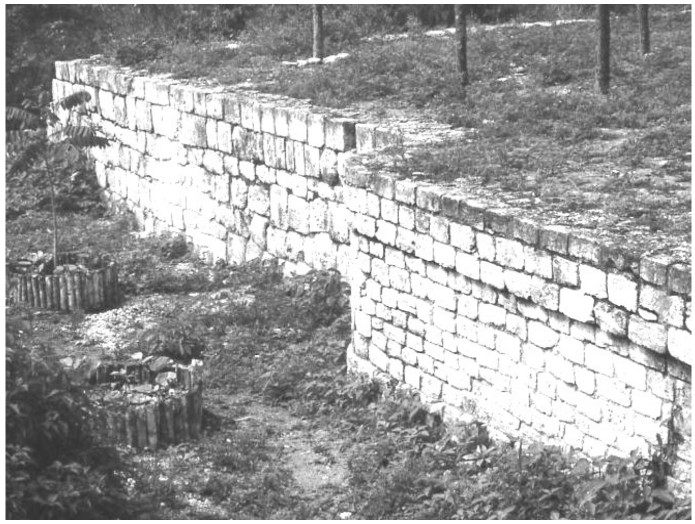


Figure 3.7 Platform blockwork at Becan with Classic style work in the foreground and Preclassic in the background.

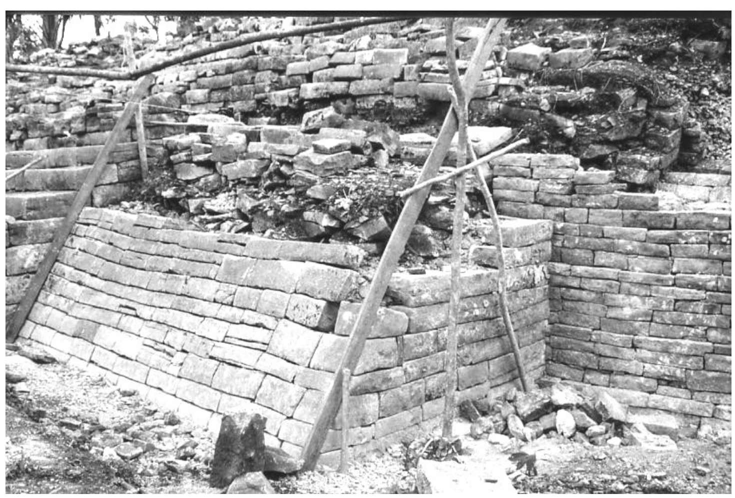


Figure 3.8 A Late Classic dry stone platform at Lubaantun. Note the trimmed stone face and rubble fill.

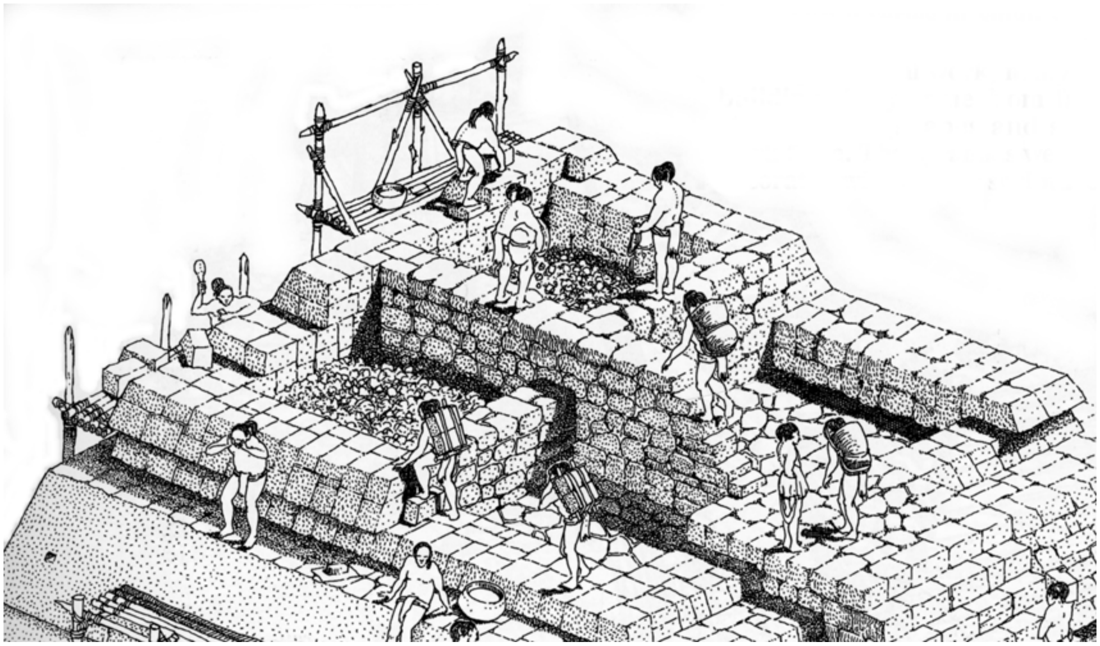


Figure 3.9 Maya construction cells being filled (illustration by permission, Hernandez 1992).

Jamison and Wolff n.d.; Morris 1931; Quintana 1995; Schortman, et al. 1986; Sharer and Sedat 1987; Zeleznik 1993). Square portions of the platform would be marked off and crude dividing walls constructed and then these cells would be filled in. The fact that these cells often show significantly different fill types leads to the conclusion that different work parties, obtaining their materials from different sources, were responsible for filling in assigned cells. Although there are regional differences, the infill can tell us a lot about the construction history. Distinctive materials, such as midden infill with ceramics etc., or the Middle Preclassic clean cobble fill made up of piled chert cobbles can provisionally date a construction.

Maya platforms were plagued by a number of fundamental engineering problems that led to frequent structural failures. Differential settling of the disparate materials used to build platforms would have required constant maintenance (Larios Villata 2000; Pendergast 1990) . Although construction via the cell method described above would localize a major problem it could not eliminate it. If settling cracks were not handled expeditiously water could reach the interior of the structure and cause settling on a major scale or, worse, a shear event leading to collapse (Acosta 1959; Pendergast 1990). Water was not solely an exterior problem but also made its way into the interior of the structures through capillary action (Pendergast 1990).

Compression problems leading to structural failure are caused by an eccentricity in the vertical load (Gordon 1978). The limestone, clay, cobbles etc. used as fill and walls are all stable in compression. That is, as long as the load is directly vertical, the structure should stand. If, however, the stresses become unevenly distributed, higher on one part than another, this will lead to shear – displacement of that element.

This is seen archaeologically where the use of fill and retaining walls are of different materials with little attention to bonding the two together. The wall is often found toppled outward from the structure (Morris 1931; Gordon 1978). Some attempts at bonding were made - at El Pilar a massive platform wall was excavated made up of ashlars one meter long set in header and stretcher construction (Figure 3.10) (Wernecke, et al. 1998). Unfortunately, in this case the header blocks were anchored into very loose light dirt and rubble. Consequently, the wall would have been pushed outward as the interior fill settled.

Figure 3.10 The backside of the megalithic retaining wall underneath structure EP7 at El Pilar. Note the header and stretcher bond.

Besides bonding and differential materials the Maya penchant for excavations and burials in existing structures could contribute to weakening the building. At El Pilar, a six-centimeter settling crack clearly delineated a later Maya excavation into a monumental pyramid (Figure 3.11) (Ford, et al. 1995).

Summary

This chapter examined the precursors to the process of construction up to the actual construction of the building platforms. The planning phase is poorly

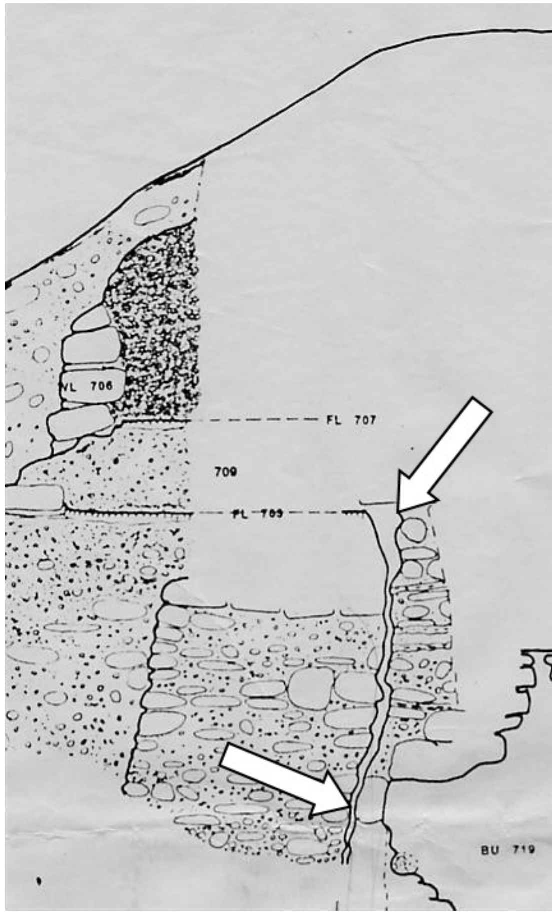


Figure 3.11 The settling crack between construction episodes found at the top of structure EP7 at El Pilar.

understood and documented. There is no evidence for formal building plans or models that may have guided the process. Lines and marks, however, that may have served to divide the work itself have been excavated. If there was a formal plan, the Maya apparently did not count the hot, humid climate as an important factor to design for.

There are many current ideas regarding the positioning of Maya monumental constructions. Discussed were astronomical, cosmological, directional, geomantic, topographic, and cultural planning schemes, none of which can be directly proven. Each of these would have been simple to lay out given ropes and a rods. Maya mathematics would be up to the task of laying out a structure and building its components in a reasonably standard fashion. Their mathematical skills were not equal to the task, nor were modern mathematics until the eighteenth century, of the complex engineering computations which would have made their structures more stable or led to architectural advances.

Recent studies have made it clear that fewer workers than previously thought would have been necessary to construct Maya monuments and this must lead to changes in our assumptions regarding labor organization. With fewer workers, and the possibility that they may have been organized through kinship or community, a complex organization is not essential. Workers groups could have functioned autonomously once given their tasks.

Literally the building block of Maya architecture is the structure platform and this chapter looked at site preparation and construction practices for them. Sites were often cleared to bedrock and the platform built in cells or stages out of various materials at hand. Little attention was paid to formal foundation preparations nor was the fill consolidated in such a fashion as to preclude later settling and compression problems.

Chapters four, five and six will now examine the suite of architectural components that the Maya drew on to create their monuments. Special attention will be paid to their change, or lack thereof, through the roughly fifteen centuries of monumental Maya architecture.

Chapter 4

Architectural Elements: Floors and Stairs

Think simples' as my old master used to say – meaning reduce the whole of its parts into the simplest terms, getting back to the first principles.

Frank Lloyd Wright

The fabric of a building is made up of a number of architectural components. Wright liked to compare architecture to a musical composition where all of the notes combine to make a unified whole. Some, like floors and walls, are essential to the structure while others, such as stairs and windows, may be optional. There is an element of style inherent in the construction of these elements. While a building might require a floor, for example, the choice of an elaborate mosaic over dirt makes a design statement. Other components of the overall style are additive, a stucco mask on the wall or particular design on the floor will generally be disregarded in this study as nonstructural. The next three chapters will discuss a number of the components regarded as “first principles” in Maya construction.

Floors and Pavements

The earliest floors in public structures were similar to those of domestic structures. As early as B.C. 1000 the Maya began to build platforms topped with perishable structures for public or ceremonial use (Hammond 1982, 1991). New research along the Pacific coast of Chiapas, at Alvarez del Toro, may indicate that lime cement or cement-like floors may be as old as 3000 BC (Quick 2004). The floors were of packed earth, clay, sascab, or lime plaster. Clay floors could be mixed with a tempering substance such as pine needles to form an adobe coating or fired to a hard surface (Parsons 1969; Wauchope 1948).

Sascab, as previously mentioned, is often used in modern Maya housing and makes a fine, hard floor after it is wetted and dried (Figure 4.1). The major drawback to a sascab floor is that it does not take wear well and must be periodically raked out and wet again to give it a wearable surface (Wauchope 1938). It may be difficult to tell the difference between sascab and burnt lime in a deteriorated floor found archaeologically. There may be some structural differences between the two substances that can be noted under a microscope but, as they come from the same parent material and chemical ageing processes work toward returning them to similarity, sascab may have been used more often than previously thought (Littmann 1967).

These surfaces can be divided properly into two categories; floors are inside buildings, pavements are outside. Structure floors can be equivalent with platform floors. Platforms were often constructed, plastered and the structure built on top of the floor (Prem 1995).

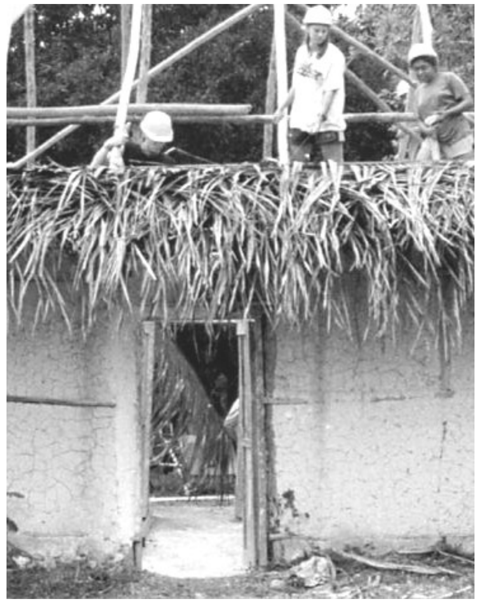


Figure 4.1 The sascab floor is visible through the door of this bajareque structure.

The Maya, either due to local shortages of suitable limestone or even perhaps design criteria, uncommonly made floors and pavements of substances other than earth, clay, and lime. These floors are often prominently mentioned in monographs due to their eccentricity. At Copan, for instance, lime plaster was earmarked for decorations and many floors had a surface of crushed rhyolite and pebble floors were found in the area (Sharer 1990; Schortman 1993). Pavements have been found of cobbles, earth and stone, rubble and even, unusually, of dressed stone (Houston, et al. 2000; Parsons 1969; Schortman 1993).

It is safe to say that, by the Middle Preclassic, most floors in monumental buildings were constructed of burnt lime cement (Littmann 1972). Edwin Littmann is one of the few researchers to closely examine Maya floor construction in a series of journal articles and reports starting in 1957. His accumulated data was synthesized in one journal article which reported on an observed floor “system” which seems to be the norm for Maya construction from the Preclassic to the Postclassic (Littmann 1967). Littmann reported finding a three element construction “unit” throughout the Maya region. The first layer was a rough fill or foundation for the floor. This, in turn, was covered with a gravel ballast layer and, lastly, capped off with a thick mortar or plaster layer. The quality of these elements, as seen in the sample of floors examined by Littmann, declined after the Middle Preclassic. He also noted that a wash or finish coat of plaster was often applied last to complete the construction. The three element technology is independent of materials – local materials could be used for any of the three layers. The final wash coat of plaster was often coved up against the walls which disguised the fact that the walls were built on a single floor (Figure 4.2) (Prem 1995).

The ballast layer is often what Littmann termed “lime aggregate” (Littmann 1957, 1959a, 1959b, 1972). He noted that it had “the appearance of packed earth” when damp which may indicate that it is often a mixture of sascab and large lumps and chips of limestone. This mix, when wet, would serve to bind the finished floor to the underlying fill. An underlayment of this nature would also serve to even out level differences and imperfections in the fill and to provide added strength to the finished floor surface. Yet, a thin lime cement floor applied directly over fill would suffer greatly from cracking due to settlement.

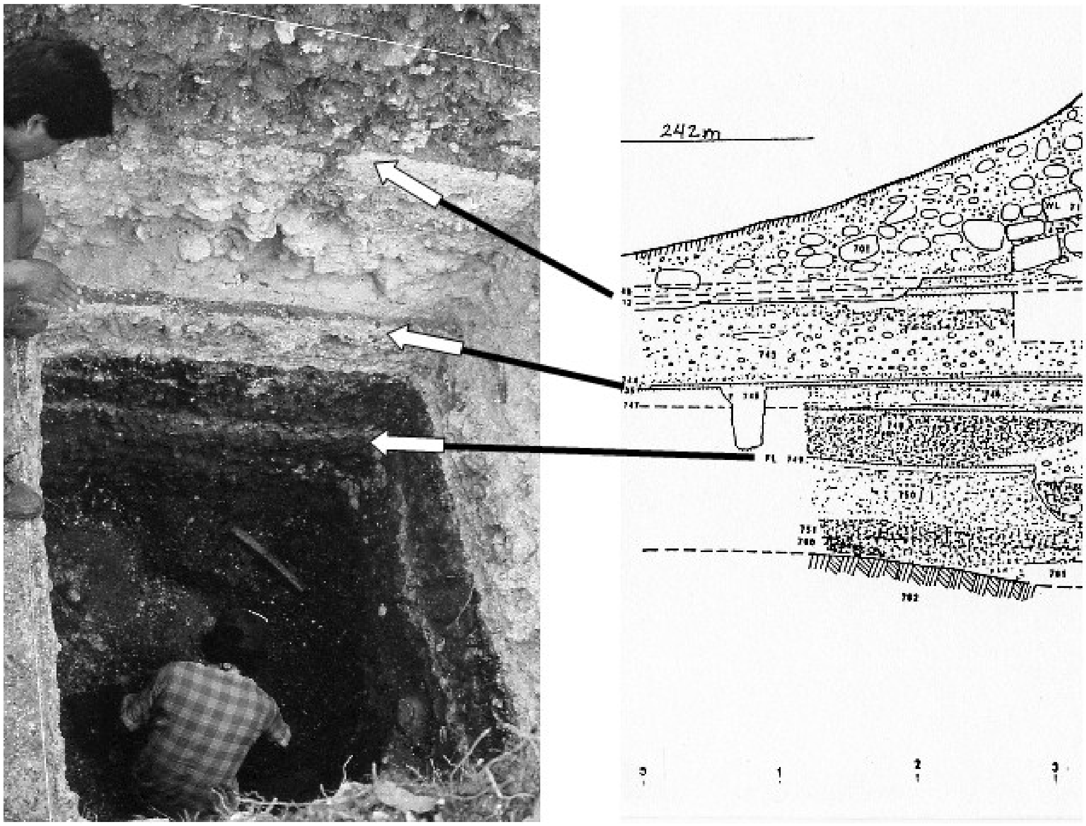


Figure 4.2 Pavements in Plaza Copal, El Pilar. Note the ballast and surfacing layers evident in the drawing.

Lime cement floors are also prone to damage from friction albeit to a lesser degree than sascab. A thick cement floor in a heavily-tread area would need frequent patching of cracks and to prevent the formation of worn path. The Maya cleverly found a way to mediate this that isstill used in the modern plaster and cement industry – chemical admixtures (see Chapter 2). In the case of floors it appears as if organic agents were added to the final layers of many lime cement floors, which gave them a polished, extremely hard surface. Where it is necessary, archaeological excavation through structure and plaza floors can be made very difficult by this tough material (Figure 4.3). At El Pilar, excavations through early plaster plaza pavements required the extensive use of a wrecking bar (Ford et al. 1995).

Figure 4.3 A Preclassic round structure with a hard plaster floor found beneath pyramid EP9 at El Pilar.

Stairways

Stairways are important connective elements in architecture. Their construction can draw attention or remain architecturally anonymous depending on the builders' purpose. They can serve functionally, decoratively or both. The simple act of ascending and descending stairs is rife with meaning for humans and that is often reflected in the construction. Lothrup (1925) compares Maya stairways to the classical Temple in Antis, where the Maya stairs take the central place of the projecting temple walls (*antea*). The noted architect Christopher Alexander (1977) simply states that staircases are living spaces, stages.

In many cases the ancient Maya seemed to have started out with ramps, especially in plazas, which were much easier to construct. Ramps of this type were found at La Milpa, El Pilar, Tikal, and many other sites (Ford, et al. 1995; Hammond, et al. 1996; Rudy Larios and Miguel Orrego, personal communication 1995). Often these ramps were later converted to stairs. These are not to be confused with stairway balustrades, the flanking “rails” on either side of stairways, which are often mistakenly called ramps.

Usually the Maya built their stairways out of stone though there are intriguing bits of data that suggest a rich tradition in wood as well. Totten (1926) cites the possibility of wooden stairs on Maya structures based on the lack of obvious access to the upper stories of some buildings. A wood stair to the second story of Naranjo’s “Palace of the Tigerhead” was postulated, as was a stair to access the labyrinth at Yaxuna (Maler 1908; Suhler and Friedel 1994). The Maya had access to many woods that were resistant to rot and insect damage (mahogany and cedar for instance) but if such stairways had existed the tropical moisture and insects would still have destroyed them within 50 or less years. We should not dismiss the possibility, however. It has long been apparent that the Maya made extensive use of wood scaffolding in construction yet the only evidence we have for this are putlog (a short piece of lumber that holds up a scaffold) holes in some buildings. Another line of evidence is the great wood stairway at Bolonchen (Xtacunbilxunan) described by John Lloyd Stephens that took Maya water carriers 450 feet down to the source

(Figure 4.4) (Stephens 1963). This may have been no more than a series of ladders but, as they appeared to allow the bearers to walk upright, could be interpreted as a stairway.

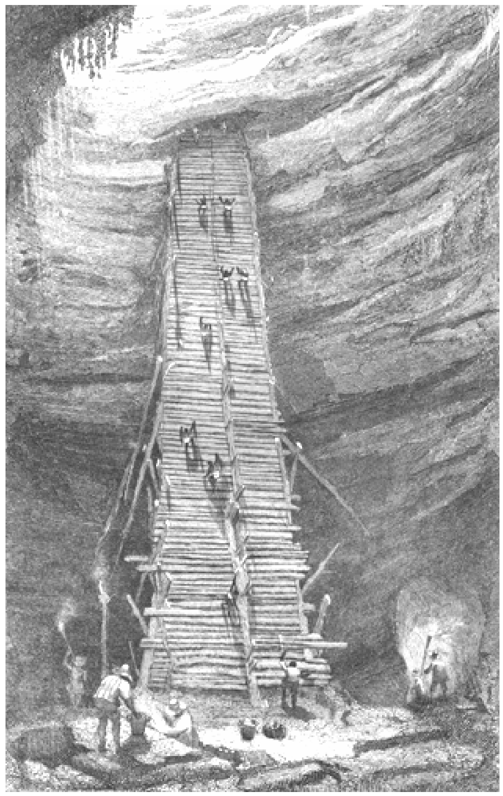


Figure 4.4 Catherwood's engraving of the stairs at Bolonchen (with permission, from Stephens 1963).

