Structure Collapse and Abandonment: Patterns in the Archaeological Record

A Senior Honors Thesis for the Department of Archaeology

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Section 1:

Introduction

The basic goal of any archaeological investigation is to understand the behaviors of ancient people (Stein 38). This understanding is accomplished by analysis of physical remains; what is found and what is not, where an artifact is found in relation to other artifacts, and the condition of the artifacts can all provide evidence for their relationship to the people that made and used them. Drawing accurate conclusions about human behaviors based on artifacts or assemblages requires analysis of the ways in which those artifacts/assemblages have been deposited, changed or moved over time (Stein 39). A significant portion of the archaeological record consists of abandoned material. Abandonment as a concept covers a large suite of human behaviors including the deposition of broken ceramics or abandonment of settlements. In this thesis I wish to focus on how archaeologists should investigate the abandonment of structures. While in use, structures range from stone walls and palaces to mudbrick residences or even simple shelters of organic material. Because of these differences, structures do not survive equally in the archaeological record. Even the best preserved structures, those made of stone, are subject to decay and collapse. The goal of this thesis is to explore the patterns associated with structure abandonment and collapse, including patterns in human behavior before, during, and after abandonment, and the patterns derived from the physical reaction of a structure to natural stimuli. It is because of the existence of such patterns and predictability that I am able to propose a method for calculating the time since abandonment based on the change in shape of a structure/mound post-abandonment.

I developed the concept for this thesis while studying in the Program for Belize Archaeology Project (PfBAP) field school. I observed several things while in the field and excavating Structure 5 at Las Abejas (See Figure 1) that lead me to study the physical sequence of structure collapse. Las Abejas is a mid-size Maya site in Belize, with a mix of structures of residential and non-residential uses located in several plazas, that was occupied with varying population levels from the Middle Preclassic to the Terminal Classic (approximately 900-300 BCE to 900 CE) (Sullivan 174-176). First, I noticed that the top layer of stones in the preserved walls of Structure 5 were pushed out from the face of the wall and that large building stones were found on top of a floor near the base of the wall and within the wedge of dirt that extended from the wall. My second observation was the similarities in shape of unexcavated structures, both at Las Abejas and during survey with Michael Maddox. An angled surface of soil, rubble, and vegetation had formed from a once vertical wall. These two observations are connected through the processes of structure collapse and mound formation. Structure collapse and mound formation are consequences of structure abandonment, and thus the events occurring prior to, during, and after abandonment are manifested in the resulting mound.

Figure 1: Structure 5, Las Abejas, Belize. This photo shows how the once vertical wall is now leaning slightly outward (see top right – the wall is not perpendicular to the leveled floor) and that the top stones in the wall were displaced to a greater degree than those at the base (why this happens is discussed in Section 2: Factors Post-Abandonment). Courtesy of the PfBAP.