In addition to wood, stairs are also found in brick, irregular masonry, ashlars, megalithic, and monolithic stone (Siller 1992). In large construction projects it was common procedure to build a temporary stairway utilized by the construction workers that would have a finer stairway built over it in the finishing stages. These "construction stairways", which can be clearly seen at Tikal (Temple 1) and

Xunantunich (A-1), were poorly fashioned and subject to a lot of wear (Figure 4.5) (Smith 1982).

Figure 4.5 The construction stairs on structure A-1 at Xunantunich (visible beneath the finished stairs that are near the bottom of the photo).

Fired brick stairways are found in the northern Maya area, the modern Mexican state of Tabasco. The major city of Comalcalco used bricks extensively in its last phase of construction as did the surrounding sites Bellote, Juarez, Jonuta, Allende, and El Encanato (Figure 4.6) (Torres 1997). As noted in Chapter Two, this could have been an adaptation to the lack of stone in the alluvial plain. The builders most likely were influenced as well by the neighbours to the north as bricks were used in construction at La Venta and Cholula. Adobe (sun-dried clay) stairways are found in the southern Maya area, Copan and sites in El Salvador (Sheets 1984).

Figure 4.6 Brick Stairways on Temple IV at Comalcalco.

Both irregular masonry and ashlar stair construction are quite common throughout the Maya area. In fact, it is not unusual to see the two methods in the same stairway. Stairs at Lubaantun in Belize, for example, have risers made of ashlars with wider treads consisting of irregular masonry (Figure 4.7). The presumed construction stairway of unworked cobbles at Seibal was replaced by a stairway of worked ashlars (Smith 1982).

Figure 4.7 Trimmed blocks with rubble fill stairway at Lubaantun.

Monolithic stairways can be divided into two categories, depending on the definition of the term. It can refer to stairs in which each riser /tread is made up of one large stone and it is also used in the case of stairs carved out of solid rock. Monolithic, literally “one stone”, is often used incorrectly as a substitute for megalithic. While Maya monolithic sculpture is common, true monolithic stairways are quite rare. Stairways with individual monolithic steps are found throughout the Maya area with examples at Pusilha, Piedras Negras, and Yaxuna (Braswell 2001; Houston, et al. 2000; Suhler 1995).

Megalithic stairways variously defined by site are those built out of very large stones and are common. In some cases it appears as if the word megalithic is used to describe stones simply larger than the average at a particular site. There are, however, stairs built out of very large stones such as the north stairway to the Copan acropolis where stones roughly a half meter square and two meters long are recorded (Figure 4.8) (Sidrys 1978). Megaliths are found in several sites in southern Belize and in abundance in northern Yucatan (Braswell 2001; MacKinnon and Olson 1993; Suhler 1995; Taube 1995).

Siller (1992) goes further to define the structure of Maya stairways, dividing them into recessed, semi-recessed, superimposed and “flown” (stairs that lean over a corbelled passageway). There are also unfunctional Maya stairways. The best example of this is Structure 1 at Xpuhil whose three towers are, in effect, scale models of pyramids complete with unscalable stairways and small structures on top

Figure 4.8 Megalithic stairway at Copan (with Vanessa Bunton of the BRASS/El Pilar Program for scale).

(Figure 4.9). This is indicative of one of the “meanings” of stairways in Maya architecture. Sometimes a stair is simply a stair, a way to tie two levels together, but stairs also can be used to convey motion, symbolism, or serve as handy “billboard” space. Glyphic stairways are a potent expression of this use. Good examples are found at Dos Pilas, Naranjo, Copan, Yaxchilan, and Palenque. Harder to confirm are suggestions that some Maya stairways may deliberately incorporate sound into their design or visual phenomenon such as the famous serpent shadow at Chichen Itza (Hall 1998). There also was, undoubtedly, symbolism built into many stairways. It has been repeatedly pointed out that the Castillo at Chichen Itza has 365 steps, 52 panels and 18 terraces, all calendrically important numbers (Figure 4.10). Simply constructing the stairway in a certain fashion is important. Ching (1979 wrote that “stairs, in accommodating a change in level, can reinforce the path of movement,

Figure 4.9 False stairway on Structure 1 at Xuphil.

Figure 4.10 Two of the radial stairways on the Castillo at Chichen Itza.

interrupt it, accommodate a change in its course, or terminate it." The stairway to the central acropolis at El Pilar that changes pitch multiple times could signal increasing exclusivity (Figure 4.11). A stairway like this forces a pedestrian into being aware of their every footstep.

Figure 4.11 The stairway from Plaza Imix to the Acropolis at El Pilar changes pitch at least three times.

The Maya also built significant interior stairways. Many of them were simple single flights; the stairs to the roof of Grupo G at Tikal, that in 10L-11 at Copan, or the stair from the labyrinth to House E at Palenque. More complex examples are found in the Palenque tower and stairs to Pacal's tomb, the palace at Santa Rosa Ixtampak, the Caracol at Chichen Itza, the "secret stair" on the west side of Structure IV at Becan, and Structure 1 at Xpuhil (Figure 4.12) (Pollock 1970; Potter 1977).

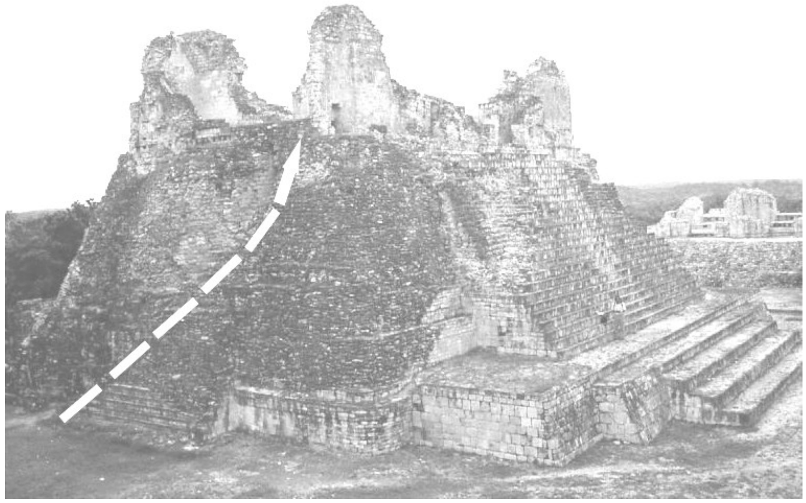


Figure 4.12 Dashed arrow delineates the path of the concealed staircase on Becan Structure IV.

Summary

Two architectural elements, floors and stairs, were examined in this chapter. Floors were made of a variety of materials including sascab, clay, earth, stone rubble, or even dressed stone. By far the most common floor in monumental construction was, however, the floor of lime cement. By the Middle Preclassic, the Maya seemed to have developed a system that was in general usage for building lime floors which included a foundation, layers of lime cement and additives for strength.

Stairs are an element that can solve transition problems in architecture as well as signal larger intentions by the builder or patrons. Stairs can be used to include, exclude, awe, surprise, or even tell a story. Most Maya stairways were built of stone but there are extant examples of clay and brick and there may have been a tradition of wood stairways as well.

The next chapter will examine the fabric of Maya buildings, the walls and openings in them. Together with Chapter 6, which will address the roofs, these will list the elements utilized by the Maya in monumental construction and what archaeological excavation has shown us of their techniques.

Chapter 5

Architectural Elements: Walls, Columns, and Windows

Consider the momentous event in architecture when the wall parted and the column became.

Louis Kahn

Walls

For much of the early history of the Maya the walls of public buildings were made of perishable materials. It has long been an accepted theory that Maya public architecture developed directly from the traditions of domestic architecture. The suggested path of development of wall architecture begins with the simple stick or thatch wall, with gradual replacement by bajareque, non-load bearing stone walls, load bearing walls supporting light thatch roofs, and finally, fully load-bearing walls with stone superstructures (Andrews 1975; Hansen 1998). There were, of course, exceptions to the rule. Individual buildings stand out as being built by someone with a better understanding of construction than the norm. Others, due to a lack of the appropriate materials, utilized simple materials such as brick or bajareque long after the rest of the Maya had adopted stone architecture (Loten 2002).

The genesis of Maya public architecture can be seen at Cuello, Belize, and structure E-VII at Uaxactun where the remains of wood corner posts clearly indicate a wooden superstructure with walls of perishable materials (Hammond 1991; Heydon and Gendrop 1975). These walls were often covered in daub to give them a more substantial appearance as well as a vertical surface that could be decorated as befits public architecture. The structures appear to be identical in construction to domestic structures both historically and archaeologically (Figure 5.1) (Sheets 1992; Wauchope 1938).

Figure 5.1 A traditional bajareque structure at El Pilar, Belize.

The second theoretical stage, creating non load-bearing walls by filling in between the load-bearing posts, is harder to document archaeologically. In most cases there probably was not a transitional stage of wood and stone, simply wood OR stone. It is not, however, an illogical step and examples of this style have been documented historically in domestic architecture in the region (Wauchope 1938).

The next stage of development, the construction of load-bearing walls with perishable superstructures, has been well documented throughout the Maya region. Tatiana Proskouriakoff's illustration of structure K5 3rd at Piedras Negras is a good case in point (Proskouriakoff 1963). One dramatic example of load-bearing walls with thatch roofs is the estimate that less than 50% of the structures at Piedras Negras may have had stone corbelled roofs (Satterthwaite 1938). Perishable roofs were in broad use even after the use of stone superstructures became widespread. It is cheaper, faster to build and more environmentally friendly than the use of stone corbelling.

Living in structures built entirely of stone in the humid tropics can be fraught with problems including high humidity, lack of air circulation and low light (Fitch and Branch 1960; Fry and Drew 1956; Ketterer and Ketterer 1971; Pendergast 1990; Rapoport 1969). Perishable superstructures and walls are lacking only in perceived status. The ancient Maya even tried to have the best of both worlds, status and comfort. On Cozumel, “Potemkin” structures were built that appear to be of stone construction from the front, but actually are primarily perishable structures (Sabloff and Rathje 1975).

The final developmental step was the integration of load bearing stone walls with stone superstructures. This innovation probably took place some time in the Middle or Late Preclassic as evidenced by the corbelled tomb at the Olmec site of Teopantecuanitlan and burial 85 at Tikal (Coe 1990; Martínez Donjuán 1995). There is some evidence that the Maya adopted several construction practices, including corbel vaults and internal cells, from their northern neighbors (Clark and Hansen 2001).

Generally speaking there does seem to be a progression of wall construction styles that can be traced throughout the Maya area (Von Falkenhausen 1985). Some variations are noticeable, due to material availability and quality, but overall the Maya seemed to learn new methods and they would very quickly. Most early wall construction is made up of large roughly shaped stones and unmodified cobbles often with mud mortar and chinking. Little attempt was made to dress the faces of the stones or to bond the face and core together. Courses are nearly nonexistent and the interiors of the walls were filled with rubble and rough tight fill (Robicsek 1972; Spinden 1957; Von Falkenhausen 1985). These early walls often had a significant batter, a backward (receding) slope in the face of a wall (Pollock 1965).

The Early Classic saw a change to more finished ashlar blocks containing a looser fill and, in some places, the addition of sascab to the fill (Smith 1982). Even in sites using dry stone masonry there is a change from rough blocks to more finished blocks, such as Lubaantun and Nim Li Punit (Hammond 1975). The blocks formed the load bearing portion of the wall supporting the corbel mass above. The interior fill, often of soil and broken rock, was weak and had little structural value (Robicsek 1972; Spinden 1957; von Falkenhausen 1985). Some researchers have detected sascab in the core which may explain the use of the plaster cap found on many walls (Garcia de Miguel, et al. 1995; Loten 2002; Smith 1982). As mentioned previously, sascab can be a very strong bonding agent when used as a mortar but must be kept from wear and moisture. Another change in building procedure was a switch from walls built above previously prepared floors to floors being built after the walls (Loten 2002; von Falkenhausen 1985).

There is an important observed difference between exterior masonry work and interior work. Interior masonry is often of significantly poorer quality than the exterior with smaller stones, less finishing work and chinking (using chips and small stones to fill gaps) (Gendrop 1998; Potter 1977). The resulting stonework was covered, particularly on the inside, with a thick coat or coats of plaster that hid the imperfections. In one case this stonework appeared as bad as to require 35 layers of stucco to conceal it (Andrews and Andrews 1975: 54). The poor interior stonework may be product of division of labor. In many Maya structures the front and rear walls seem to have been built with care and concurrently while the end walls (non-supporting) were added later by less skilled craftsmen (Figure 5.2). It would be logical to imagine the best workmen building the visible exterior walls and the less skilled building the interior walls. This would explain the evidence seen in Maya architecture; "Wall lines are normally straight; vertical walls are plumb, and battered walls quite constant in slope. *Exact right angles, however, are seldom found* [emphasis added]" (Brainerd 1954). In other words, there is ample evidence of skilled stone working craftsmanship, but entire structures are not assembled with the same consistency or possibly by the same builders.

The last major change in wall construction has often been seen as a change

Figure 5.2 Note the difference in masonry between the side wall (in rear of picture) and the front wall in this structure at Manos Rojas, Campeche.

from ashlar construction to “veneer” block construction. This method utilizes a hearting (the masonry forming the interior of the wall) of concrete and either block or tile-like, non-supporting, stones stuck to the hearting as a facing (Pollock 1965; Potter 1977; Hansen 1998). “Veneer” style masonry was often attributed to the Puuc region or the Yucatan but is found throughout the Maya region as far south as Seibal (Andrews 1995; Hansen 1998). There has also been much written about the difference between block and tile veneer, whether or not the blocks were anchored to the hearting, and the relationship of decorative moldings and roof transitions to the wall. As far as construction goes these are minor matters, the real importance is the shift from a load-supporting face to a load-supporting hearting (Andrews and

Andrews V 1980). George Andrews (1995) and others make the point that not all walls of this period are strictly speaking veneer (Von Falkenhausen 1985). Many structures have blocks that are well bonded to the hearting and would be better characterized as formwork for the concrete.

An ongoing debate regarding Maya stonework involves the traits architectural historians look at when judging technical expertise; breaking joints, bonding and interlocking. Breaking joints are any arrangement of the masonry units that prevent continuous vertical joints in adjacent courses. By staggering the joints, the wall is made stronger. Many archaeologists have written regarding a lack of breaking joints in Maya architecture (Holmes 1897) (Morris 1931) (Potter 1977). Recently an attempt, claimed as conclusive, has been made to put this to rest by demonstrating that the Maya did consistently break vertical joints in their constructions (Abrams 1994) (Hansen 1998). The work done by Elliot Abrams (1994), however, examined *via photographs 12 reconstructed structures at the site of Copan*, Honduras. This is by no means a scientific examination of the subject. Even quickly reviewing monographs, photos and sketches of structures from throughout the Maya area it can be seen that there is a distinct lack of consistency regarding the breaking of vertical joints and, even on the same structure, breaking joints often seem to occur randomly. This is also not a scientific examination but sufficient to refute Abrams assertion. Keep in mind that the breaking of vertical joints in "veneer" style masonry is not necessary and imparts no greater strength since the veneer blocks are not load-bearing. It is possible that some Maya masons may have utilized breaking joints as a professional practice but it is clear that this knowledge was not widespread or consistently used.

As noted in Chapter Three, the bonding of walls to interior fill was infrequently used in the construction of platforms (Morris 1931; Gordon 1978). Bonding the inner and outer walls to the core will greatly increase the strength and lifespan of a masonry wall. In this area the Maya record is poor. Walls that had fill of unconsolidated earth or rublle were prone to settling or slump (Pendergast 1990; Heyman 1995). When the material in the core settled it would apply lateral pressures pushing the walls outward and contributing to their early collapse (Oliver 1997). There was considerably less post-construction settling in walls with concrete cores but moisture in particular could get between the face and the hearting and force a separation. Wet/dry expansion and contraction greatly exacerbate the problem (Pendergast 1990). Ledyard Smith wrote (1982) that there was no intentional bonding in wall construction evident at Seibal. There is evidence of bonding in some Yucatecan block veneer construction, but not in the underlying platforms (Andrews 1995). Overall evidence seems to point to the lack of any consistent bonding knowledge in the Maya area. In later Maya construction, however, this is often irrelevant because the prolific use of cement causes the wall to act as a monolith. Therefore, the entire wall acts as a load bearing wall and the interior and exterior faces do not matter structurally (Staneko 1996). While irrelevant *structurally*, insufficient attention to bonding on "veneer" stones would also lead to significant maintenance problems and possibly early collapse.

Another way to counter the lateral pressures in Maya walls was to batter the wall, that is to make the walls wider at the bottom than the top. A battered wall is, in effect, a buttressed wall capable of withstanding much of the force exerted by the slumping of the wall fill. Maya builders often adapted this expedient which strengthened the wall, but also exposed more of its surface to weathering. To compensate for perspective some structures were built with a negative batter – i.e. the walls were narrower at the bottom than at the top – a design that sacrificed strength for beauty (Figure 5.3) (Blom 1932; Smith 1937).

Figure 5.3 An exaggerated negative batter on the Temple of Ahmuzemcab, Tulum, Quintana Roo.

The interlocking of corners not only strengthens the corner, but also is often a valuable clue as to the architectural history of a structure. This technique also appears to have been used in specific areas but not generally. Early reports from

Copan cite the presence of interlocking corners (Spinden 1957) as do reports from Piedras Negras (Satterthwaite 1943). Other reports, from the Yucatan peninsula, record a general lack of corner bonding (Potter 1977; Andrews and Andrews V 1980).

Like the core-face bonding cited above, the presence or absence of corner bonding may be a red herring. It has been generally interpreted as either a proof for or against advanced masonry knowledge, yet it may be a relic of the building process itself. Detailed measurements of multiple structures often find that the front and rear walls are well made and very close to perfectly parallel but the end walls are less well made and not perpendicular to either the front or the rear (Potter 1977). Since the front and rear walls, especially in the structures that will carry a vaulted roof, are the crucial components it would make sense if the skilled masons concentrated on them and the less skilled erected the end (non load bearing) walls later (Figure 5.4). In this scenario, the lack of corner bonding and right angles would not be an indicator of masonry knowledge but an indicator of priorities and available resources during the building process. Due to the lack of corner bonding and often sloppier masonry work the end walls would be weaker and more prone to failure but, with proper maintenance, they may have lasted well enough and if worse came to worse and they collapsed they could be easily replaced.

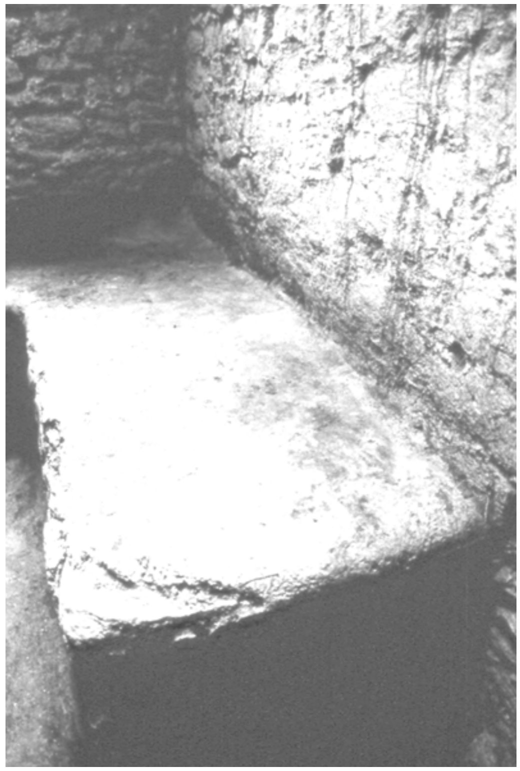


Figure 5.4 Note the lack of interlocking bond on the back corner of this structure (Structure EP22W in Plaza Jobo, El Pilar) and the difference in masonry technique between the two walls.

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Maintenance was crucial to Maya architecture (Garcia de Miguel et al. 1995; Pendergast 1990; Schele and Mathews 1998). The limestone utilized at most Maya centers is subject to exfoliation and efflorescence without the proper care and cover. The Maya covered monumental structures with thick coats of protective plaster some of which may have had organic and mineral hardeners added to the plaster or included in the paint. A large Maya center would have had to employ a significant number of “janitors” who would constantly check for cracking and sloughing and putty up the problem areas. Slump, or the settling of the fill components, would have been the constant enemy. Settling cracks would allow water to enter the structure causing increased settling rates, exfoliation and salt efflorescence that would quickly destroy a structure (Garcia de Miguel et al. 1995; Ginell et al. 1995).

Doorways and Columns

Doorways were very simple squares or rectangles in the masonry wall. Some doorways with corbelled arches exist, like the interior doorways in the Temple of the Foliated Cross at Palenque or that of Structure 41 at Yaxchilan, but these are exceptions to the rule. Jambs were usually of multiple large single stones stretching from front to back wall. There are also some examples of monolithic jambs but, again, these are the exception (Potter 1977).

Doorways are spanned with stone or wooden lintels (Figures 5.5, 5.6). Hardwoods, especially chicozapote, seem to have been preferred due to their strength both in bending and tension. In some sites in the Yucatan additional supports of wood have been found spanning the doorway above the lintel and buried in the masonry (Andrews, et al. 1985). Limestone, with very poor bending strength, could only be used to span fairly narrow doorways. Stone was generally used for doorways one meter and under in width with wood being used for wider doorways. There are, as always, exceptions to this rule such as the 1.45-meter stone lintel at Tabasqueño (Potter 1977). One hypothesis is that stone lintels were used where there was a

Figure 5.5 Chicozapote lintel in place at Manos Rojas, Campeche.

Figure 5.6 A Maya god erecting a lintel from the Madrid Codex.

shortage of appropriate wood. It appears, however, that this was much more a matter of choice or design. Yaxchilan, for example, sits in the middle of prime territory for tropical hardwoods and many of the surrounding sites make great use of them, but all of its existing lintels are of stone and under a meter in length (Tate 1992).

The choice of material also may have had a lot to do with planned decoration. Limestones in the Maya world varied from soft and easy to carve to very hard and more difficult dolomitic limestones. An area rich in easy-to-work limestone would have a choice between wood and stone lintels. Given a wood lintel, the choice of which wood was used involved a similar choice. At Tikal the sculpted lintels are of chicozapote while many non-sculpted wood elements are of logwood, which is extremely durable but has a twisting grain (Rudy Larios, personal communication 1995).

Although not structural, some mention should be made of the Maya use of rodholders and cordholders in the construction of doorways. Michael Anderson's study (1985) on the cordholders at Palenque sums up many of the hypotheses regarding these architectural artifacts and the forms they come in. The consensus among scholars is that the Maya used curtains or screens for privacy or effect and tied them off (or hung them) from prepared cleats. At Palenque these take two basic forms, as biconically drilled holes through which a rope could be threaded and as inserts with cylindrical posts to tie to. It is common in the Peten to have ceramic jar necks used to set off the holes much like modern switch plates (Figure 5.7).

Figure 5.7 A jar neck insert in the jamb of Structure EP22 in Plaza Jobo, El Pilar.

Although strongly associated with doorways these artifacts also occur in ceiling capstones, walls and in the exterior eaves and may have been used to hang awnings, banners and drapery (Anderson 1985).

Columns are often described in evolutionary terms and elaborate developmental schemes have been drawn (Acosta 1959). Kubler (1958) makes the valid point that there is not a developmental sequence. The earliest vernacular structures in the Maya region are post and lintel architecture making ample use of shafted supports. The architectural nomenclature regarding these vertical elements is often used incorrectly or confusedly. A post is made of wood, a column is the round equivalent in stone, pilasters and columnettes are decorative and have no structural value, a pier is square or polygonal in section and broad in relation to height, and pillar is an encompassing term that can refer to any strong vertical support (Loten and Pendergast 1984; Harris 1993).

Since the Maya had been utilizing posts from the beginning it is not necessary to trace their development from Teotihuacan or Tula – the simplest idea is that they knew about them all along. It has also been suggested that, along with diffusion of the knowledge, that the Maya only became interested in columns and piers when their architecture began to emphasize interior space in lieu of monumentality (Kubler 1958; Kostof 1985). A picture of the Temple of Warriors/Thousand Columns at Chichen Itza inevitably accompanies this argument (Figure 5-8). This is a unique grouping of buildings around a large courtyard that has more than 200 load-bearing piers and columns which are thought to have supported thatched, corbelled and flat beam-supported roofs (Proskouriakoff 1963; Andrews 1975). Interior columns in Maya stone architecture are rare and this structure has often been used to show outside architectural influence (Spinden 1957). As noted above there is no need to look further than Maya domestic architecture.

It has long been argued that Maya stone architecture derived directly from the original wood architecture (see Taube 1998 for an early history) (Heydon and Gendrop 1975; Stierlin 1964). If there is any truth in this assumption, then even the Thousand Columns group does not need the presence of an outside influence to explain it. The thatched structures in particular would be very similar to the common vernacular architecture with taller, stone columns in place of the usual wood.

Figure 5.8 Columns from the Court of a Thousand Columns at Chichen Itza.

Innovations cited in this example include the fact that the columns at Chichen Itza are the tallest Maya examples known and that they are grouped in new ways (Sharer 1994). These are innovations, however, when compared to other Maya standing stone architecture and are much less so if compared to wood architecture.

Maya columns are considered to be a northern Yucatecan Late Classic phenomenon, predominantly found in Puuc style structures and along the east coast of the Yucatan Peninsula (Gendrop 1998; Kubler 1958; Lothrup 1924; Spinden 1957). There are, however, a number of examples of columns found outside of the Yucatan and some earlier than the Late Classic period. For example; an early colonnaded building at Blue Creek, Belize, columns in the Rio Bec region, at Lacanja on the Usamacinta and Topoxte in the Peten (Bullard 1960a; Driver 2002; Healey 1950; Potter 1977). There are columns possibly earlier than the Late Classic at Ake and Sihunchen in the northern Yucatan (Andrews and Andrews V 1980). It is also hard to ignore prototypical colonnades evident in structures such as N10-2 at Lamanai, which apparently had two rows of wood columns (Pendergast 1981).

A black and white distinction is often made between building piers and "pillars" (see Gendrop 1998, for example). The use of the generic term pillar instead of pier makes these square examples, which are integral to the wall, seem to be innovative rather than a continuation of a building tradition. Structures with multiple doorways and narrower piers between them are not unusual in any part of the Maya region as illustrated by examples at Palenque, Zacaleu, Copan, and Piedras Negras (Figure 5.9) (Carver 1965; Fash and Sharer 1991; Pollock 1965; Proskouriakoff 1963).

Figure 5.9 Narrow masonry piers on the Palace at Palenque, Chiapas.

Structurally these columns, piers and posts are load-bearing elements. It is a mistake, however, to assume that the development of the column was an innovation in response to a new interest in interior space (Kostof 1985; Kubler 1958). Throughout 15 centuries of monumental stone construction the Maya showed very little interest in interior space. Many Maya structures would be better termed monuments than buildings, the latter a term which is synonymous with enclosed space. As previously mentioned, Maya stone structures are poorly designed for the climate and the Maya were, and are, a people who utilize the outdoors to the fullest extent. An argument for a new interest in interior space also precludes other explanations for their use, like bringing more light and air into the interior (Spinden 1957). Columns are still used today to emphasize facades and, especially entrances (Trevelyan 1977). We do know that this was an important factor in Maya design by looking at the elaborate reliefs and sculpture on such structures as Rosalilla at Copan or Structure II at Chicanna (Figure 5.10). Another reason for more freestanding columns and piers may have been symbolic. Stelae are often described as pillars and rituals pillars, such as those at Izapa, are not unknown in Mesoamerica (Taube 1998). Many columns may have more to do with World Tree imagery than interior space (Pugh 2001). The World Tree is a powerful symbol in Maya iconography, separating and connecting the earth and the sky (Friedel et al 1993).

Windows and Vents

True windows are rare, but not unknown in Maya stone architecture. Usually small (less than .5m square) they have lintels made of wood or stone and tend to be at eye level (Pollock 1965). Loten (2002) reports a number of examples from Tikal with stone or logwood lintels (the Bat Palace for example). It is apparent from the plan views that most rooms do not have windows. At Palenque a number of

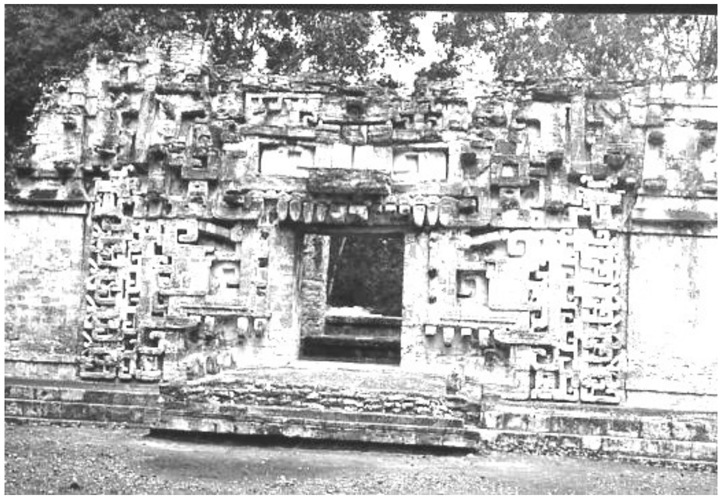

Figure 5.10 Elaborate zoomorphic façade of Structure II at Chicanna, Campeche.

structures, such as the Temple of the Cross and MR33 have small widows in the shape of crosses or T's (Figure 5.11) (Eckhardt and Hurst 1999). A small polygonal window is reported from Structure A-XVIII at Uaxactun and a rectangular one in the Temple of Venus at Copan (Smith 1950; Aveni 1980). Some windows were covered by a lattice or open-work grille either for privacy or decoration. Loten (2002) also reports a grooved window sill that may have held such a grille in structure 5C-13 at Tikal while Structure 21 at Tulum has a window with a stone "X" lattice in it (Lothrup 1924). Like doorways, some of these openings may have had curtains covering them held in place by pegs (Lothrup 1924).

Many structures have holes in the walls which have been called vents or ventilators. These tend to be small (6-15 cm high X 8-20 cm wide) and, at least in the Yucatan, located just below the spring of the vault (Andrews and Andrews 1975; Pollock 1965, 1980). Holes of this type can be seen in a structure in the Las Monjas

Figure 5.11 “Windows” in the Temple of the Cross, Palenque, Chiapas.

group at Chichen Itza (Figure 5.12). These holes would be inefficient vents for the room and may have originally been putlog holes or held poles for awnings. Other holes and windows may have been utilized for astronomical sightings or symbolically referenced astronomical bodies or events. In this category are the windows of the Caracol at Chichen Itza, the so-called “Venus tubes” and the holes through the round towers found in the Yucatan (Aveni 1980).

Decorative holes, neither windows nor vents, but often called one or the other, are found in the vault masses at Palenque (Figure 5.13) (Holmes 1897; Spinden 1957). Since they are between two interior rooms and well-overhead they could hardly have served as windows and also would not do much to improve ventilation. Constructions like these were probably inventions to lighten the vault mass and secondarily decorative.

Figure 5.12 Holes in La Iglesia at Chichen Itza, Yucatan.

Figure 5.13 Holes in the vault mass of the Temple of the Foliated Cross, Palenque, Chiapas.

Summary

Maya walls in monumental structures may have gone through a series of developmental stages from bajareque structures, non-load bearing stone walls, load bearing stone walls with a perishable roof, to stone loadbearing walls with stone roofs. Structures of all types would have also existed simultaneously in centers. The stone walls themselves went through a transformation as well. Masonry styles changed through time from a rough masonry to dressed ashlars and finally to a veneer style. Like the walls of Maya structures this is a generalization of trends throughout the Maya area and individual sites may have continued on with a favored form.

Through 15 centuries of construction the Maya never showed a real interest in interior space and their structures are better termed monuments than buildings. This is reflected in both the lack of care taken in the work and the slow process of change in construction techniques. The masonry work was better on the exterior than on the interior and actually seems to have gotten worse as the Maya advanced towards the Terminal Classic. Maya masons also gave no more than lip service to masonry techniques that would give the walls added strength. Bonding, breaking joints and interlocking were used infrequently and haphazardly. Walls frequently were battered to counteract the slumping action of the interior fill and also to shed destructive rain. The destructive climate and the settling of these monuments over time would have required constant and labor-intensive maintenance.

Structure openings were simple, square doorways, or entrances with columns or piers. Narrow doorways could be spanned with stone lintels but larger openings demanded wood. A continuing tradion of post and lintel construction in the Maya area is the likely source for columns which were not utilized, with the exception of structures at Chichen Itza to expand the interior space.

Another indicator that the Maya were indifferent to the problems of architecturally creating interior space is the relative lack of windows and openings for light and air. While some windows and vents do exist, many of the openings found could very well have been used as scaffolding putlog holes, sockets, mass-lightening voids, or even sighting instruments.

Proceeding with the survey of architectural elements the next chapter will deal with roofs and roof treatments. A large section of this discussion will be devoted to a construction element that has come to symbolize the Maya – the vault.

Chapter 6

Architectural Elements: Vaults, Roofs, and Roof Crests

The triangular ceiling in effect, is an attempt to extend the lintel in sections across the vault of a chamber in the place of joists, and, so far as the writer is aware, the only attempt ever made by any barbarous people to form a ceiling of stone over ordinary residence rooms (Morgan 2003 [1881]:263)

Vaults and Roofs

The vault system utilized by the Maya is first found in tombs. It is possible that this was not a homegrown innovation, but one borrowed from their neighbors to the north. Vaulted tombs are found in Guerrero and at La Venta in the Middle Preclassic (Martínez Donjuán 1995; Hansen 1998). In the Late Preclassic vaulted tombs had found their way to Tikal, Holmul, and Uaxactun (Merwin and Vaillant 1932; Smith 1937; Coe 1962). By the Early Classic, the vault was adopted and utilized prodigiously throughout the Maya Lowlands expanding from the use in tombs to monumental structures. Interestingly, with few exceptions, the vault was not used in the highland Maya sites (Smith 1965). Archaeologists, architects and art historians have long lauded this vaulting concept as a great accomplishment and technological leap forward (for example, Townsley 2004). In fact the vault system used by the Maya is very simple and logical. Children observed in block play have utilized the same building concept (Provenzo Jr. and Brett 1983; Hanline, et al. 2001).

One of the fundamental problems encountered in any study of Maya construction is the multitude of definitions and explanations for vaulting methods. They have been called Maya arches, false arches, corbelled arches, cantilevered arch, and Maya vaults. Archaeologists, architects, art historians and engineers have written the definitions in the literature. Consider the following definitions for arch:

ARCH An assemblage of masonry units, with its center higher than its points of support, that spans a void but does not roof a space such as a room. . . . The term "arch" is often erroneously associated with the presence of radiating voussoirs and structurally employed keystones, attributes which are not integral to the definition, and are rarely found in Maya construction. (Loten and Pendergast 1984)

Arch A structural form in a building that spans openings by arranging wedge-shaped blocks (voussoirs) such that the pressure exerted by the part of the building above the opening is channeled to the vertical supports of the arch on either side of the opening. . . . A false arch can be formed by other means such as corbelling. (Crane 2004)

Arch A curved construction which spans an opening, usually consists of wedge-shaped blocks called voussoirs, or a curved or pointed structural member which is supported at the ends or sides. (Harris 1993)

The first definition is by two Mesoamerican archaeologists, the second from a classical archaeologist and the last from a dictionary of architecture and construction. This fundamental disagreement about what constitutes an arch (does, may have. or does not have voussoirs) has colored much of the discussion of Maya construction. For the purposes of this dissertation I will define the term arch as a construction that spans a void, but does not roof a space and is curved. A "true arch" is one in which the forces acting on it are channeled to the vertical supports on either side of it usually via voussoirs. A vault is a construction that covers a space such as a room. A corbel is a stone jutting out to carry any superincumbent weight.

Given these definitions what kind of a construction is the Maya vault? This has become the central question of most architectural analyses. To explain some of the confusion surrounding this question let us first examine what Maya vaults *look* like before proceeding to a functional analysis. One of the more remarkable elements of Maya architecture is the amazing homogeneity and conservatism that marked their construction (Prem 1995). Although there are different styles of vaults from triangular to trefoil shaped they are all built in much the same way. Basically they have been described as vaults capping bearing walls, the vaults being made up of two free-standing inclining walls of cantilevered stones with a non-structural capstone bridging the gap at the top (Figure 6.1) (Kubler 1962; Loten and Pendergast 1984; Roys 1934). Maya vaults have often been called corbelled vaults, a vault in which corbelling is essential to its stability, but the extensive use of cement in their construction has led others to term them concrete or monolithic (Andrews 1984). A comprehensive history of the study of the Maya vault may be found in Justine Staneko's dissertation, *Peeking at the Puuc* (1996).

Much of the confusion over the nature of Maya vaults stem from two areas; the first is the complex nature of the interplay of the structural components, the second is the fact that it has not been possible, until recently, to adequately construct an engineering model of them. A typical Maya structure may have two parallel walls, often three with a central "corbel mass", a long vault, wooden cross members,

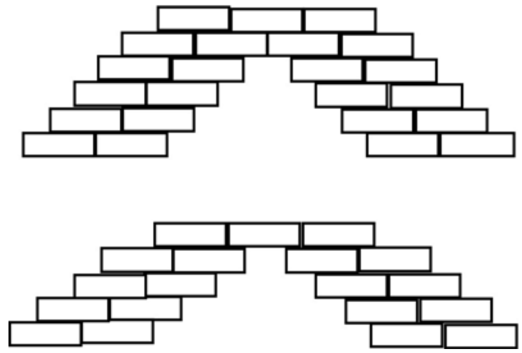

Figure 6.1 In a corbelled arch (top) the twosides physically lean against each other while in a Maya vault (bottom) they remain apart with a capstone bridging the gap.

tympanum or small vaults leaning inward on both ends, and a broad continuum of materials from mortar to rubble (Figure 6.2). Each of these structural members plays a part in the whole yet it is difficult to examine the interplay of more than two of them due to the complexity of the modeling. Many of the key theories regarding the mechanics of materials, such as eleasticity, were not developed until the nineteenth century. Engineers have been unable to examine this interplay mathematically until the advent of modern computer simulation modeling. This is why, when Lawrence Roys looked at Maya engineering knowledge, he was forced to model simple corbel arches using bricks and attempting to extrapolate from his observations as well as come up with his own mathematical models (Roys 1934). Adding to the misunderstanding is the attempt made by many archaeologists to report on architectural and engineering problems outside their expertise. For example, Spinden (1957) reported that the vaults were not cantilevered, an opinion agreed to by Pendergast (1990) who added that there was great compressive force. Peter Harrison (1999), who has excavated and written on architecture at Tikal, states that Maya vaults rely on the cantilever principle while George Andrews, an architect, states they are structurally independent corbelled vaults (Andrews 1975). This is not an attempt to criticize the excellent archaeology these researchers have participated in, but to illustrate the complexity of the structural engineering problem.

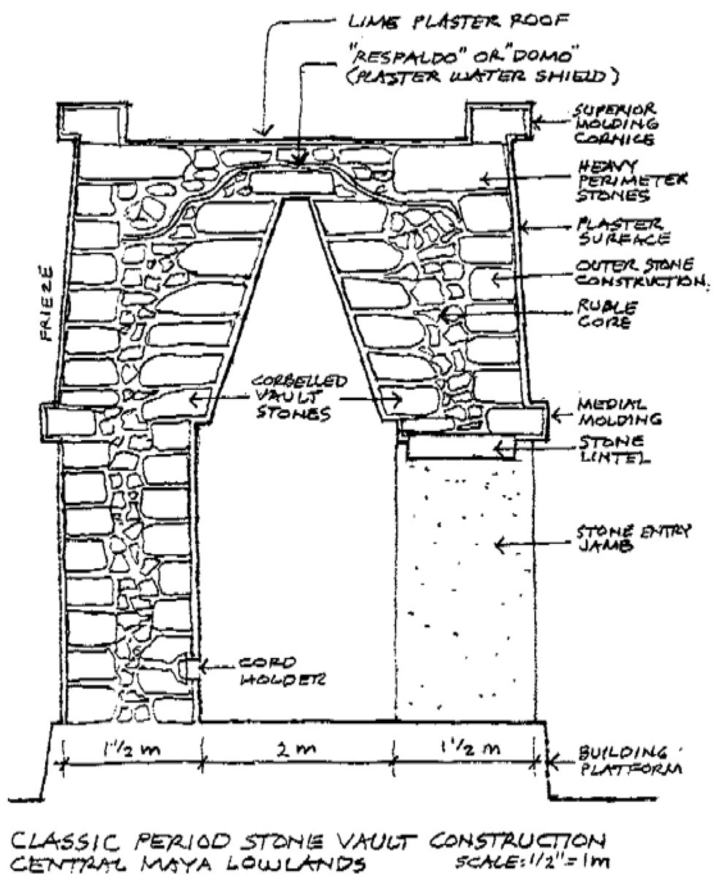

Figure 6.2 Maya stone vault construction (drawing by Paul Bailly for the BRASS/El Pilar Program).

Justine Staneko's architecture dissertation (1996) is the first examination of this problem from an engineering standpoint since Roys pioneering work. She examined a sample drawn from Pollock's survey of Puuc architecture (1980) and chose to test 565 half vaults of which 181 vaults could be examined utilizing the two complete opposing vaults. In addition to Pollock's data she spent 15 weeks in the field over four seasons groundtruthing his measurements. One of the first problems encountered was that she could find no detailed architectural drawings of standing remains. Archaeologists will often draw sections or details of structures but often with drawing conventions for monographs. In looking for similar materials I found that the only data of this kind I could identify were collected by George Andrews in a large database, primarily of Puuc architecture. Unfortunately, Professor Andrews became ill and subsequently passed on during the preparation of this dissertation, making his database inaccessible. It is possible that another acknowledged expert in Prehispanic architecture, Paul Gendrop, also did such work though his publications utilize modern architectural renderings that convey style rather than detail.

Staneko also had to make some assumptions while modeling the structures. Her modeling formulas reflect Roys, since one of her primary goals was to test his modeling. In her conclusions, she acknowledges having had to examine Maya vaulting as a two-dimensional planar arch and speculates on other models as well as three dimensional computer modeling (which would entail the gathering of super-accurate architectural data in the field). She also calls for replicative experiments to examine construction methods and the action of structure parts first hand. Staneko examines, as did Roys, the Puuc architecture in the Yucatan.

My own biases in regards to Maya construction stem from the excavation and consolidation of structures at El Pilar in Belize, under the direction of acknowledged expert Rudy Larios Villata. The structural fabric (rather than cosmetic styles) of the vaults of the Puuc and the rest of the Maya world have more similarities than differences and, acknowledging this sample bias, the general engineering work can be applied throughout the Maya area.

Staneko found that there were no traditional corbel vaults in her sample. In a true corbel vault the two corbelled sides meet at the top, which gives the structure tremendous stability (Cotterell and Kamminga 1990). A corbel vault is considered stable due to the compressive force exerted downward by the mass above it. Maya vaults have been seen as two self-supporting half vaults with a capstone overhead. If the vaults are self-supporting there should be no horizontal forces operating in the structure. The data show that there are horizontal forces at work. A number of the vaults studied by Staneko turned out to be true vaults converting the weight into lateral thrust that exerts outward and downward force on the supports. A third set of structures were combinations, though close to true vaults, with one side stable and the other side unstable. None of the 565 vaults utilized in this study were found to act as monolithic. At best they were composites that would have been inherently unstable during construction.

Staneko points out that experimental replication, detailed architectural data and data from Maya areas other than the Puuc should be pursued. Her study does examine several traditional concepts of Maya vaulting. She found that the Maya did not build one type of vault, as viewed through structural engineering, but three (if you do not count the true arches which Lothrup [1925] said existed). Maya vaults do not act as monolithic concrete structures despite the specialized stone forms (like “boot” stones) that had been thought to operate in this fashion (Figure 6.3). She also found Maya vaults to be inherently unstable under construction and postulates that formwork (wood support work) would have been required.

Figure 6.3 “Boot-shaped” vault stones in a vault at Chichen Itza, Yucatan.

This area is, undoubtedly, one that requires a great deal more study by specialists. Staneko’s work highlights the importance of architectural and engineering studies by non-archaeologists. Just because a structure appears that it may act in a certain fashion does not mean that that is necessarily so.

So how were the vaults constructed? From the limited studies of this question it appears as if there was not just one method used but that there are some general rules. Pollock (1980) conservatively proposed three stages; 1) the construction of the wall and base molding, 2) the erection of the vault, and 3) the construction of the façade. I think it is safe to say that all researchers would agree with this scenario, as it would be impossible to build in any other order.

The walls would certainly have been built first although there is not any agreement on how. Staneko, using Pollock's data, found that in some instances the walls for an entire structure were built simultaneously before starting the vault while, in other cases, a sort of room module was used. In this second method an entire room was built, including the vault, before building the next (Staneko 1996). Before beginning the vault the walls were capped with a layer of plaster. This is consistent with the theory that sascab was often used as a consolidant (rather than lime plaster) and had to be protected from moisture (Pollock 1980; Tate 1992). Though a formal wall top has not been found to be universal the equivalent cold mortar line is often found (Loten and Pendergast 1984).