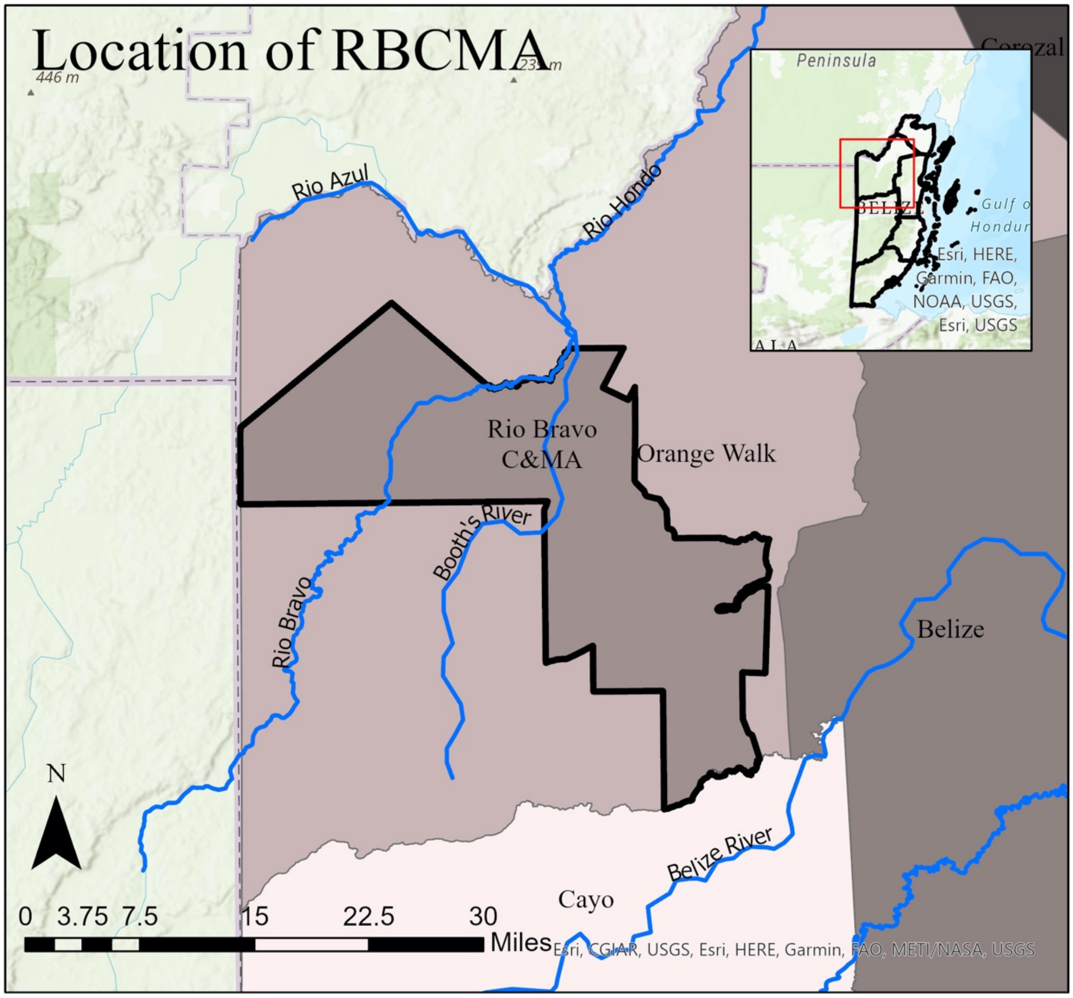
Transformative processes such as collapse cannot be effectively studied at the level of the artifact because these processes effect more than just a single artifact or just cultural material. Utilizing an earth science approach broadens the analytical focus from an artifact to a deposit, which includes cultural material and the natural matrix that surrounds it (Stein 38, 42). In this thesis, I am studying mounds as a single deposit in order to consider how abandonment, collapse, and degradation affect all that is contained within the mound, both natural and cultural elements. Visually, “mound” evokes something hill-shaped yet relatively small in size. In this paper, “mound” refers to the collapsed structure and all of the natural material – soil, vegetation – that surrounds and covers it to form a small hill shape (Figure 2). In my discussion of post-abandonment processes, I refer to both hills and mounds. “Hills” indicate formations without any archaeological material and "mounds" refer to formations that do include archaeological material – particularly a structure or structures.

Figure 2: Mounds in the North Courtyard at Las Abejas, Belize. These mounds contain the remains of structures surrounding a leveled courtyard. Courtesy of the PfBAP.