Above the wall top was the vault spring, the line from which the vault begins to rise. The lowest course of the vault, the springer, has been found in three varieties; inset, outset, or suppressed. Outset springers protrude outward from the wall. Inset springers form a small ledge above the wall and a suppressed springer shows no outset or inset. The outset variety appears to have been the favored although there are areas, notably the east coast of the Yucatan peninsula, where they are the exception to the rule (Smith 1940; Staneko 1996). The choice of spring style seems to have been of fashion or tradition. Spinden (1957) speculated that the shoulders of the spring were for formwork to hold the vault in place as it was built. Although there is still a great deal of speculation regarding the use of formwork, the spring would not have worked well in the way Spinden envisioned and his theory does not explain the many vaults with inset or suppressed springs.

The springer, as the stone forming the vault spring is called, often extended through the wall in one or both directions. This served to cap the wall off and further protect it from damaging moisture and also formed an offset within and/or a molding without (Brainerd 1954; Smith 1937; Spinden 1957; Prem 1995). In the consolidation work on Structure EP25 at El Pilar, you may note the large springer covering the wall in the lower left foreground and the second decorative offset on the inside of the building two thirds of the way up the vault (Figure 6.4). Structures in the Central Peten often used single large stones as springers, which is less common in other parts of the Maya area.

The two vault halves were often constructed separately as evidenced by pre-plastered capstones placed between them (Loten 1991). The vaults have three parts; the vault face or inner face, the façade or revetment on the outside of the building, and the infill (Juvanec 2003). The infills of the Maya vaults are very often divided

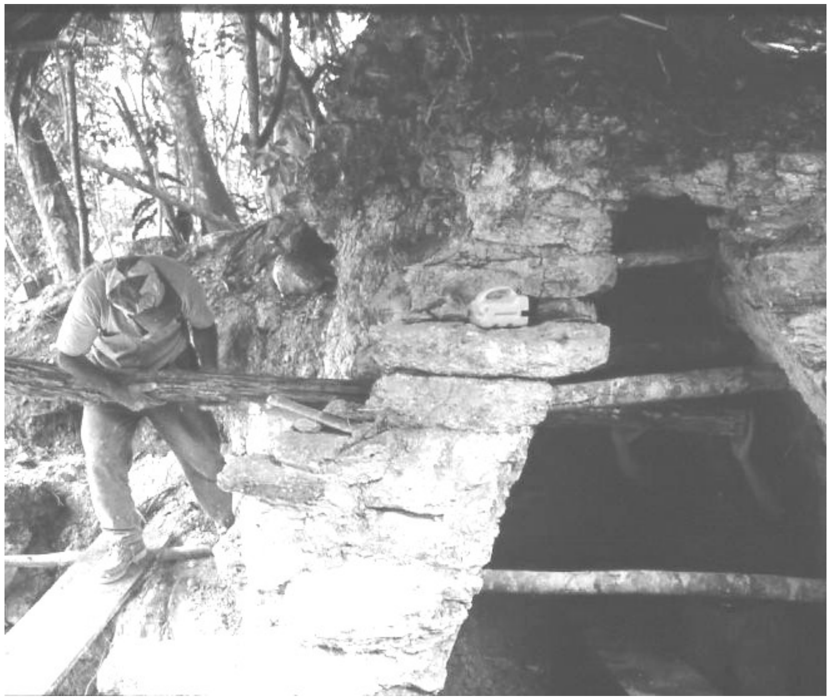

Figure 6.4 Consolidation work on Structure EP25 at El Pilar. The worker is installing replacement vault beams, note the meter long stone covering the entire wall top in the lower left foreground.

into two parts by the respaldo or vault back, a distinct plastered break partway between the vault face and the façade and finished roof surface. Loten (1991) suggests that a quantity of infill was placed on the walls and then a vault face stone placed and this sequence repeated until the top stone was placed. This assumes (and his diagrams show) a tapered or “boot-shaped” vault stone. The Central Peten architecture often has large stones separated only by mortar with the infill contained behind them. Either way, the vault was fairly rapidly built up without significant pauses that would show as cold joints (Pollock 1980; Loten 1991; Staneko 1996). During the consolidation of structure EP25 at El Pilar it was found that the increased mortar strength gained by 24 hours of drying (plus the added weight of the infill) was sufficient to hold the vault in place and allow further work. In many cases the back of the vault infill was then consolidated or plastered over forming another waterproof barrier (Morris 1931; Pollock 1980; Kowalski 1987; Loten 1991). The last part of the vault construction process was the spanning of the gap between the two vault sides with a capstone.

Once the vault was in place the façade was added. The break provided by the vault back made this a separate structural unit and it is common to see collapsed structures that failed along this joint. Once the façade was in place the rest of the roof could be constructed.

Before continuing on with a description of the construction process it is necessary to address the question of formwork and the role of the wooden crosspieces often found in intact Maya vaults. Wooden beams, usually of chicozapote or logwood, are found in most Maya vaults. Many of these members have long since rotted away leaving only sockets in the wall to indicate their presence. There are three basic schools of thought regarding these beams. The first is that the beams are nothing more than a holdover, a cultural survival, of the Maya wooden structures that predated the stone architecture. Another idea is that they formed part of a scaffolding or formwork necessary for building the vaults. Finally, there is the idea that the beams perform some essential structural function in the vaults.

That crossbeams are a cultural survival is an old and persistent idea. Edward Thompson outlined the idea in *The Genesis of the Maya Arch* (1911) and it still utilized today (Harrison 1999). The beams are thought to be either simply a holdover of the structural members used in the traditional beam and thatch architecture and/or have some utility purpose as a place to store items, hang hammocks etc. The Argument against this line of reasoning is that the members are simply too heavy to be utilitarian or a holdover (Roys 1934). Roys also looked at the idea of the lower beams holding an attic floor for storage but found that the spaces were simply inadequate to be explained that way.

Crossbeams as scaffolding is best illustrated by Loten's 1991 article entitled *Tikal Vaulting*. In it he describes a theoretical system of scaffolding members that hold up a central mast (Figure 6.5). The scaffolding is used to build the vault and then the mast and lower members are removed and the lower sockets plastered over. Although some have argued for a more complex formwork akin to that used to erect a keystone arch consolidation and reconstruction efforts have not found this necessary (Spinden 1957). The necessity of a scaffold for vault building has been defended by pointing to both the number and position of existing beams and the sockets for those that have rotted (Prem 1995; Staneko 1996). It has been noted that there do not seem to be a sufficient numbers of members to serve a structural function and that the placement of some, especially those found in the top foot or so of the vaults, would prevent them from serving a structural function.

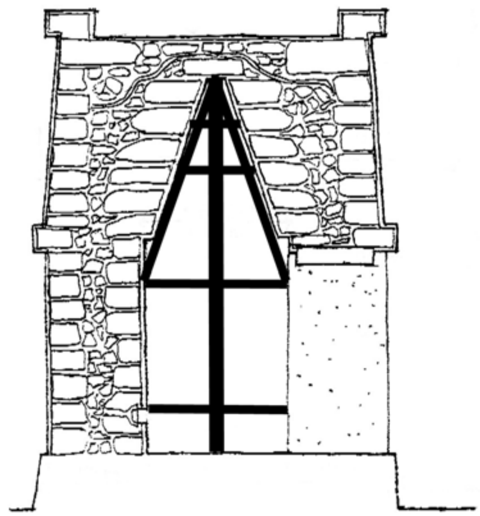

Figure 6.5 Loten's proposed scaffolding system for erecting Maya Vaults (drawing by Paul Bailly for the BRASS/El Pilar Program, scaffolding after Loten 1991 added by author).

There are many, however, who feel the beams could have added structural strength (Brainerd 1954; Kubler 1962; Roys 1934; Wurster 1991). Since lime mortar is slow to reach optimal strength the beams could have helped maintain the integrity of the vault halves while the mortar was drying. Roys noted that, for units often judged to be cultural remnants, the beams were almost excessively strong and heavily embedded – often more than 30". He discussed the possibility of the cross-beams serving as tension members and also adding strength against downward loading. To my knowledge there are no engineering studies of these beams. Anecdotal evidence from experts in the consolidation of Maya structures strongly supports the necessity of the beams to successfully re-erecting Maya vaults (Enrique Monterroso and Rudy Larios, personal communication 1997). Another indication of the Maya using these beams for structural purposes is the stone beam used to bridge the Maya vault over the Otulum at Palenque and those in the stairway and crypt of the Temple of Inscriptions (Kubler 1962; Marquina 1951; Wurster 1991). There is also significant evidence that similar crossbeams were often used as tension members in Byzantine architecture and medieval architecture (Ousterhout 1999; Wilcox 1981).

I strongly believe that these beams, in the mind of the builders, had several purposes. Masons working on consolidation today utilize the lower beams as a handy scaffold from which to build the vault halves. Although it is highly improbable that this much effort was expended to insert the beams to use for utility purposes (and there is the problem of the many small beams high up in the vault) they undoubtedly were used for hanging things simply because they were there. A detailed study, such as Staneko's study of vaulting, could answer the question of whether they served a useful engineering purpose. It should not be overlooked, however, that the beams may have served a *perceived* engineering purpose rather than an actual one (Pollock 1965; Andrews 1975). The skilled consolidators I have spoke to told me that you "had" to replace the beams before rebuilding the vault but, when pressed, could not say why. There is also a perception among archaeologists that they serve a structural purpose. One good example is the statement that vaulted structures at Aguateca collapsed due to the burning of their beams (Inomata, et al.

2001).

Vault stones come in many shapes and sizes. Evolutionary schemes showing a gradual change from rough slabs to specialized beveled stones have been devised and widely quoted (Brainerd 1954). While Maya vault stonework did generally get somewhat neater, (rough slabs to smoother interior surfaces) the shape of the stones themselves seems to have a lot more to do with local architectural preferences and traditions. Both large slabs and the so-called veneer-like stones have been found side by side in the same buildings (Pollock 1965). Generally speaking, the specialized stones set less deeply into the masonry heart tend to be characteristic of the Yucatan and Classic to Post Classic construction. George Andrews (1975) described a change from slab to veneer to monolithic concrete but, as was discussed previously, Maya vaults were never truly concrete vaults (Staneko 1996). Other variations included the clay bricks set in lime mortar found at Comalcalco, and large stones set in mud mortar at Copan.

Early Maya structures often have significantly thicker walls supporting the vault and heavier corbel masses behind them, which may indicate that Maya builders were unsure of the structural qualities. Later, they began to experiment with lighter walls, higher vaults and with various methods of lightening the corbel mass. Palenque, in particular, appears to have been a center for this sort of experimentation and we find voids cut into the vault masses and the development of Palenque’s distinctive “mansard” roof style that significantly reduced the mass of the façade (Figure 6.6, see also Figure 5.13). Maya builders were never comfortable with dry stone vaulting either. Though the earliest examples of Maya vaults tend to be dry stone tomb vaults these are small, tentative attempts at vaulting. Singular examples exist, such as a dry stone hemispherical vault roofing a tomb in structure EP11 at El Pilar, but these do not approach the dry stone corbelling of Mycenaean *tholos* or Italian *trulli* (Figure 6.7). Significantly, Maya sites that use exclusively dry stone architecture, such as Nim Li Punit or Lubaantun in Belize, do not have any vaulted structures.

Figure 6.6 The Palace at Palenque, Chiapas, note the mansard roof design.

Vaults also come in many shapes and sizes (Figure 6.8). The structural weakness of the system restricts spans to about 3 meters but vaults can reach as high as 9 meters (Structure VIII at Becan). Modifications to the basic design include the

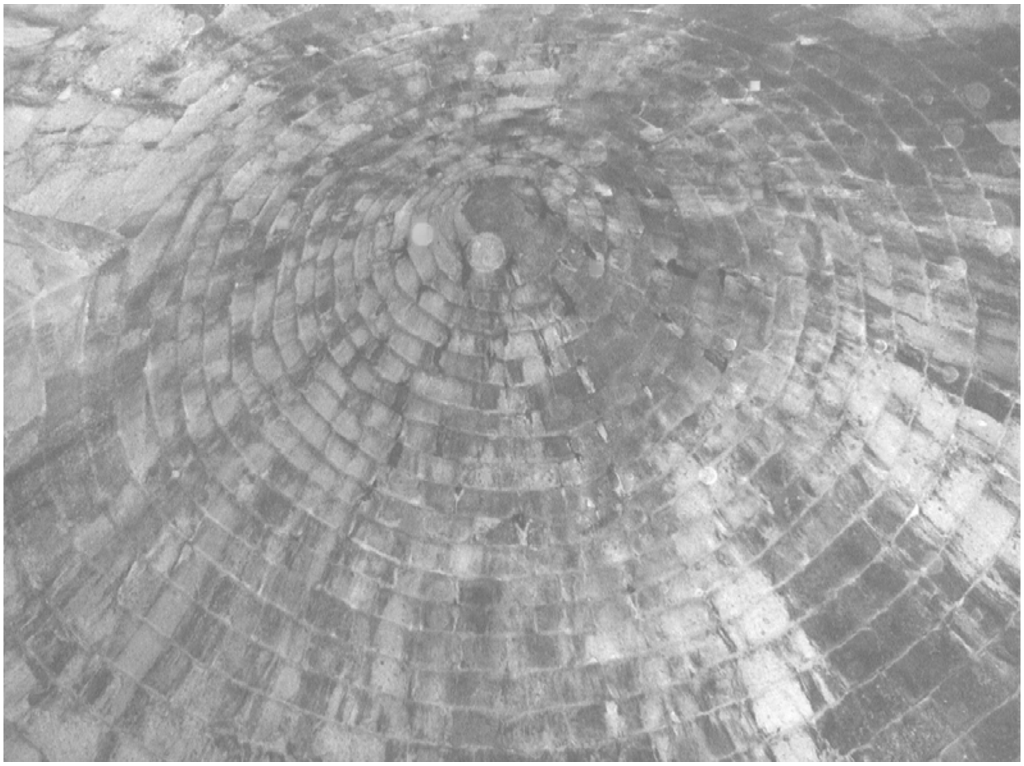

Figure 6.7 The ceiling of the Treasury of Atreus at Mycenae, Greece. An excellent example of a dry stone corbelled *tholos* tomb.

“bottle shaped” and the trefoil vaults at Palenque. Seriations of vaults in evolutionary schemes have suggested that the line of vaults go from irregular to stepped to straight to the more unusual curved varieties (Andrews 1975; Brainerd 1954; Pollock 1980; von Falkenhausen 1985). Yet, no evidence has been given that supports the varieties as anything but builder or local preferences. Tatiana Proskouriakoff depicted one unusual hybrid in her sketch of the Maya sweat bath P-7 at Piedras Negras (Proskouriakoff 1963). Her view showed a corbel vault with a beam and masonry roof replacing and spanning a wider space than the normal capstone (Figure 6.9).

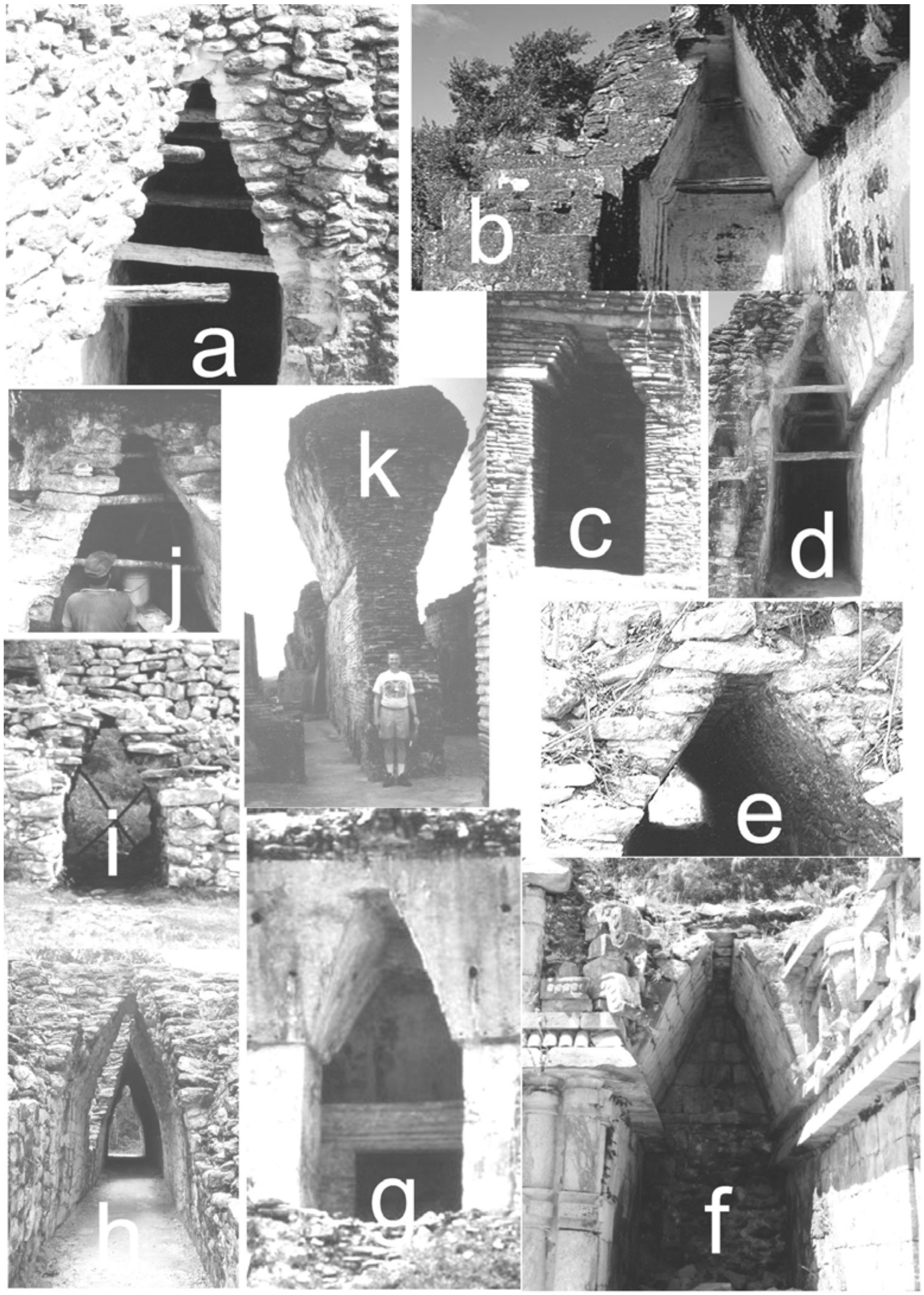

Figure 6.8 Maya vaults: a) Uaxactun, b) Tikal, c) Tonina, d) Uaxactun, e) Coba, f) Uxmal, g) Palenque, h) Becan, i) Tulum, j) El Pilar, k) Comalcalco.

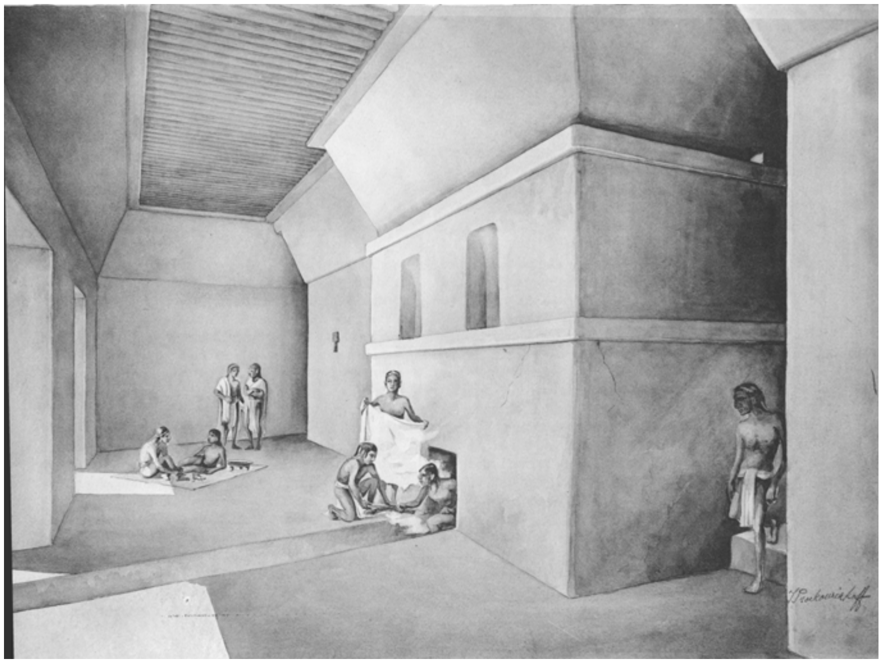

Figure 6.9 The sweatbath at Piedras Negras, note the half vault and flat beam roof (with permission, Proskouriakoff 1963).

Proskouriakoff's view of a hybrid roof illustrates that not all Maya structures were roofed with vaults. Perhaps partly due to the differential preservation of vaults versus other roofs the emphasis in architectural descriptions of Maya architecture has been on this one type of structure. The Maya continued to build structures that had stone walls and thatch roofs into the Late Classic. The beam and masonry roof depicted by Proskouriakoff may be even more important than the vault.

Beam and masonry roofs are often thought of as late introductions to the Yucatan (Andrews 1975; Andrews and Andrews 1975; Brainerd 1954; Totten 1926). They were thought to have been introduced by the Toltecs and, although allowing for larger interior spaces, to have been technically backward in comparison to vaults. George Andrews (1975) makes this point by noting that while there are still vaults standing, all the beam and masonry roofs have fallen. A more important point to the Maya would have been what roof served them better while they were in residence and not what happened after abandonment. The beam and masonry roof could provide much more interior space with less effort than the stone vault (Figure 6.10).

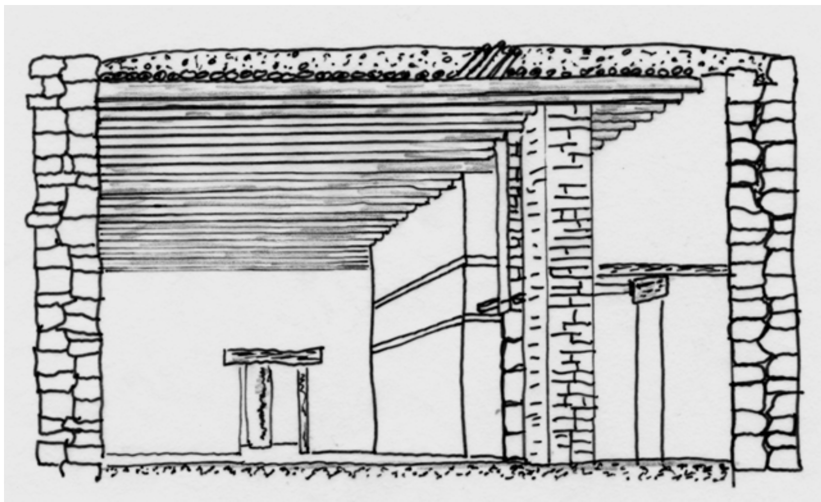

Figure 6.10 A flat beam and mortar roof at Tulum (after Lothrup 1924).

These roofs were not only confined to the Yucatan peninsula either. Brainerd (1954) places them throughout the Maya civilization in the highlands. They have also been assumed at Copan and in the dry stone constructions of southern Belize (Sedat and Lopez 2003; Thompson 1931). They also seem to have been prolific in the Petén as evidenced by roofs at Topoxte, Uaxactun, and Piedras Negras (Andrews 1943; Bullard 1970; Satterthwaite 1943). It is thought that this type of roofing system was used from the Preclassic on through the Postclassic and that it may have been more common than previously assumed. When Piedras Negras was abandoned in the mid-ninth century more than half of the roofs in the city could have been beam and masonry (Satterthwaite 1943).

Although remnants and standing beam and masonry roofs have been noted in the earliest studies, not much attention has been paid to them in studies of Maya architecture (Lothrup 1924). Some of the reasons for this may be that archaeologists have concentrated their work on better preserved architectural remains, that beam and masonry roofs were more ephemeral and have long-since disappeared, or that these roofs tended to be on less important structures and thus overlooked (Andrews 1943). Modern excavations, in the absence of shaped vault and cap stones, speculate on the existence of a perishable roof without further definition.

Generally, beam and masonry roofs would be constructed in several layers. First large beams or poles, depending on the span, were laid across the room and their ends embedded in mortar. Perpendicular across these a layer was laid of smaller poles or branches. In some cases a rubble layer similar to floor ballast was laid on top of these and then layers of lime cement were coated across the top to form a flat waterproof surface.

Roof Crests

This section is entitled “roof crests” rather than the more prevalent “roof comb” because crest is a more precise way of defining these structures and agrees with the Spanish term *crestería* that is in common usage (Gendrop 1997). *Crestería* is also seen in many European publications on Maya architecture and is akin to the English architectural usage of the term (see, for example, cresting on Queen Anne or

Second Empire architecture) (Harris 1993). As used, crest is a functional term emphasizing the meaning associated with a crest as an identifying emblem or device. Structurally they can be a number of things – walls, facades, and even towers.

There is no consensus on what roof crests may have meant or represented to the ancient Maya. The simplest attempts at explanation are that the crests serve as a means to strive for greater height or monumentality as a means of demonstrating the power of the Maya ruling class (Andrews 1975; Fash et al. 1992; Fash 1998; Lothrup 1924) (Figure 6.11). They can be huge additions to already tall structures; the roof crests on the Temple of Inscriptions and Temple V at Tikal are 13 meters high (Coe 1988; Quinones and Allende 1974). Surviving roof crests are often covered with decoration, glyphs, and symbology which are unlikely to have been just incidental to the structure. The roof crest on Temple of the Inscriptions at Tikal, for instance, has one of the longest extant Maya inscriptions. It is probably more likely to suppose that the crest was built to hold the sculpted text rather than that the crest was built for another purpose and made a convenient surface for the long text. Of course, this is a simplified argument and it is likely that more than one meaning was embodied by the structures.

Another hypothesis is that crests served as a visual device that set aside the

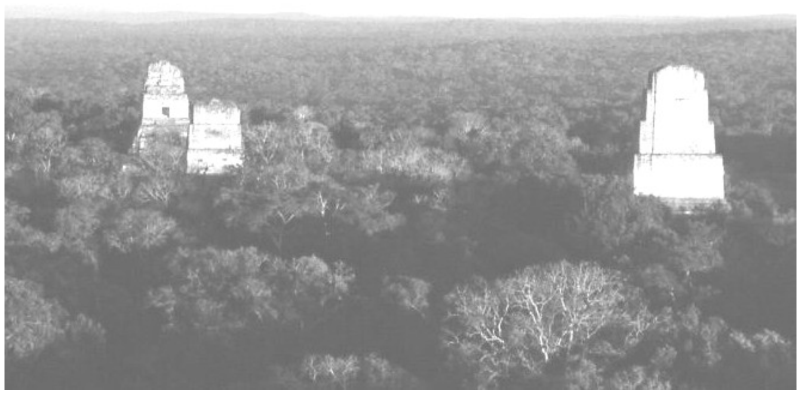

Figure 6.11 A view of Temples I (left background), II (left foreground), and III (right) at Tikal, Guatemala.

structure as “ritual” or “temple” much like a church steeple or minaret (Harrison 1999). Depictions of roof crests at Teotihuacan, for instance, show elaborate constructions of perishable materials such as feathers, wood, and reeds topping significant buildings (Sejourne 1966). Iconographic signifiers are thought to mark the Rosalila temple at Copan, for instance, as a “house of smoke” or ancestral temple (Agurcia Fasquelle 1998). These perishable signifiers may have been large versions of headdresses or backracks certifying the importance of a particular structure the same way these objects would for a person (Taube 1998).

Roof crests may have been icons emphasizing some aspect of the actions taking place in or around a structure or the person who had it built. One suggestion is that crests represent a scaffold from which Maya kings symbolically entered the sky ritually celebrating the rebirth of the Hero Twins and their victory over death

(Suhler and Friedel 1994). Fitting with this theme is an interesting reconstruction of the stucco sculpture facing the Temple of the Seven Dolls at Dzibilchaltun that includes a serpent (sky?) on the roof tower (Coggins 1983). It could be that structures with crests may have been more monument than structure. McAnany (1998) argues that many of these structures are *muknal* or burial shrines, the crests being in effect large tombstones proclaiming their worth and deeds. The fact that many of the crests that still maintain much of their sculpture, or where there is enough to reconstruct, have large seated figures of Maya Lords as their centerpiece may support this idea. Good examples of this are structure 10L-22A at Copan, Temple 33 at Yaxchilan and the reconstruction by Merle Green Robertson of the Temple of the Cross at Palenque (Fash 1998; Griffin 1980; Tate 1992). Many of those whose stucco has long vanished also appear to have throne-like structures in the center position (for example, Temple V at Tikal) (Quintana and Noriega 1992)(Figure 6.12). Gendrop (1998) noted that this was the rule for roof crests throughout the Yucatan peninsula. The long surviving text on Temple VI at Tikal supports this idea as it glorifies events in the reign of Ruler Yax Kin. A hypothesis akin to this last is that they may be propaganda reinforcing the rulership much like stelae on a larger scale (Griffin 1980).

The earliest roof crests in the Maya area may have been made of perishable materials (Griffin 1980). Like other architectural developments by the Maya they may have been heavily influenced if not directly borrowed from their neighbors to

Figure 6.12 A stucco seated figure at Balaam Ku, Campeche.

the north. Mezcala (modern Guerrero, Mexico) stone architectural models from the Late Preclassic show crest like appendages on the roofs of temples (Miller 1986). The Maya certainly had a relationship with Teotihuacan and reconstruction drawings of structures there have crenellation like cresting (Coe 1988). One Teotihuanaco ceramic incense burner in the form of a temple clearly has feather-like fans on the roof (Sabloff 1989).

The principle problem in trying to trace the development and construction technology of roof cresting is the fairly limited number of examples. The earliest examples were undoubtedly of perishable materials and have not survived. Wauchope (1938) reported that Sapper had seen a thatched Lacandon shrine with roof decorations of bird feathers and monkey skulls. The earliest possible physical remains in the Maya area may be Late Preclassic clay-modeled figures from a temple at Kaminaljuyu (Griffin 1980).

Even when the Maya used stone construction, we do not have much evidence for the crests. Structures were routinely leveled to the platform level and incorporated into new, larger structures (Kramer 1935; Griffin 1980). A rare example of the entire structure, including crest, being preserved is the Early Classic Rosalila temple at Copan (Agurcia Fasquelle 1998). Another factor is that both vaulted and beam and masonry roofs were inherently unstable in the long run so while wall masonry may be preserved, most roofs and roof structures have not lasted. We can tell, however, that roof crests were in much greater abundance than the surviving examples. In architectural graffiti on 140 bricks from Comalcalco almost all depict roof crests (Andrews 1989). Depictions in other genres, ceramics, painting, and sculpture, also show most structures with crests (Houston 1998a). Lastly, in areas previously thought to have not adopted roof crests, such as Copan, early and excellent examples of roof crests have been found after further excavation (Spinden 1957; Agurcia Fasquelle 1998). The surviving roof crests are made up of fitted stone blocks and mortar and rarely contain any of the rubble fill used throughout Maya architecture (Figure 6.13) (Roys 1934). This may be a question of survivability; roof crests constructed with rubble fill may have long since crumbled.

As with most Maya architectural elements there were several early attempts at developing, from the scant evidence at the time, evolutionary development

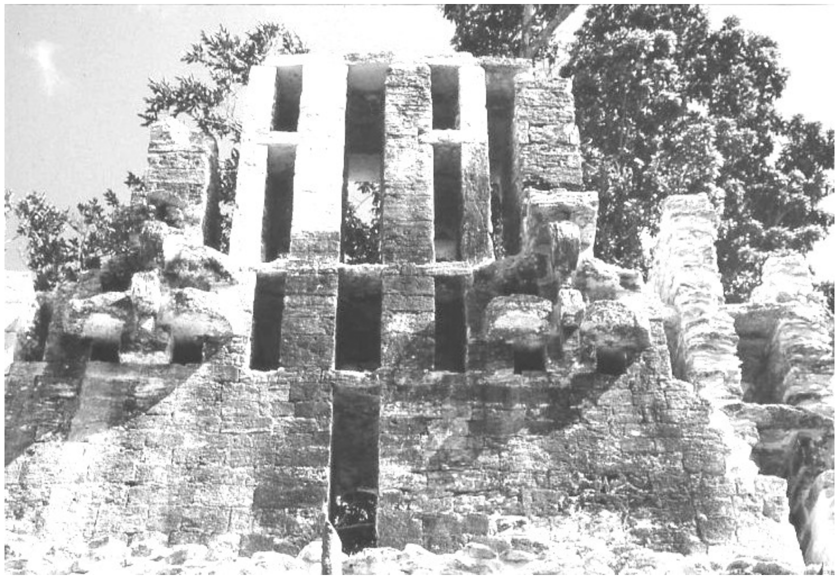

Figure 6.13 Stonework on a roof crest at Xuphil II, Campeche.

schemes for roof crests. Most favor a similar scheme of development of massive crests in the central Peten (Tikal) with a gradual change toward lighter structures (hollows, piercing) culminating in the latticework crests found at Palenque (Lothrup 1924; Kramer 1935; Spinden 1957). These plans were built on primarily the subjective aesthetic of the crests, as they currently exist. All agree that the light lattice-like Palenque crests are the culmination of this development and, as Kramer (1935) put it, these are the only crests that were built integral to the structure.

There are multiple problems with these ideas. Firstly, they are not objective views of the evidence at hand even prior to the 1960's. Secondly, the general idea of a south to north diffusion starting in Tikal ignores the chronological evidence. The evidence that the ideas for many Maya architectural components were borrowed or influenced by groups in modern Mexico has already been discussed. Add to that, the standing evidence, Early Classic roof crests at Yaxchilan and Copan (Str. 6 and Rosalila), 7^{th} century AD crests at Tikal (Temple I) and Palenque (Temple of the Cross, and 8^{th} century AD crests at Tikal (Temples II and IV) and Yaxchilan (Structure 33). Despite Kramer's claim (1935) that Palenque's roof crests were the only integral ones, I know of no existing roof crests that show discontinuities between the roof of the structure and the body of the crest that would indicated that they were added. In other words, the roof crests were part of the original concept of these buildings and built as a part of them and not as an afterthought. Steirlin also believes that the crests are a "…decorative addition …intended to lighten the appearance of a sanctuary or palace" (Stierlin 1997:232).

There are prevalent regional roof crest styles. Gendrop (1998) has drawn a map of the styles as he has defined them including sites with possible and undetermined roof crests (Figure 6.14). His three major styles are: "Peten-style" with a heavy superstructure and resting on the back of the roof, "Palenque" with light structure resting on the center of the roof, and "Peninsular" with a thin simple superstructure resting on the front of the roof. The map shows Peten-style roof crests in Belize, the Northeast Peten, and the immediate area around Calakmul. The Palenque Style appears primarily along the Usamacinta drainage. The Peninsular style extends from the Rio Bec area in the south of the Yucatan Peninsula up through the Chenes and into the Puuc area. Note that Gendrop's definitions hinge on the size of the roof crest and its placement on the roof.

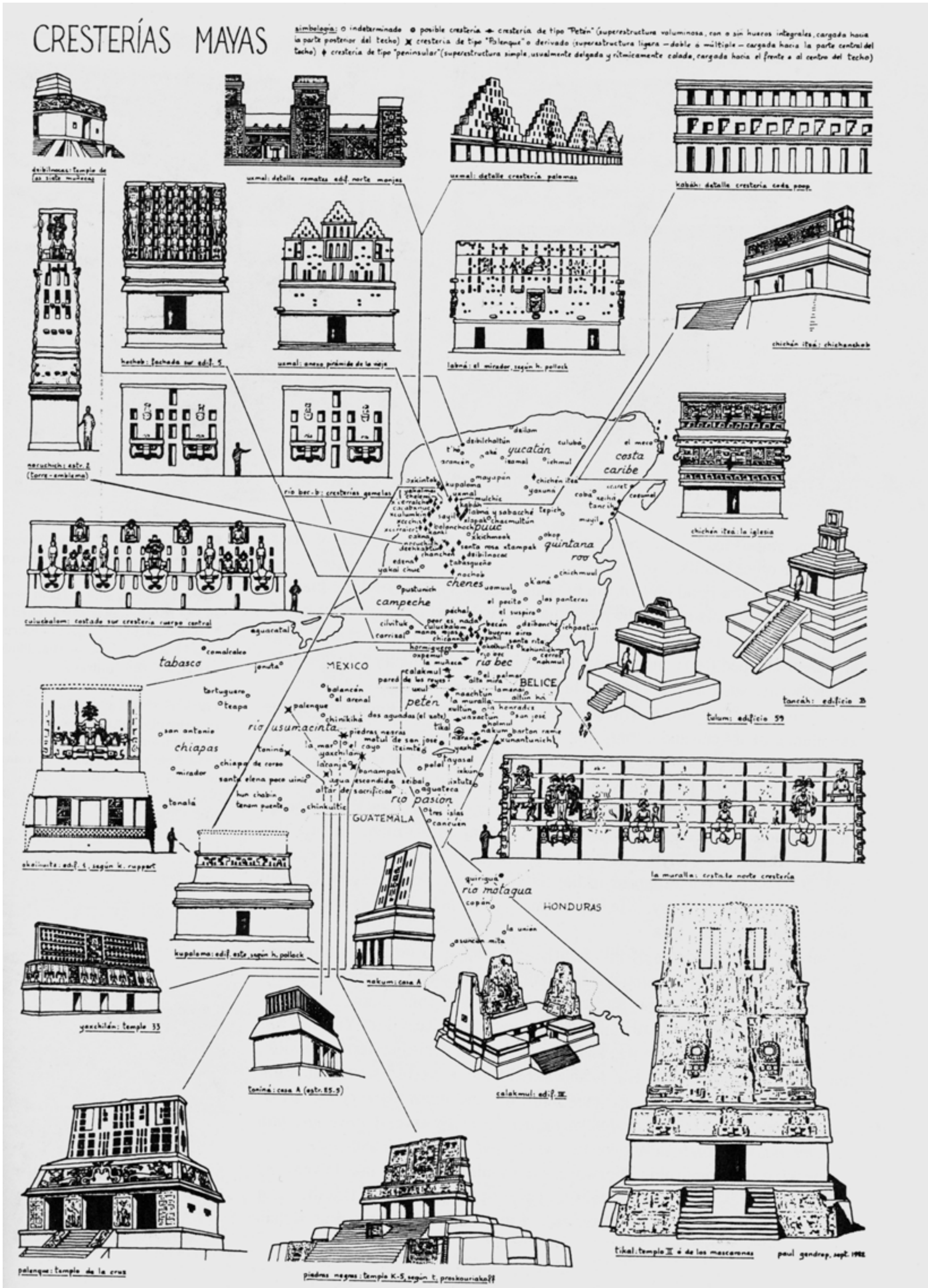

Figure 6.14 Paul Gendrop's map of roof crest styles (with permission, Gendrop 1998).

The crests are not only integral to the design but, if these are *muknal,* or ancestral shrines, then they play the crucial part of telling the public whose shrine it is. Some, especially Gendrop's Peten style crests, are very massive. Figure 6.15 shows the roof crest of Temple I at Tikal in profile. The superstructure and crest on Temple I rise 15.45 meters and the vast bulk of the crest is over two of the three narrow interior rooms (Quintana 1995). For Kramer this design was "entirely impractical." Though the crest rises straight up from the back it rests evenly from the back of the structure to mid-roof which Kramer felt was structurally unsound. Most of the specific studies of roof crests hold that as Tikal's builders learned, they began to include hollows in these massive structures to lighten the load. Yet Temple V, the earliest of the five crested pyramids at Tikal's heart, is the only one with these hollows (Griffin 1980; Kramer 1935; Spinden 1957). Contrast this, however, with the three "Peninsular" roof crests in Figure 6.16, which clearly rise directly above the face of structures and you, get the gist of Gendrop's seriation. The point is that his seriation is not entirely a structural argument; there is a significant aesthetic bias.

The Palenque style roof crests take somewhat of an architectural middle ground. They have been extolled as light and airy though the Peninsular roof crests are much lighter both structurally and aesthetically. The Palenque crests are quite solid double-walled structures with a trellis-like look (Figure 6.17). They have window "shelves" and pegs for the support of stucco ornamentation and even sometimes an internal staircase for maintenance (Griffin 1980; Pollock 1980).

Figure 6.15 The roof crest on Temple I at Tikal, Guatemala.

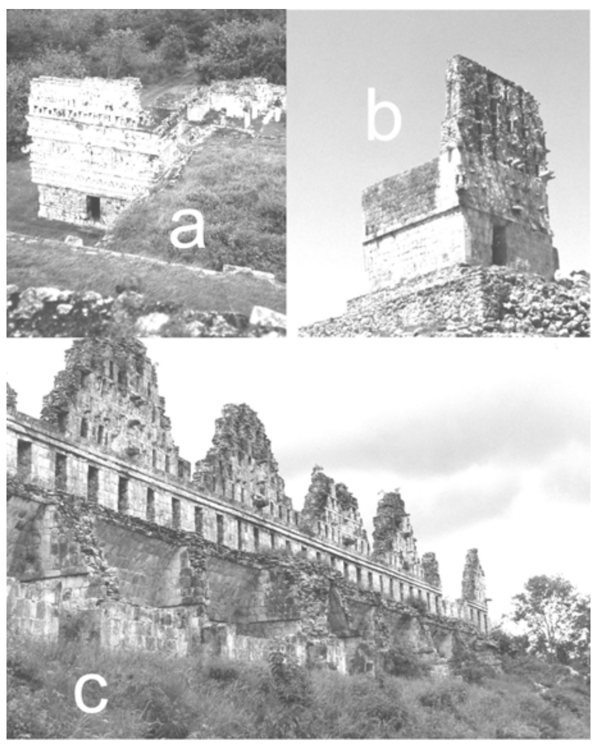

Figure 6.16 "Puuc style" roof crests at a) Chichen Itza, b) Labna, c) Uxmal.

Figure 6.17 Side view of roof crest construction at Palenque, Chiapas

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Keeping in mind that they were heavily decorated and brightly painted, the Palenque style crests are scaled somewhat smaller on the average than the other styles (Figure 6.18). The crests on the five large pyramids in “downtown” Tikal or the crest (Figure 6.16b) on the pyramid at Labna would probably have made a greater impact on viewers from below.

Although there are regional favorites there also seems to be some experimentation going on. Yaxchilan, for instance, has a bit of every style. Structure 6 has a nearly solid double-walled roof crest rising over the middle room, while Structures 33 and 40 have more open latticework double-walled crests. Structure 21

Figure 6.18 Front vew of roof crest construction at Palenque, Chiapas.

had a single wall rising over the façade and Structure 23 had a single wall rising over the center (Tate 1992). Solid partition walls at Yaxchilan have been interpreted as reactions to the failure of roofs bearing roof crests (Kramer 1935; Spinden 1957). It is lucky that Yaxchilan has a number of standing crests and has been well recorded. Crests were a heavy burden on top unstable vault structures of which the more massive survive.

Another variation on the roof crest may be tower like structures. Several towers have been recorded in Yucatan, some with lattice combs on top and armatures for stucco sculpture (Tichy 1992). Another, at Nocuchich, has a monumental stucco face on one side (Andrews 1997; Gendrop 1998). These are not structurally that far from the three tower-like crests at Nakum (Marquina 1951). The tower like structures on the Temple of the Seven Dolls at Dzibilchaltun and the Rosalila Temple at Copan are also in this tower crest tradition (Figure 6.19).

Figure 6.19 Tower-like construction on the Temple of the Seven Dolls at Dzibilchaltun, Yucatan.

Summary

Maya vaulting in monumental structures has become an important part of both the popular and archaeological view of Maya architecture. Vaults are portrayed as evidence of advanced architectural knowledge or as a technological leap. While the interplay of materials in Maya vaults is complex and they are difficult to mathematically model they are neither unique to the Maya nor difficult to build. Modern structural analysis indicates a Maya lack of knowledge of materials mechanics and a subsequent tendency to grossly overengineer structural parts to avoid failure. Maya vaults took little specialized knowledge to build and could be easily built with the labor force at hand.

Not all Maya structures were vaulted yet, partially due to preservation issues, perishable and beam and mortar roofs on monumental structures have been given little attention. It may be that a majority of roofs on large Maya structures were in this latter group.

Crests or *Cresteria* were examined as an integral part of a Maya roofing system. Roof crests are widespread and the different construction methods and overall styles do not seem to follow any chronological/evolutionary path. Crests, which may have included a variety for perishable roofs as well as towers, may have served as; 1)functional identifiers, 2) powerful symbols, 3) ancestral monuments, 4) political propaganda, or 5) ruling class reinforcement.

Chapter Seven will examine the tools that the Maya would have used in the construction process. This will take us from the layout of a structure to obtaining and utilizing building materials and, lastly, the decoration and finishing work.

Chapter Seven

Tools

Man is a tool-using animal… Without tools he is nothing, with tools he is all.
Thomas Carlyle

A quick scan through web pages on the Maya today turns up some of the same phrases again and again. High on this list is some variation on the theme of the Maya doing all they did despite their lack of the wheel, beasts of burden, metal tools or pulleys (also often used for the ancient Egyptians). It can be an ethnocentric argument that is often used to add mystery and awe to the modern myth of the "mysterious Maya." These tools, which we take for granted, were not necessary for the construction of Maya structures and monuments though they might have been useful. Their lack, however, did not make the job appreciatively harder. The Maya were very skilled at using available materials and tools to their best advantage and selecting for those that worked.

Survey, Layout, and Measurement

As far as surveying and the layout of structures is concerned, a great deal more sophistication is assumed for the ancient Maya than is supported by the available information. Much has been made of supposed archaeoastronomical alignments and possible geometrical relationships (Ashmore 1991; Aveni 1980; Aveni and Gibbs 1976; Aveni and Hartung 1982; Broda 1982; Brown and Witschey

2003; Carlson 1972; Fuson 1969; Hammond 1972; Hartung 1981; Houk 1996; Ricketson 1928; Ruppert 1940; Vinette, 1986). While questions remain about the validity of some of these, what is apparent is that the Maya would have needed instruments no more powerful than their eyes and a lot of patience to gather the astronomical information (Aveni 1980; Kohler 1991). Friedel and Suhler (1999:251) argue that Maya architecture is a model of what “master builders can achieve with simple tools and good organization.” No recognized Maya surveying tools have yet been found, but the possible existence of some can be surmised.

The simplest tools used were probably body parts used for measurement purposes (see Chapter 3). There are many depictions of a Maya glyph, for instance, that have been interpreted as the representation of the word for “hand span” and perhaps involving a distance standard in the ballgame (Macri and Looper 2000; Zender 2004). Arm length and arm span were probably used as well for structure measurements. The use of the human foot and pace are also reflexive measurements commonly used today.

The Maya may have used a number of simple instruments for the layout of buildings. The only one we have good evidence for is the rope as a measurement device, though none has survived archaeologically. Historically, the Maya have been known to use ropes to measure out land parcels in *mecates* (from Nahuatl *mécatl*, rope or lineage), roughly 20-21 meters square (Gendrop 1997; Steggerda 1941). One interesting possibility, based on the base measurement of 155-164 cm discussed in Chapter Three, is that 162 cm multiplied by 13 would give one a 21 meter rope.

The number 13 was of great importance to the Maya as evidenced by the thirteen gods and periods of the Tzolkin calendar. There is also preconquest evidence from the Mayas northern neighbors, the Mixtec. The Mixtec Codex Vidobonensis, for example, depicts two people using a rope for measurement of an object, possibly stone for a structure (Figure 7.1) (Ferdinand and Pérez Jimenez 1992). The Maya certainly made and used rope, as evidenced by numerous depictions of roped captives and rope used in blood-letting ceremonies. It is possible to plan very sophisticated structures with simply a rope and stakes. The Egyptians may have surveyed the pyramids in this fashion and the Greeks called Egyptian surveyors *harpedonapata* or “rope-stretcher” (Calvin 1997; Clarke and Engelbach 1990). It is a logical, though by no means conclusive, assumption that they would have used rope for measurement.

The Maya may also have utilized an instrument for measuring vertical angles similar to a medieval navigation instrument, the cross staff or Jacob’s staff. The cross staff consisted of two pieces of wood of different lengths mounted perpendicularly on a calibrated rod (Figure 7.2). Sighting over the smaller piece and aiming at the horizon, the longer piece is adjusted until it appears to just touch the object in question and the angle could then be read off the base. Used as a navigational instrument it measured the altitude of celestial bodies and the Maya may

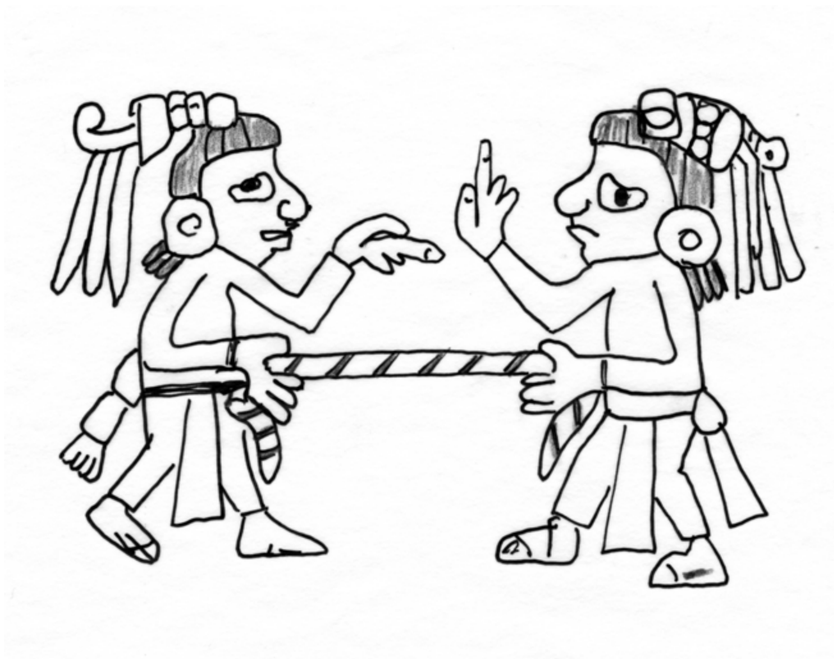

Figure 7.1 Two figures measuring with rope from the Mixtec Codex Vindobonensis (after Ferdinand and Pérez Jimenez 1992).

Figure 7.2 1986 Netherlands stamp illustrating a cross staff.

have used it for similar measurements. Aveni (1980) has made this suggestion based on a number of depictions of Maya priests apparently sighting over crossed sticks. Even without the calibration, a device like this could be used for making comparative measurements. A cross staff would also have worked well to maintain a consistent slope on a pyramid.

A surveyor's rod would also be a logical possibility for a Maya tool kit. A wooden pole or rod may have been used by the Aztec for sighting and could have been common throughout Mesoamerica (Aveni 1980). The rod could be used as a gnomon (like the pointer on a sundial), which is useful to make alignments, based on the sun and north-south, east-west alignments. Gnomons would be as easy to use for aligning structures and for longer distance projects like sacbeob. By A.D. 725 the Chinese had laid out a 2,500 km meridian line using gnomon (Calvin 1997). A surveying rod can also be useful for marking out smaller plots of land or architectural elements utilized as a measurement tool. Laying standardized poles end to end can be done with a great deal of accuracy (Clarke and Engelbach 1990).

Some authors have suggested that it would be natural for the Maya to have possessed a water level (Hammond 1990). Guerra (1969) reports that the Aztec construction tool kit contained one, but the Nahua word he offers for it, *atezcatl,* Sahagun and Molina translate as a word for a pond or water gates (Sahagun 1969; Molina 1970). Early excavators felt that there was a complete “lack of leveling instruments” (Morris 1931:209). Levels and squares are often confidently listed as part of the Maya tool kit but given the nature of the remaining structures and the frequent lack of decent foundations it would be very difficult to prove or even surmise leveling instruments other than sight from the surviving architecture (Eaton 1991; Hammond 1990).

Digging and Quarrying

The single most important tool for digging and quarrying was evidently a digging stick. Excavations of quarries have found quarrying marks of long stick-like implements and experimental archaeological study has duplicated these marks (Woods and Titmus 1996). Again, although no intact tools have been found, the evidence points to two or three varieties of this tool. One was probably a simple pointed stick not unlike a modern dibble. This may have had a fire-hardened point though many of the tropical hardwoods available to the Maya would have stood up to the work well. A second type may have had a spatulate end like the *coa* used in milpas today by the Maya (Shook and Kidder 1952). The last may have been a variety with a hafted elongate chert biface on the end of it (Figure 7.3) (Woods and Titmus 1996). The hafted pick was subject to prolonged experimental usage at Nakbe and the resulting quarry marks matched those found in the walls and block channels of excavated ancient quarries. Interestingly, modern hand quarrying is often done with a *barreta*, a hexagonal 4-foot steel wrecking bar weighing about 7 lbs. (Cook 1973). Quarrying experiments (for consolidation stone) done at El Pilar were

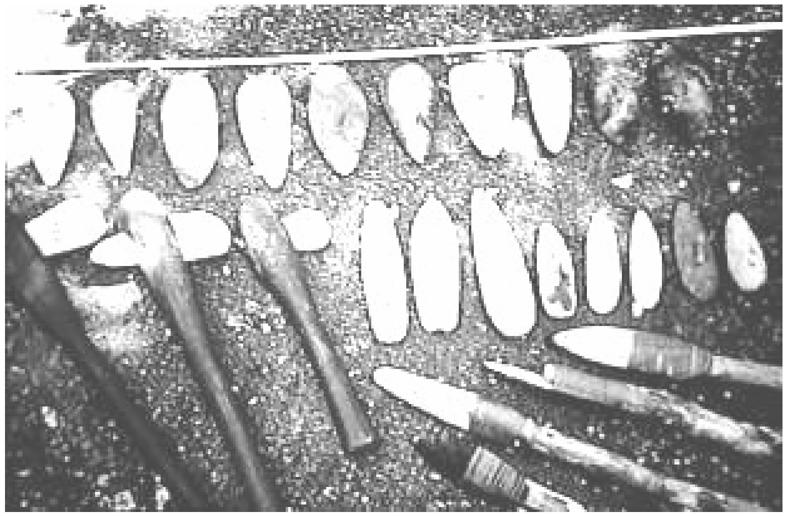

Figure 7.3 Selection of replicated tools used at Nakbe (with permission, Woods and Titmus 1997).

done with the barreta which was used in the same manner as the picks used at Nakbe. Shook and Kidder (1952) noted a perplexing absence of the so-called “donut stones” which are thought to be digging stick weights, but they do not seem to have been universally used. Quarry excavations have revealed the long parallel marks of digging sticks and a weight on the stick would have made it difficult for the stick to have fit into the block channels in the quarry (Woods and Titmus 1997).

Another tool found useful in quarrying experiments was a hafted axe (Woods and Titmus 1996). Both hafted stone axes and the tapered ovate bifaces that formed the head have been found archaeologically. The most notable, the “Puleston” axe was found in a canal in northern Belize and was probably being used for agricultural work when it was lost or forgotten (Puleston 1976; Shafer and Hester 1990). Woods and Titmus (1996, 1997) found these to be very useful for the rough layout work in the quarry and, subject to experience; they had a lower breakage rate than initially surmised. Other experimental work had found high breakage rates for the handles, but that also is subject to experience and probably also contingent on the type of wood used (Lewenstein 1987). The US Forest Service, for instance, devotes a lot of text to ax handles which ideally should be second-growth hickory which is all white in color and has less than 17 annual rings per inch of radius (Weisgerber 1999). I think we can be certain that the Maya would be no less demanding for their tools. Even before intact hafted axes were found, there was an assumption that certain types of bifacial celts were used for construction work (Morris 1931; Shook and Kidder 1952). Eaton (1974) thought that shell celts may also have been used as hafted axes in places along the coast of the Yucatan Peninsula without good tool stone. As in the case of the digging stick a modern equivalent, the hatchet, is often used to shape stone (Figure 7.4). Once a block had been removed from the surrounding matrix it is possible that the Maya may have used unhafted or obliquely hafted (mattock like) bifaces to roughly shape or trim it (Woods and Titmus 1996).

A common tool assemblage in ancient quarrying around the world includes a selection of stone hammers and mauls (Forbes 1966; Ward-Perkins 1971). Although larger stones for battering are not necessary with soft limestones, they were probably used to shape trachyte, dolomitic limestones, and harder stones. Tools in this category have been found in quarries at Nakbe and in Central Mexico (Outwater 1957a; Woods and Titmus 1996).

Figure 7.4 Shaping limestone blocks (with permission, Hernandez 1992).

Like digging sticks, a wide variety of perishable tools have been suggested for Maya quarrying operations. Some have been surmised from marks left in quarries and on building stones while others stem from speculation as to how jobs could be efficiently carried out. In the first category are bone picks and wood chisels (Morris 1931; Shook and Kidder 1952). Both are feasible quarrying tools, their presence may have been suggested by the long narrow grooves left by long handled picks. Other suggested tools are wooden mallets, mattocks, shovels, and pallets (Morris 1931; Outwater 1957a; Shook and Kidder 1952). Tools like these have been used historically worldwide but, short of finding intact examples, difficult to confirm for the ancient Maya. There is one perishable tool that is a near certainty and that would be levers. The excavated quarries at Nakbe show clearly that the Maya used the channeling method for excavating stone and strong wooden poles would have been necessary to break the blocks loose from the underlying matrix (Daumas 1969; Woods and Titmus 1996; Woods and Titmus 1997). The modern Maya still excavate volcanic tuff near Copan using levers, wedges, and heavy hammers (Wummel 2002).

Transport

The transport of materials was probably rudimentary. Tools and materials such as wood would be carried by hand. Baskets or woven bags would be sufficient to move soil, rubble, and sascab (Shook and Kidder 1952). A polychrome vase in the Boston Museum of Fine Arts has the figure of a Maya god with a backpack-style basket complete with tump line (Figure 7.5) (Robicsek 1981). The tump line is an important technology that more evenly distributes a large load across the body making it easier to carry. There are also fragments of tightly woven baskets from the Cenote at Chichen Itza (Coggins and Shane III 1984).

Figure 7.5 The Lord of Hunting carrying a basket or net backpack (with deer) using a tump line (after Robicsek 1981)

The question of how lime was delivered to the job site is a problematic one. If we assume that the Maya were slaking most of it on the jobsite to avoid transporting the water weight then they would have had to deal with transporting a highly caustic material. Barba and Frunz (1999), for example, have estimated that lime was being transported to Teotihuacan from over 60 km away. They state that the lime may have need special packing due to its corrosive properties. I believe this to be a gross understatement of the problems involved. Quicklime draws moisture from human skin and can cause severe alkali burns. Should it get wet along the journey, it very quickly generates such tremendous heat that the container may burst into flames. Ships carrying cargoes of lime have burned due to small leaks (The Manufacturer and Builder 1893).

Another transport problem involves the use of lime putty. Consolidation work today and, presumably, Maya plaster work (especially the architectural sculpture) often demands the use of lime putty. Lime putty is usually a high calcium lime that has been kept covered by water for a long period of time producing a buttery, highly plastic material. Lime putty is “fat,” it holds more water, and is slow-setting (Holmes and Wingate 1997). Ideally lime putty should be aged for at least four months and periods of more than a year are considered ideal. A modern 5 gallon bucket will hold 80-90 lbs. of lime putty. There are indications that the ancient Maya used lime putty and it would have to have been stored and transported in water resistant containers, probably ceramic (Hansen 2000).

The Maya could have used a wooden carrier like a hod used for carrying bricks and ashlars. The hod is a wood framed backrack (Figure 7.6). We know very little about the woodworking traditions of the Maya outside of building lintels and a few waterlogged artifacts (Coggins and Shane III 1984). The Maya have depicted boxes in ceramics and paint and a hod-like carrier would have been an efficient way for a single person to carry one large block or multiple small ones. Hods are used today by the Maya in the Guatemalan Highlands to carry ceramic pots to market (Anabel Ford, personal communication 2004).Modern bricklayers (and their assistants) routinely carry a dozen bricks per hod or about 50-60 lbs. at a time.

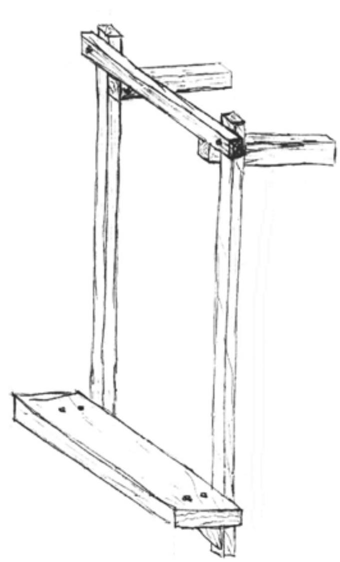

Figure 7.6 A hod for carrying bricks or blocks. It goes on the back while the hands hold the top handles over the shoulders, bricks and blocks are stacked on the shelf.

The most efficient way to carry large ashlars, given no labor restrictions, is in a litter. In the Nakbe quarry experiments, a simple litter was constructed and eight workers carried a block weighing over 500 lbs. 600 meters to the work area (Woods and Titmus 1997). There may be some correlation between quarry sites and causeways, being close enough to use a causeway from quarry to job site can help a great deal (Cobos and Winemiller 2001; Folan 1982; Hansen et al. 2002; Winemiller 1997; James Woods, personal communication 1999). We know that the ancient Maya had and utilized litters as there is a great deal of iconographic evidence as well as litters found archaeologically (Houston 1998a).

Lastly, there is possibility that the Maya used rollers or sledges for moving large blocks of stone (Heizer 1990). There is no direct evidence for this either archaeologically or iconographically, but they are simple enough expedients that they may have been used. Some monuments in Mesoamerica are simply too large to have been moved in any other fashion. The largest stele at Quirigua weighs 35 tons and some stones at Mitla approach 40 tons (Outwater 1957a). What are thought to be compaction rollers have been found on Maya causeways and, as a people accustomed to logging, the concept would not have been foreign to them. Sledges may have been very difficult to use, particularly in the rainforest, and would have heavily damaged causeways if used on them.

Masonry

There is not much written on Maya masonry tools but, what little there is, illustrates a problem facing architectural analysis. Three articles that address “mason’s tool kits”, for example, address primarily plastering tool kits (Andrews and Rovner 1973; Eaton 1991; Rovner and Lewenstein 1997). Although a person who does plastering can be called a “stucco mason,” it is a title infrequently used and confusing in the context of architecture. There is a significant task difference between those who built the walls, those who plastered over the walls, not to mention those who decorated the walls with stucco relief and sculpture. These are three different skill sets and, with a few overlaps, should be indicated by separate tool kits.

One of the primary tools for stonemasons would be a tool for trimming the blocks to size. Modern workers use a hatchet, medieval masons used a tool called a jedding axe or kevel, and the Maya probably used hafted stone hatchets (Lewenstein 1987; Andrews 1999). A stone or wood mallet would be used for bashing what could not be trimmed with the axe, particularly the inclusions often found in limestone (Daumas 1969). The tools used to trim the blocks at the site would generally be the same used in the final stages of quarrying. In the Postclassic some metal tools may have been available as well. Copper axes, one well-used, and chisels were found in the cenote at Chichen Itza, but it is doubtful that these ever played a large role (Coggins and Shane III 1984).

It is often suggested that the Maya mason used a chisel-like tool in the work though it is possible that this is due to the evidence of the long, thin marks left by the long-handled pick used in quarrying. Wood or bone chisels may have been used along with a mallet and would have stood up to the impact of repeated blows better than stone (Lewenstein 1987; Morris 1931; Shook and Kidder 1952). Unhafted stone chisels may also have been used (Daumas 1969). Experiments with unhafted chisels were unsatisfactory but there are many variables involved in addition to experiential knowledge of their use (Lewenstein 1987). It is possible that hafted chisels may have been used that duplicate the long furrows left by the picks. Short handled picks or even hafted unifaces such as found elsewhere in Mesoamerica may have sufficed for final trimming work (Hester 1971). More ornate work, such as architectural sculpture or repeated designs may have required an array of smaller tools in addition to chisels. Obsidian blades and various shaped chert flakes and gravers may have served this role (Becker 1973; Lewenstein 1991b).

A variety of measuring and leveling tools have been suggested without archaeological record. Of these, the most probable is the plumb bob. It is difficult to determine from the structures as they have settled whether a plumb bob was used consistently to keep walls vertically straight. Plumb bobs are thought to have been found archaeologically, but it is difficult to separate them from purely decorative artifacts without proper context (Figure 7.7). Rods, ropes, and levels have been discussed in the section on surveying. There is no evidence for a tool like a square; the Maya seemed to neither use nor care about right angles per se.

Templates may have been used by masons for consistency in large stone carving jobs just as they were greatly depended on in large medieval jobs (especially

Figure 7.7 Limestone balls (plumb bobs?) with biconical drilling as found at El Pilar, Belize.

cathedrals) (James 1982). Again, though no template has been found archaeologically, an argument for their existence can be extrapolated from certain structures. The Palace of the Governor at Uxmal is the best example. The stone ornamentation on the Palace includes 230 masks of Chac made up of 19 blocks each, 4,370 blocks overall, and, if you add in the rest of the ornamentation, there are more than 6,000 sculpted blocks with repeat designs (Figure 7.8) (Stierlin 1997). It is safe to assume that this was not carved by a single stonemason but by a large number of them working in unison. The easiest way to explain the transfer of this information from one mason to the next is via a template.

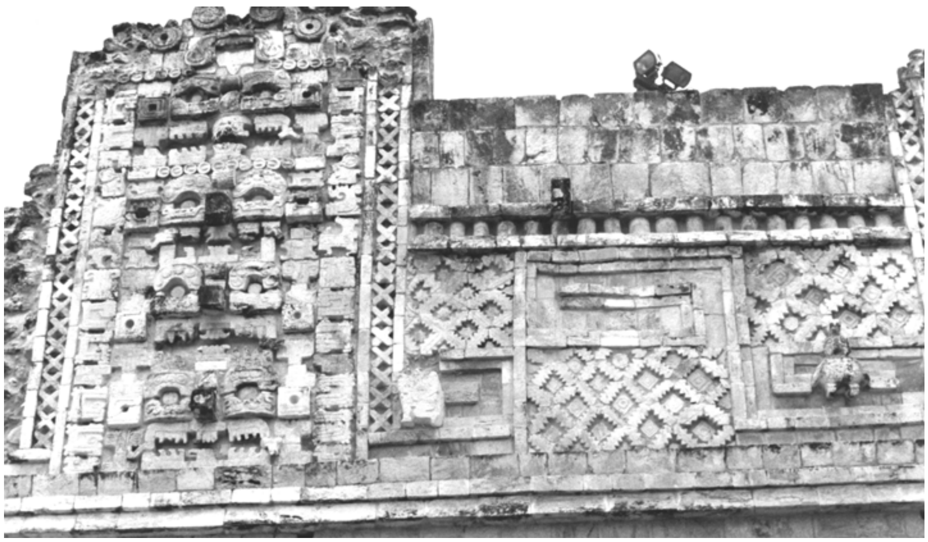

Figure 7.8 Detail of the façade of the Northern Palace in the Nunnery Quadrangle at Uxmal, Yucatan.

Masons would have had some kind of trowel to spread the mortar with as well. At the Temple of the Warriors in Chichen Itza marks in the mortar indicated a rough-edged instrument about 5 cm wide was used in long wiping strokes (Morris 1931). The local workers thought they may have been made of hardwood like the ones they used. To the north the Cholulans used stone trowels with handles and, although none have been found, the Maya may have used stone or wood trowels resembling these (Gendrop 1997).

Plaster and Stucco Work

Plaster and stucco were applied in a number of ways. The easiest way to apply base coats and thick layers was using hands as tools (Robertson 1979). The Maya probably used a variety of vegetable, feather or hair brushes to apply wash coats (Andrews and Rovner 1973). We can surmise the Maya used a wide range of brushes for painting, writing codices, and fine work on ceramics (Robertson 1979). Undoubtedly the Maya used some sort of trowel for putting on thicker layers. This may have been stone, like the masonry trowels cited above, but more probably was of some perishable material. A wood trowel would have been easier to work with and would explain the archaeological absence of these artifacts. Robertson (1979) suggests the use of a float, a specialized trowel used today to level a surface, on plaster surfaces at Palenque. Many modern day floats are made entirely of wood. Another application tool for plaster and stucco may have been some kind of screed, usually a long straight edge used for leveling a surface.

Once plaster has been applied to a surface the Maya polished or burnished surfaces to give the surface extra durability and gloss. Much of this work was probably done with smooth stones such as those found at Dzibilichaltun and Muna (Andrews and Rovner 1973). These particular stones, many of them crescent or banana shaped still had plaster adhering to them and came in a variety of sizes and shapes. The brick-like handled stone trowels would work well for larger jobs as well (Rovner and Lewenstein 1997). Again, there probably was an array of tools made out of perishable materials like the burnishers of wood or bone that have been suggested (Robertson 1979).

There is less to go on when looking at tools for carving and shaping stucco. Some sharp-edged chert tools, bifaces and flakes, have been found with plaster adhering to them and are good candidates for sculpting tools (Andrews and Rovner 1973). Obsidian may have been used for sharp incision and shaving work but, to my knowledge; there is no evidence to support this. A selection of tools made out of perishable materials is the most likely candidate (Eaton 1991). The Maya may have used simple tools not unlike modern clay-sculpting tools that are usually made of wood or bone (Figure 7.9).

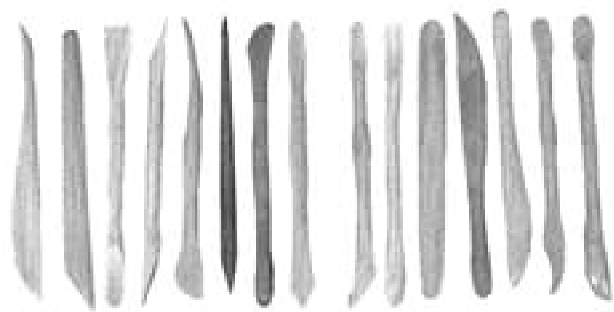

Figure 7.9 Wooden ceramic sculpting tools.

Woodworking

Given the nature of the woods used by the Maya (see Chapter 2); woodworking was not an easy job. Landa (1937) records that the Maya considered making wooden idols, for instance, a difficult and arduous task. Defining woodworking tools can also be a difficult task. First, it is important to point out that many of the tools utilized by the Maya were multipurpose tools (Eaton 1991). A hafted ax could be used to quarry or shape limestone, clear a cornfield, or chop down a tree and shape it to use as a lintel. Modern usewear analysis is still very much a subjective study and interpretation of a tool's end use and purpose may be scientific conjecture (Odell 2001).

The ax and the adze were probably the two most important woodworking tools. These are the tools used for the grunt work; felling and trimming trees, shaping logs and reducing wood to shapes useful to the Maya. The axes used are short handled axes with chipped stone bifaces similar to the "Puleston" axe (Shafer and Hester 1990). There are a large number of iconographic representations of Maya axes, including tree felling (Wilk 1977). Even the hardest Maya woods can be cut with a chipped stone ax with experience (Woods and Titmus 1997). Experiments have found ground stone celts inefficient cutting implements and these artifacts may have served as weapons, ceremonial artifacts, or even wedges (Wilk 1977; Lewenstein 1987).

An adze is a heavy tool similar to an ax, but used in a shaving motion (Figure 7.10). It may be one of the few tools examined that was utilized primarily for woodworking (Lewenstein 1991b). Bifacial stone axes and adzes are made in a similar fashion but they may have slightly different optimal edge angles (Lewenstein 1991a). Maya tool makers may either have made them differently or selected optimal

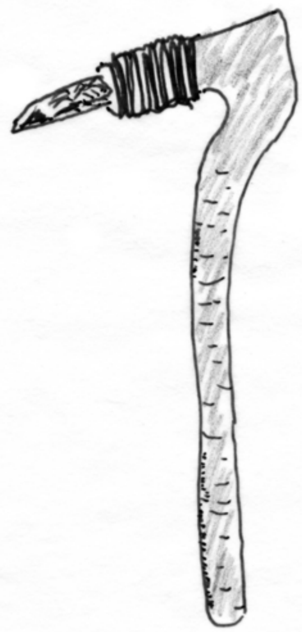

Figure 7.10 An elbow-hafted stone adze.

adzes form their finished bifaces. An adze is normally hafted transversally and many ancient examples from around the world are "elbow hafted" so that the working end angles back toward the user (Beirne 1971; Wilk 1977). It has been suggested that adzes could be used in agricultural clearing operations, but experiments with replicas have found them to be inefficient and difficult to use in comparison to axes (Lewenstein 1987; Gibson 1991).

A study of tool marks on the large collection of wood objects recovered from the cenote at Chichen Itza revealed v-shaped tool marks characteristic of sawing motions (Sievert 1992). Wear patterns on thin formal bifaces and informal tools (flakes) show patterns consistent with sawing wood (Lewenstein 1991b). The Maya may also have possessed a more formal specialized sawing tool. Outwater (1957b) has hypothesized a saw based on the design of Aztec and Maya war clubs. In experiments he mounted bottle glass fragments (substituted for obsidian) in a wood handle with resin and tried the resulting saw on a tree and cut lumber. He found that it cut easily and cleanly with little effort (Outwater57b:410). Wear patterns indicating woodworking have been found on obsidian blade fragments at several sites (Shook and Kidder 1952; Wilk 1977; Lewenstein 1991b).

Wedges were probably an important part of the woodworking tool kit. Wedges would make the reduction of hardwood logs into usable slabs a lot easier. Wedges could have been made of wood (many of the hardwoods are significantly harder when dried), wedge-shaped stones or purposely made stone wedges (Lewenstein 1987). Both ground stone celts and triangular choppers have been suggested for this role (Wilk 1977).

Another tool hypothesized to be specific to woodworking is the scraper/plane, covering a wide range of tools for shaping wood (Lewenstein 1991b). At Cerros, a large number of tools were found to have been used for wood shaping including formal ovoid unifaces with a steep-angled bit (Lewenstein 1987). Woodworking wear is also found on a number of retouched flake side scrapers and on an array of blades, denticulates, and stemmed bifaces. Some may have been used as spokeshaves or rasps (Aldenderfer 1991). Both flint and obsidian blades have been found to have been used in both sawing and whittling functions (Coe and

Shook 1961).

Gouges and chisels are another tool set that may have been used for multiple purposes. These elongate tools may have been used in stone working and stucco sculpting in addition to woodworking (Wilk 1977). Chisels or elongate bitted planes would have simplified the removal of larger chips of wood.

By far the largest numbers of identified tools with woodworking wear are informal tools, unmodified or minimally-modified flakes used expediently. At Cerros almost 70% of the tools indicating woodworking fit this category (Lewenstein 1991b). These include tools that may have been used for scraping, planning, drilling, and perforating. Carved Maya lintels illustrate the intricacy of this work (Coe and Shook 1961). Numbers of these tools are sometimes found together in “kits” (Folan, et al. 2001).

Summary

The Maya had a rudimentary yet effective construction tool kit. Working with tools made of stone, wood, shell and bone they were able to assemble visually spectacular architectural works, some of which have lasted more than 1,000 years. None of the tools used were technically sophisticated, rather they depended on time-tested procedures understood by the Maya population and a plentiful labor supply skilled in their use. Their tool kits were easy to procure, easy to use, and efficient.

This dissertation began with a discussion of the materials available to the ancient Maya, progressed to a look at architectural planning and preparation and lastly, in Chapters Four through Seven, examined the elements that were combined to create Maya monumental architecture and the tools used in their construction. Next we will look at how we can use this this knowledge to further our understanding of the Maya and their architecture.

Chapter Eight

Implications

If we possessed a thorough knowledge of all the parts of the seed … we could from that alone, be reasons entirely mathematical and certain, deduce the whole conformation and figure of each of its members, and, conversely if we knew several peculiarities of this conformation, we would from those deduce the nature of its seed.

Rene Descartes

Having examined the basic materials, tools, and methods that the ancient Maya used what can they tell us? Knowledge of the basic "building blocks" can be used to examine current archaeological problems as well as long-held archaeological truths to explore their aptness. Archaeological questions can, in turn, be examined for light they might shine on basic Maya skills or tools.

Today there are wholly practical concerns that can be dealt with effectively given knowledge of Maya materials and techniques. The 20th Century saw the beginning and almost geometrical acceleration of the consolidation and restoration of Mesoamerican monuments (Molina-Montes1982). Reconstruction, the restoration of a monument to its original (or imagined) state, was often required by governments for national or social reasons and increasingly, for the promotion of tourism (Larios Villata 2000). Restoration is sometimes undertaken with the understanding that we cannot understand monuments unless we "behold them" (Piña Chan 1974).Whether consolidating monuments to preserve them or attempting reconstruction an understanding of the materials and techniques is essential if the work is not to be in vain. The differences between Maya lime cement and modern Portland cement with steel reinforcement can mean the preservation or destruction of archaeological remains. Removal of the rainforest cover that has kept Maya monuments in a balanced equilibrium can lead to rapid destruction through biological and climatic destruction as well as the introduction of water to interiors of structures (Hale, Jr. 1984). There are many examples of this type of damage due to a lack of knowledge by well-meaning archaeologists (Larios Villata 2000, Molina-Montes 1982).

In addition, this data can be used to look at existing theories regarding Maya methods and expertise as well as more theoretical questions regarding Maya social structure as it pertained to building. The following two examples will explore this reasoning further.

Did the Maya possess advanced lime-burning technology?

This is a very important practical question since current work, especially in the area of energetics and the environment, hinges on certain conceptions of Maya lime burning. Estimates of how long an action took, or how difficult it was, inform theories of social structure, areas of cultural importance, and economic models. The end result of these theories and experiments can be exciting new work such as that at the site of Copan (Abrams 1994; Carreli 1997). These studies have dramatically changed the way many view the construction of large Maya monuments. By attempting to quantify many of the procedures they are able to show that it could have taken fewer people and less time than previously believed to build such structures. This has major repercussions for studies of the ancient Maya economy, as well as political and social structures.

At the heart of these studies, as far as lime-burning is concerned, is an almost slavish acceptance that the ancient Maya made quicklime in the way described by Morris in 1931 during his reconstruction work at Chichen Itza. For example, in Thomas Schreiner's otherwise excellent review of current firing practice he states, "the traditional process of burning lime which is very likely an ancient Mesoamerican method" and yet he records a significant amount of information that should cause one to question that view (Schreiner 2002:28). Morris stated that "the Yucatecan method of producing lime at the present time is an ancestral heritage that has come down through the centuries with practically no change except the substitution of steel for stone tools" (Morris 1931: 235). Effort has been expended on experimental burns and ethnographic recording of burns to produce lime, but almost all are based on the belief that this was the way the Maya had always done it (Morris 1931; Erasmus 1965; MacKinnon and May 1990; Mazzullo, et al. 1994; Bury 1996; Mathews 2002; Schreiner 2002). This is dangerously similar to the way that Mesoamericanists long accepted that the Maya practiced almost-exclusively swidden agriculture; with all the environmental baggage it carries, because that is the agricultural practice today (Turner 1978).

Did the Maya burn lime in open heap burns? The assumption is based on the fact that, when Morris needed lime for reconstruction at Chichen Itza, his local workers made a *calera* (the heap kilns used by todays Maya) for him and he dutifully recorded it (Morris 1931). First, I should not have to mention the dangers of using ethnographic analogy to bridge more than a thousand year gap – there should be significantly more questioning of a model that assumes that the method used in 1931 is the same "traditional" method as used in A.D. 1000 or 800. It should also be noted that Morris implies that his workers would have preferred to use a more efficient kiln but told him that there was not a local source for the proper clay or rock (Morris 1931:235).

There are other intriguing, unfortunately vague, references that may be even more to the point. A description of various "heathen" rituals carried out by the Aztecs describes a ceremony for burning lime and appears to describe a free standing lime kiln (Ruiz de Alarcon 1984). There is also linguistic evidence for alternatives to open-air burning, such as the Yucatecan use of the Spanish 'trinchera" or trench for lime-burning (Schreiner 2002). Although we cannot determine the method used, the clay bricks of the construction of Comalcalco were fired and the evidence suggests high-temperature firing (George Andrews, personal communication 1999).

A number of Mesoamerican pottery styles have been thought to be kiln-fired (Bryant and Brady 1986; Krotser 1987). The archaeological remains of possible pottery kilns have been identified as early as the 1940's, but the search has taken on new life in recent years. Kilns from Honduras to Central Mexico, ranging from Middle Preclassic to Postclassic, have been tentatively identified in such numbers as to no longer be in the realm of theoretical (Becker 2003). These include pit kilns, trench kilns, and even updraft kilns (Figure 8.1)(Stone and Turnbull 1941; Winter and Payne 1976; Flannery and Marcus 1983; Balkansky, et al. 1997; Diehl, et al. 1997; Pool 1997; Urban, et al. 1997; Schortman, et al. 2001; Becker 2003; Castanzo 2004; Stark and Garraty 2004). If the Maya utilized advanced kiln technologies for firing pottery then a crossover usage in lime production would not be surprising. In fact, lime-burning technology (at least in the Old World) is seen as a precursor to ceramic kiln technology (Frierman 1971; Gourdin and Kingery 1975).

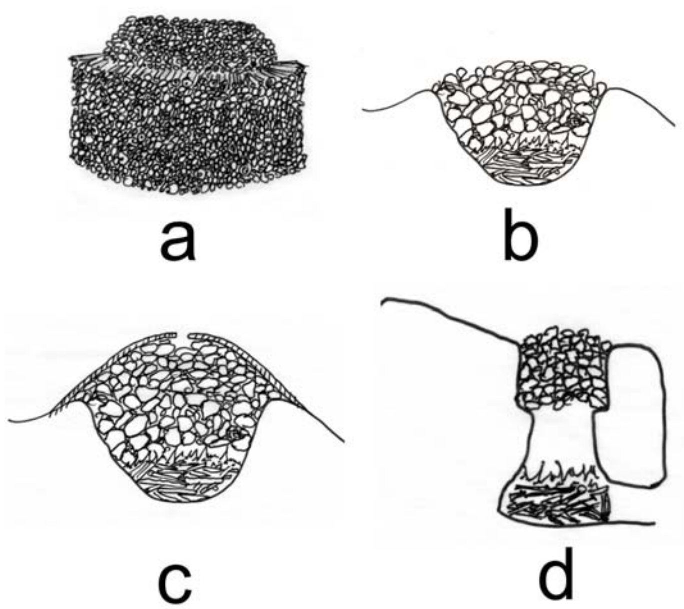

Figure 8.1 Lime kilns: a) "traditional" Maya heap burn, b) pit kiln, c) clamp or damped kiln (covered pit kiln), d) simple updraft kiln cut into a bank.

Indeed possible kiln sites with evidence of lime production have been identified archaeologically. A circular Late Classic kiln has been identified at Copan with traces of lime and a Middle Preclassic feature resembling an updraft kiln was identified at Chalcatzingo (Grove 1984; Abrams and Freter 1996). A number of pit kiln-like, albeit questionable, features associated with burnt limestone have also been found in Belize (Ettlinger 1983; López Varela, et al. 2001; Mathews 2002). Similar features have been identified in Veracruz, Mexico (Diehl, et al. 1997). A continuing problem with the identification and excavation of kiln structures is their ephemeral nature (Krotser 1987; Balkansky, et al. 1997; Deal 1998). Pike's (1980) detailed ethnography of Mixtec lime burning describes opportunistic updraft kilns that would leave next to no archaeological signature. Pursuing pottery-firing facilities archaeologically can be made more logically with predictive locational models and the identification of wasters and ceramic debris (Stark 1985). Not so with lime burning. In one case, even with historical records pinpointing manufacturing sites, archaeologists found little on the surface to indicate kiln facilities (Harrington 2000). Even though they are known from both writings and illustrations no Byzantine lime kilns have been excavated either (Ousterhout 1999). Kilns are likely to be located near limestone quarries and may be destroyed in later quarrying operations or unrecognizable with out painstaking excavation.

If the Maya did possess firing technologies more advanced than "heap" burning, and I think the evidence is strongly in favor, than what does that mean for our other assumptions? First, it means that we need to significantly rework our ideas about Maya energetics. It may have taken even less time, labor, and resources to produce quicklime than the modern reworking of these figures have suggested. This has implications for the importance socially and economically of major monument construction.

In addition to the study of architectural energetics there are a growing number of environmental studies, most tied to the “collapse” of central lowlands civilization, that invoke lime burning. The Maya production of lime is blamed, in part, for massive deforestation and the collapse of intensive agriculture. An example of this is from Hansen et al. (2002:288); “Evidence suggests that lime and stucco production are very likely to have contributed to, and may have been responsible fro, the extensive deforestation that accompanied the loss of soils and clays.” Often this takes the form of circular reasoning that states that lime-burning for mortar and plaster contributed to deforestation and, by way of proof, points to massive amounts of mortar and plaster used in sites. One study tried to examine the question from the bottom up by estimating the quantities of construction lime used at the site (Teotihuacan) and then examining evidence for deforestation at the time. Unable to find evidence for deforestation on the assumed scale (the Teotihuanacos would have had to burn every tree in the valley twice) the study concluded that people were hauling quicklime or wood from up to 60 km away (Barba, et al. 1995; Barba and Córdova Frunz 1999). Nowhere did they question their assumptions about how the lime was made. There is also the issue of how they arrive at their estimates of quicklime used. As noted in chapter two, sascab may have often been used as a consolidant and, as at Copan, clay was often used as a mortar.

What about the environmental implications? While it may not change any ideas about the nature of the environment it may change some theories about how it changed throughout the height of the Maya civilization. It is important to note that there is still a great deal of controversy about this subject. Core samples looking at pollens and sampling have indicated that massive deforestation may have taken place throughout the central Maya lowlands primarily based on a change from tree to grass pollens starting ca. 500 BC (Rue 1986; Rice 1993; Gill 2000; Haug, et al. 2003). The lion's share of this deforestation would have been for settlement and agriculture for a population that may have been close to the density of modern Los Angeles County (Turner 1990; Rice and Rice 1990; Scott 2004). Lime burning for architecture has taken a good deal of the blame along the way (Rice 1993). Often overlooked as well, but probably second only to agriculture, are the Maya use of wood for cooking and construction.

One of the controversies surrounding this hypothesized deforestation are the increasing indications that the Maya practiced silviculture and managed forests. Archaeological, botanical, and ethnographical studies support the conclusion that the ancient Maya were managing and using many forest resources (Folan, et al. 1979; Nations and Nigh 1980; Gomez Pampa 1987a; Gomez Pampa 1987b; Wilk 1991; Crane 1996; Ford and Gerardo 2001). In addition the Maya were existing beside, and utilizing a large number of animal species (jaguar, deer, peccary, and turkey) that must have forests to survive (Carr 1996; Emery 2004; Emmons and Freer 1990; Kerr 2004; Landa 1937). The zooarchaeological evidence does not support a dramatic change in the habitats of the animals utilized by the Maya (Emery 2004). The Aztec tribute lists from the sixteenth century still show the Maya exploiting rainforest resources such as jaguar (Figure 8.2)(Berdan and Anawalt 1997, Voorhies 1982). Another problem involves the tremendous regrowth of the deforested areas. In order for primary rainforest to renew itself the land must have access to a tremendous "seed bank", primary rainforest with the diversity needed to redevelop the full range of growth (Rice 1996; Gomez Pampa, et al. 1972).

Figure 8.2 Ceramic Maya jaguar effigy from El Pilar,.

The possession of kilns would have reduced the Maya dependence on fuel timber in lime production, depending on the design they could have increased their efficiency by 40-50% (Urrutia F. and Monterroso 1983; UNDP/World Bank 1987; The Ministry of Foreign Affairs of Japan 1998; Wingate 1985). The implication is that the contribution to deforestation and environmental change of lime burning may have been minimal.

Did the Maya have Architects?

Utilizing all the construction and material data presented in this dissertation to examine specialization among the ancient Maya is a daunting task. There have been many archaeological definitions of specialization and what quickly becomes obvious is that most of them deal with the production of portable artifacts (for an excellent summary of specialization as seen by archaeology see Costin 1991). It is telling that many important articles in this area have the words "craft specialization" in the title (Arnold 1987; Clark and Parry 1990; Costin 1991; Shafer and Hester 1991). An architect's role is that of a profession rather than a craftsman and, even today, the numbers of "high-style" architects whose work can be easily discerned by eye is relatively limited. Examining architecture supplies us with a whole new set of problems not encountered when looking at ceramics, lithics, or other portable goods manufacturing.

One good definition of craft specialization is "the regular and standardized mass production of a nonfood item in quantities clearly higher than those necessary for household consumption, by persons having restrictive access to specific technology, knowledge, skills, or raw materials, and characterized by a vertical division of labor" (Michaels 1989). The archaeological visibility of many of these traits as they pertain to architects is a difficult question. When looking at lithics or ceramics, for instance, evidence of large-scale production or factory-like mass production are taken as signs of specialization. Specialized tools or skills that rely heavily on experience and training are other indicators (Costin 1991). There are obvious problems when looking at architecture for signs of a professional. There is still considerable controversy regarding how long structures took to build or how many laborers might have been used. We cannot determine how many buildings “exceed household consumption” and there are questions regarding the extent of Maya planning and building skills.

There is a broad assumption that the Maya did have architects. Most of these assumptions stem from a belief that size and the perception of complex planning would have required an architect. “Architectural construction and planning were undoubtedly professional skills, as is evidenced by the monumental platform plaza groups …that required the coordination of unskilled labor and a number of different kinds of professional craftsmen” (Sanders and Price 1968:11). In a similar vein, Elliot Abrams supports an architect “based on the skills and high-value of architecture” while conceding that there is no archaeological evidence to support this (Abrams 1994:114). Marshall Becker relied on two fellow professionals (Kubler and Harrison) to state “the existence of large, complex, and apparently well-planned structures provides sufficient evidence for inferring that professional planners and designers were involved in these constructions” (Becker 1973:403). In more recent years there has been a tendency to hedge the bet by not using the term architect directly. A good example is this statement – “Pre-Columbian Maya architecture is a legacy to the world, declaring the aesthetic sophistication that master builders can achieve with simple tools and good organization” (Friedel and Suhler 1999). The popular press pulls no such punches and declares that the Maya were “among the greatest architects in the western hemisphere” (Townsley 2004).

The evidence for specialization presented generally boils down to two subjective ideas; that Maya architecture is big and complex. Utilizing the information from the first half of this dissertation can we discern better evidence for specialists, especially architects, than these criteria? One important note is that specialization is less of a black-white position than it is a matter of degree (Costin 1991). It is difficult, given material remains, to discern a part-time from a full time specialist. Ethnographic researchers look for a number of factors to identify economic specialists: amount of time spent at the specialty, proportion of their "living" made through the specialty, if goods or money was exchanged for their product, and if a name or title existed for the position (Rice 1981). Obviously, the first three of the four criteria will leave no discernable archaeological signature for an architect but the last has possibilities.

The existence of a title or name for an architectural or building specialty would be the best direct indicator for architects. Titles for a number of specialties have been identified including sculptors, artists, scribes, and woodworkers, but there has been no identification of a term for either architect or the oft-stated alternative master builder (Tate 1992; Schele and Mathews 1998; Houston 1998b). Linguistic work has identified colonial terms for architect and builder that imply artisan status or a status open to everyone (Houston 1998b). Elliot Abrams has repeatedly compared the Maya to Pharonic Egypt to show the need for the position of architect and yet architectural titles and names of individual Egyptian architects have been identified (Abrams 1987; Abrams 1994). The position of architect is usually thought to be an "attached" specialty, a position that served the Maya elite (Brumfiel and Earle 1987; Earle 1981; Abrams 1994). There is ample evidence that scribe/artists

(*Ah Ts'ib*) not only worked for the elite, but also had elite, even royal, status and worked on the decoration of public structures (Tate 1992; Tate 1994). It is hard to believe that a royal architect would not also be mentioned and recognized.

Costin (1991) lays out a framework for examining the presence of specialization by looking at the direct and indirect evidence. The scheme was developed for looking at production specialization of portable objects, but can be used as a rough outline to examine the conceptions and preconceptions for an architectural specialty. Her first category, that of direct evidence, looks at five criteria; loci, context, concentration, scale, and intensity. Adapting for architecture we can examine the direct evidence of the buildings themselves and look for a Maya title or designation of an architect.

The perceived siting and planning involved in Maya architecture is among the most cited proofs for existence of Maya architects. Chapter three has gone into detail as to planning possibilities and the skills required. There is no concrete archaeological evidence for sophisticated site or building planning. There is also a chronological problem with many of the site planning schemes that have been proposed as they call for not a single architect but, at the very least, a master plan in effect for decades and even centuries (Wernecke 1994; Houk 1996).

To examine Costin's criteria of scale and intensity perhaps we should examine what the demand for an architect might be. If this is a full-time specialization there should be an indication of a lifetime's work at a Maya center. A Maya architect, assumed to be an elite rank among many authors, should have enough monumental construction work to create a reasonable demand for a full-time position. Though it is possible, I am unaware of any studies of architecture in Maya centers that plot out all of the monumental construction with best approximations for contemporaneity. It may be possible to assemble this information for sites that have had extensive investigation, like Copan and Tikal. It is doubtful that in examining 15 centuries of construction at any one center you would find that a substantial number of buildings (perhaps 10 major structures over a 20-year professional career) were constructed in a time framework to suggest a single architect or planner. For a Maya specialty to have evolved it would be expected that many if not most large sites would have a similar pattern. Abrams (1987), arguing for a single royal architect, admits that the demand for an architect would be very low and that the common laborers may only have worked on two or three structures in their lifetime.

Is it possible to identify a single designer’s work in multiple structures not part of a single construction event or even at multiple sites? This type of stylistic analysis has been done in apparently successful attempts to identify individual Maya scribes, artists, and sculptors (Cohadas 1980; Schele and Miller 1986; Cohadas 1989; Tate 1994). Again, there has been no apparent analysis of this type done on architecture. The largest problem is that Maya structures share overall and regional construction traditions that span centuries and, if the decorative style alone is examined, what is to say that this is not the work of an artist (rather than an architect) that did the finishing work on the structure? Innovations and inventions in construction technology other than stylistic are few and generally isolated which may indicate extraordinary individuals rather than a specialization as a whole.

In terms of indirect evidence for specialization, Costin examines four criteria: standardization, efficiency, skill, and regional variation (Costin 1991). There are many problems with looking at standardization as an indicator for specialization (Arnold 2000). Maya construction could be termed very standardized, conservative and traditional with little fundamental change over a period of at least 15 centuries. There are few basic building designs, a very limited repertoire of construction skills and a low rate of innovation. I would argue that this is evidence for the proposition that the Maya did not have professional architects or master builders.

Full-time specialists tend to put their mark on their work, changing it in ways that may or may not be better or evolutionary. Archaeologists depend on these changes in style and substance to seriate artifacts. The relationship between the specialty and the specialist is a dynamic one that encompasses both the ability to replicate and the need for experimentation and innovation (Kingery, et al. 1988; Fleck 2000; Ottaway 2001). Artifact classes with exceptionally long records of stasis are known (see Martin 2000, for instance, on Japanese sword making), but these usually fall in the “if it ain’t broke don’t fix it” category. Maya architecture, however, does not fit into this category. It was fundamentally structurally flawed in multiple ways many of which had simple fixes and were readily evident at the time (Pendergast 1990). Rather than see the occasional structure that contained incremental improvements, which I would argue reflect individuals, it would be more logical to see a pattern of structural changes other than cosmetic over the 15 centuries and differing regionally.

Would the position of royal architect be the efficient way to handle construction? As Costin points out there can be social, political, or economic aspects that impact the relative efficiency of a system. Energetics studies have pointed out Maya monumental construction took fewer people and less time than previously thought (Abrams 1994; Carreli 1997; Abrams 1999; Abrams and Bolland 1999). Organization of labor could have been done on the basis of lineage, residence, or by deferring to the most-experienced (first among equals basis) in much the same way as a barn-raising in North America (Abrams 2001). Elliot Abrams (2000:40) wrote that in Maya house building "the highest-status individual, possessing the greatest knowledge and background on house construction, assumed the role of supervisor, but no formal position existed." Although various labor supply scenarios have been explored (see Chapter 4), the possibility that labor could have been not only voluntary, but also sought after is not usually broached. Buddhist stupas were and are often built using voluntary labor. A stupa, in its traditional form a large reliquary, becomes a focal point for a community with tremendous symbolic and commemorative links. Work on a stupa is thought to be work of merit and purity that can bring peace, happiness and prosperity to the laborer (Tucci 1988; Oliver 1997). Many Maya monumental structures are also thought to be commemorative in nature and packed with symbolic meaning.

The Maya elite may also have participated in construction projects. Adams (1970) thought that the Maya elite would have had a determining role in the planning, organization and direction of building projects. The titles of some artist/scribes have been found to contain the royal title *ahau* that could indicate that the overall direction in some projects came from nobles while laborers did the work (Tate 1992). A Maya vase portrays a ruler’s son and notes that he is an artist and ballplayer (Reents-Budet and Bishop 2003). Rather than a professional architect with a full-time position the Maya royalty and priesthood may have designed or directed the design of structures (Oliver 1997). The Roman Emperor Hadrian, for instance, was apparently involved in the design of the Pantheon and his villa at Tivoli (Taylor 2003).

Many of the skills required for construction have already been reviewed. The earliest reviews of Maya architecture plainly reveal the overall simplicity in construction (Roys 1934; Kubler 1962). Procurement of materials, including lime, and basic construction skills did not require extensive or “secret” knowledge. Many of these skills could be extensively honed by experience but the basics were very clear and being used everyday (Adams 1970; Abrams 1987; Abrams 1994). Planning is thought involve “sacred lore” but, as related in Chapter 3, could simply be the consistent use of traditional ideas of enclosure, directionality and line of sight (Wernecke 1994; Houk 1996). There are no signs of a sophisticated knowledge of engineering and in those cases where the Maya “got it right” may be examples of craftsmen using empirical rules devised from watching previous projects and discerning what worked and what didn’t (Timoshenko 1953; Martin 2000). A Maya craftsman did not need to possess any real knowledge of why what he did worked as long as it was observed to work (Martin 2000). The “big and complex” argument does not stand up. Many Maya structures were big, but Monk’s Mound at Cahokia, for example, is the largest earthen construction in North America and the Mississippians were not thought to have professional architects.

What about complexity? If the planning or siting is not necessarily complex or not done by the builders, then what part of Maya architecture is considered complex? The popular answer is usually the vault system. The vault system has been dissected in detail in chapter seven and shown to be not as complex as previously thought. Dry stone corbelling, probably significantly more complex than a system utilizing cement, is found in vernacular architecture throughout the world most often built by farmers and shepherds (Figure 8.3). Figure 8.4 illustrates a remarkable structure that, at first glance, could be taken for a Maya construction. It is in fact a shepherd’s shelter constructed ca. 18th century in Eastern France. These dry stone structures, as complex as any of the Maya constructions, were built by farmers, herdsman, and villagers. Some are beautifully finished, like the *trulli* of Italy or the Mycenean *tholos* tombs, while others are much cruder looking, like the *nuraghi* of Sardinia or the *clochans* of Ireland (Brice and Donmez 1948; Walton 1951; Cassar 1961; Walton 1962; ; Allen 1969; Juvanec 1998). The point is that they are all considered vernacular architecture done without the benefit of formal architects and yet they have all the complexity (short of the outer artistic design) of Maya buildings. Even complex designs and symbology do not necessarily support the presence of an architect. The Norwegian stave churches are every bit as complex as a Rio Bec “monster mouth” structure but are considered vernacular architecture (Bugge 1983; Gendrop 1985).

Regional variation certainly exists in the Maya world. For the most part it is stylistic variation (rather than variation in construction procedures or methods) that may strengthen the argument against the presence of professional architects. The

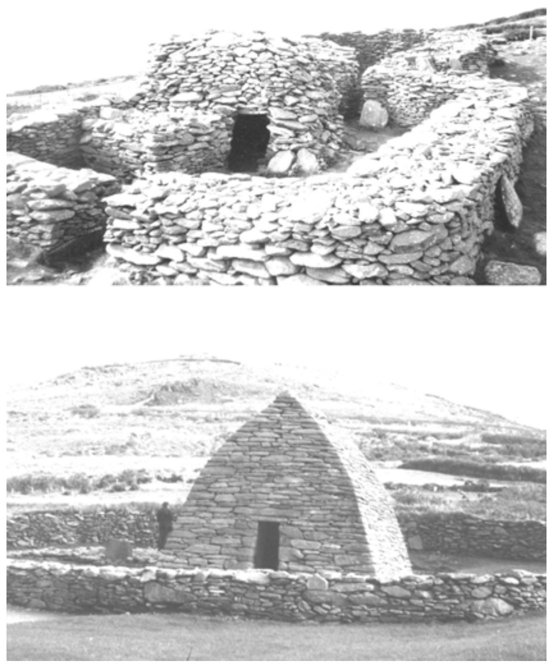

Figure 8.3 Irish dry stone corbelling – a *clochan* hut on the Dingle Peninsula above, and the famous Gallerus Oratory (8th Century A.D.) below.

Figure 8.4 A shepherds hut or *cabane* in t he Jura Mountains of Eastern France.

styles are in broad enough areas (Gendrop defined seven “stylistic provinces for the Late Classic) to argue for regional traditions and too broad, both spatially and chronologically, to argue the influence of a few professionals (Heydon and Gendrop 1975). Much of the perceived construction variations are due to the differential availability of materials rather than skills.

I believe the information gathered does reflect the presence of professional artists and that they probably had a hand in the design of structures and, more deeply, the execution of the final decoration. The Maya never had, and still do not, any real use for indoor space as a culture – they are an outdoor people even today. Both archaeological and ethnographic evidence show the extensive use of Maya patios in preference to interiors (Arnold 1990; Hayden and Cannon 1983; Killion

1992; Vogt 1990). Maya architecture reflects that in the narrow, dark, airless spaces that are the culmination of massive building projects. If, however, we look at Maya structures as canvases for artistic expression rather than as structures and monuments, the process makes a little more sense. In the western artistic tradition an artist's flax, jute or cotton canvas has not changed appreciably in form for more than four centuries – the materials used to prime it and the paint technology has changed, but not the framework (Claessens 2004). Houston (1998b) wrote of the perception that Maya structures were frames for ceremony and "billboards" for key symbols.

Houston (1998b) examines concepts of vernacular architecture in great detail. He comes to one important conclusion – that Mesoamerican studies are ill-served by "Euroamerican" connotations of terms like vernacular and, I would add, architect. The concept of vernacular architecture is a varied and ill-defined one. To some, vernacular architecture is a geographic term akin to the linguistic use of the term while others divide architecture along aesthetic lines, distinguishing between a "high style" and the vernacular or common architecture (Pevsner 1990). Many definitions, however, agree on a package of traits that vernacular architecture should possess. These include being built out of local materials, following traditional forms, and being constructed by non-professionals. By this measure the construction techniques examined here are part of a monumental Maya vernacular architecture.

Chapter Nine

Conclusion

Architecture, to state the obvious, is a social act – social both in method and purpose. It is the outcome of teamwork; and it is there to be made use of by groups of people, groups as small as the family or as large as an entire nation. (Kostof 1985:4)

Writing this dissertation has been a learning experience for me. I started with this subject because I had a previous interest and experience in the field of building materials and, in pursuing archaeological field work in Mesoamerica, was surprised by a general lack of basic knowledge and research in this area. There are currently researchers pursuing basic materials and technology research; people such as Eric Hansen, Joaquin Rodriguez, Thomas Schreiner, and Ruth Mathews. The work that is still used by professionals in the field is, however, quite old and often incorrect or incomplete. Houston notes (1998b) that our fundamental resource for Maya domestic architecture is the excellent, but outdated work by Wauchope (Wauchope 1938). As I observed in the introduction Mesoamericanists still depend on Roy's short speculative note on Maya engineering from 1934. Justine Staneko's study has not drawn much professional attention, but even her work points out more glaring gaps in our knowledge than are answered (Staneko 1996). There are no archaeological reports, that I am aware of, that examine architectural processes in the detail that Earl Morris did at Chichen Itza – he recorded important minutiae like observed marks in the mortar (Morris 1931). Morris' work was excellent for the time, but we should have so much more by now.

When I began to research this project I thought, naively, that much of the information I wished to compile was "out there", but scattered about. Examination of many archaeological reports began to show a pattern of statements that were supported by previous statements ad nauseum. The end result boiled down to two types of arguments although I found none crude enough, or more probably aware of the problem, to state them this way. The first was the "because it is obvious" argument where the author felt no need to back up a statement because, of course, we all know it is true. The second came down to the "because I said so" argument familiar to all parents. I am not trying to impugn anyone's reputation here. These arguments regarding Maya construction materials and technology are, for the most part, by excellent reputable mesoamericanists. In some cases it was a fundamental ignorance of a material or technological characteristic that led to the statement and in others it appears to be a more complex deep set "not knowing that we do not know".

I found myself falling prey to this as well and I hope that the more technical sections of this dissertation are clear on what I could not find out. In the field it is easy, and sometimes there is no choice but, to stray outside your area of professional expertise and "become" an engineer, geologist, or architect. It behooves us as professionals to be aware of those situations and, whenever it is possible, to consult professionals in those fields.

While not all will agree with my conclusions in Chapter Eight regarding the need to look for advanced Maya kiln technology and the lack of evidence for professional Maya architects, the arguments themselves should be clear enough to illustrate the utility of such “bottom up” analysis of Maya architecture. A good familiarity with the characteristics of quicklime and its manufacture, for example, should lead you to question some of the incongruities of the research into Maya architecture, technology and the environment of the Late Classic period. The same is true when examining questions of specialization in Maya construction. Stating that the Maya had architects because it is obvious that they had to is not a valid argument in professional research. I do not pretend to have the answer here, just data that should lead us to further study.

It has become an archaeological cliché to end all papers with “much more work needs to be done” and never has that been truer than for the material and technological data presented here. There is not a single chapter where glaring gaps will not appear to the discerning reader and, I hope, ideas for new research that will bring us closer to understanding some aspect of Maya architecture. It is my sincere hope that this work will serve as a framework for identifying and filling some of those gaps and my dream that Maya researchers may have a more complete compendium of construction and material knowledge such as those used in Old World archaeology.

Appendix A

Maya Chronology

Post-Classic		1575 to 1000
Classic	Late	600
	Early	A.D. 250
Pre-Classic	Late	300 B.C.
	Middle	1000
	Early	2000
Archaic		

Appendix B

Glossary

This glossary is designed to provide further information and definitions of both foreign language and architectural terms that are not fully defined in the text. Much of this information comes from four primary sources:

Gendrop, P. 1997 *Diccionario de Arquitectura Mesoamericana*

Harris, C. (ed.) 1993 *Dictionary of Architecture and Construction*.

Loten, H. and D. Pendergast 1984 *A Lexicon for Maya Architecture*.

Wikipedia – The Free Encyclopedia (www.wikipedia.org), especially the 1913 Unabridged Edition of Websters Dictionary online.

Ahau – a lowland title translated as "lord" or "noble. The equivalent highland phrase is *ah po* (Lounsbury 1973).

Ah ts'ib – a Maya term that has been defined as the phrase "he of the writing" meaning scribe (Stuart 1987).

Antea – the classical "temple in antis" configuration consisted of a main chamber (Naos or cella) with an antechamber (pronaos) which is flanked by extensions of the side walls (antea).

Ashlar – a block of hewn or squared stone for building purposes

Bajareque – wattle and daub construction, sticks or cane walls plastered with clay, mud or sascab.

Barretta – a modern steel wrecking bar with one spatulate end, one pointed end and weighing about seven pounds.

Batter – a backward (receding) slope in the face of a wall.

Chinking – utilizing small chips and stones to fill the gaps in masonry courses.

Coa – a Central American traditional digging or planting stick. Essentially a dibble often with one flattened end and one pointed end.

Compressive strength – sometimes called crushing strength, the capacity for a material to withstand axially directed pushing forces, when the limit is reached the material is crushed.

Cresteria – the Spanish term for roof crests. Cresting is an ornamental roof decoration that generally runs along the ridge.

Dolomite – in its pure form dolostone, a calcium magnesium carbonate sedimentary rock usually found with limestone. Dolomite or dolmitic limestone is generally thought to be limestone with more than 10% and less than 80% of the mineral dolomite.

Efflorescence – a white crystalline deposit caused by water seepage through an object, evaporating and leaving a coating of salts on the surface. It can cause deformation, defacement and spalling on the surface.

Fathom – a measure of length containing six feet. Originally was the span of a man’s outstretched arms and was used for land measurement but not a nautical measure. From the Old English *faethm* or “bosom”.

Gnomon – a rod, stake, pole or column erected perpendicularly to the horizon and used in astronomical observations such as the altitude of the sun based on the length of its shadow.

Header – a masonry unit laid so its ends are exposed.

Hearting – the masonry forming the interior of the wall as opposed to the facing.

Hod – a device consisting of a shelf and a handle that is used to carry bricks or blocks over the shoulders.

Jedding ax – also known as a kevel, a stone masons axe usually with an blunted end for knocking off angular bits and a pointed end for reducing a surface or cutting to size.

Mecate – a Yucatecan land measurement, Steggarda (1941) found it to be roughly 20 meters but the length of the rope used has been known to vary more often on the long side of 20m.

Megalithic – built of unusually large stones.

Mohs scale – the scale that measures the scratch hardness of a mineral on a scale of 1 (talc) to 10 (diamond).

Monolithic – a structure or monument built with one large stone, or hewn out of bedrock.

Muknal – a burial place or shrine, and ancestral shrine or burial monument (McAnany 1998).

Pit kiln and clamp – a pit kiln is a simple pit filled with fuel. Much of the heat is lost through the top though the earth, acting as an insulator, concentrates the remaining heat. A clamp kiln is a pit kiln with the top covered over (except for air holes) with clay, earth, or sod further concentrating the heat.

Pozzolanas – materials containing reactive silica and/or alumina which have little or no cementing value by themselves, but when ground and in the presence of water react with calcium hydroxide to form compounds with cementing properties.

Puddling – the process of working clay or earth with water to render it compact or impervious to water.

Putlog – pieces of timber on which a scaffold is laid, one end of which rests in a putlog hole in the masonry.

Quicklime – calcium oxide (CaO), a highly caustic substance resulting from the thermal decomposition of limestone. The addition of water creates hydrated or slaked lime, used in mortars and cements.

Respaldo – or vault back, the sloping surface within the roof mass that separates the vault masonry from the rest of the upper façade and roof. Though not always present, many are finely capped with lime cement forming a cleavage line in the construction.

Sacbe, sacbeob (pl) – "white road", maya causeways often raised that run inter and intrasite. The longest maya causeway is from Coba to Yaxuna, nearly 100 km.

Sascab – (also sah cab, sachab, white marl) a powdery saprolitic limestone with cementitious properties when dry.

Slaking – to add water to quicklime, hydrating it and forming lime putty.

Springer – the stone or support where the vertical support or wall terminates and the curve of the vault begins.

Stretcher – a masonry unit laid horizontally with its length in the direction of the wall face.

Tensile strength – the resistance of a material to rupture when subject to tension (pulling or stretching).

Tholos – can refer to any round classical Greek building but more specifically to the Mycenean subterranean dry stone corbelled domed tombs.

Trinchera – "trench", a Spanish term often used in modern and historical Yucatan to (improperly) describe limestone "heap" burns.

Trulli (pl.) – trullo are dry stone corbelled domed structures still being built and used in southeastern Italy.

Tump line – a strap slung across the forehead or chest to help support a load carried on the back. By distributing the load in this fashion much larger individual loads are possible.

Updraft kiln – an installation for burning lime with a firebox below a chimney-like enclosure for the limestone taking maximum advantage of the rising heat.

Voussoir – a wedge-shaped masonry unit in an arch or vault.

Wattle and daub – see *bajareque*

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Vita

Daniel Clark Wernecke was born on November 11, 1958 in Cedarburg, Wisconsin, one of three children of Sue and Bill Wernecke. His life long interest in history and abhorrence of snow led him to get his B.A. in History from Southern Methodist University in Dallas, TX in 1981. After being advised that he would need a "real job" before pursuing history and archaeology, Clark entered the world of Lumber and Building Material sales, holding management positions in companies in Wisconsin and Florida. He also pursued a better knowledge of his profession and earned an MBA from the prestigious Kellogg School of Management at Northwestern University. Sensing an opportunity to switch careers again Clark attended evening classes and received an M.A. in Anthropology from Florida Atlantic University with a thesis focusing on his work at the Maya site of El Pilar in Belize and Guatemala. Moving to Austin, Texas, Clark entered the University of Texas at Austin to finish this Ph.D. and simultaneously worked as Project Director for the Clovis-age Gault Project. He is married to a wonderful woman, Melissa, and has two beautiful daughters, Honor and Arden.

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