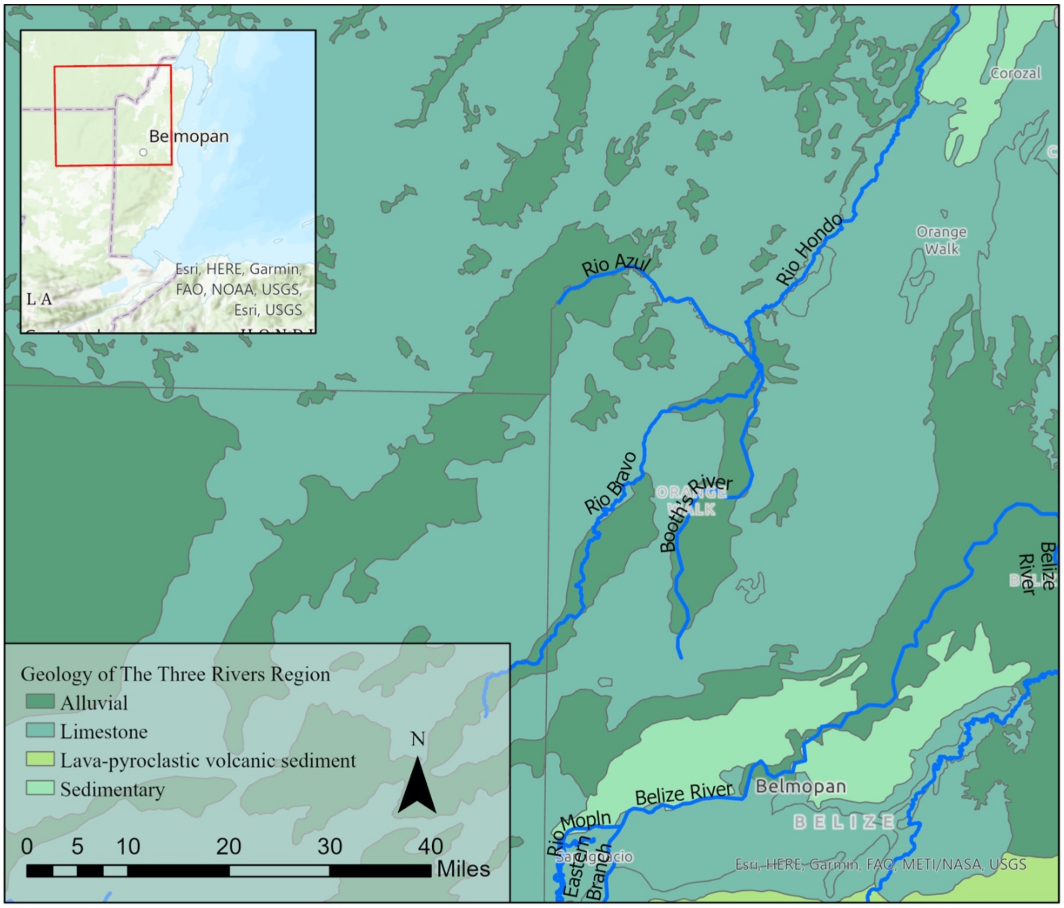
Originally this thesis was based on field data collected during the Summer of 2020, testing methods of mathematically modelling collapse. However, the onset of the COVID-19 Pandemic prevented travel and any fieldwork in Belize. I therefore restructured my thesis to include a proposal for the fieldwork I would have performed and a larger focus on the impacts of structure abandonment and natural deteriorative processes with a case study of sites in the Maya lowlands.

Environment and Geology

The environment in which an archaeological site exists plays an important role in its development and eventual destruction. A site's environment is the physical setting in which it exists – the climate and weather patterns typical of the area, the geology and topography of the area including proximity to rivers or coastlines, and the flora and fauna that coexist with the site. Because I am considering specific manifestations of abandonment and structure collapse in Maya sites in Belize, primarily those within the Rio Bravo Conservation and Management Area (RBCMA) in the Orange Walk District, it is important to discuss the modern environmental conditions of the area. The RBCMA exists within the geographic region referred to as the Three Rivers Region (See Map 1) because of the rivers that border it: the Rio Azul, Rio Hondo, and Booth's River (Moats 35). The Three Rivers Region is characterized by karst topography formed from Miocene/Oligocene (Cenozoic) limestone bedrock that extends through the Yucatan and into Guatemala (See Map 2) (Farnand 4, Ower 498).



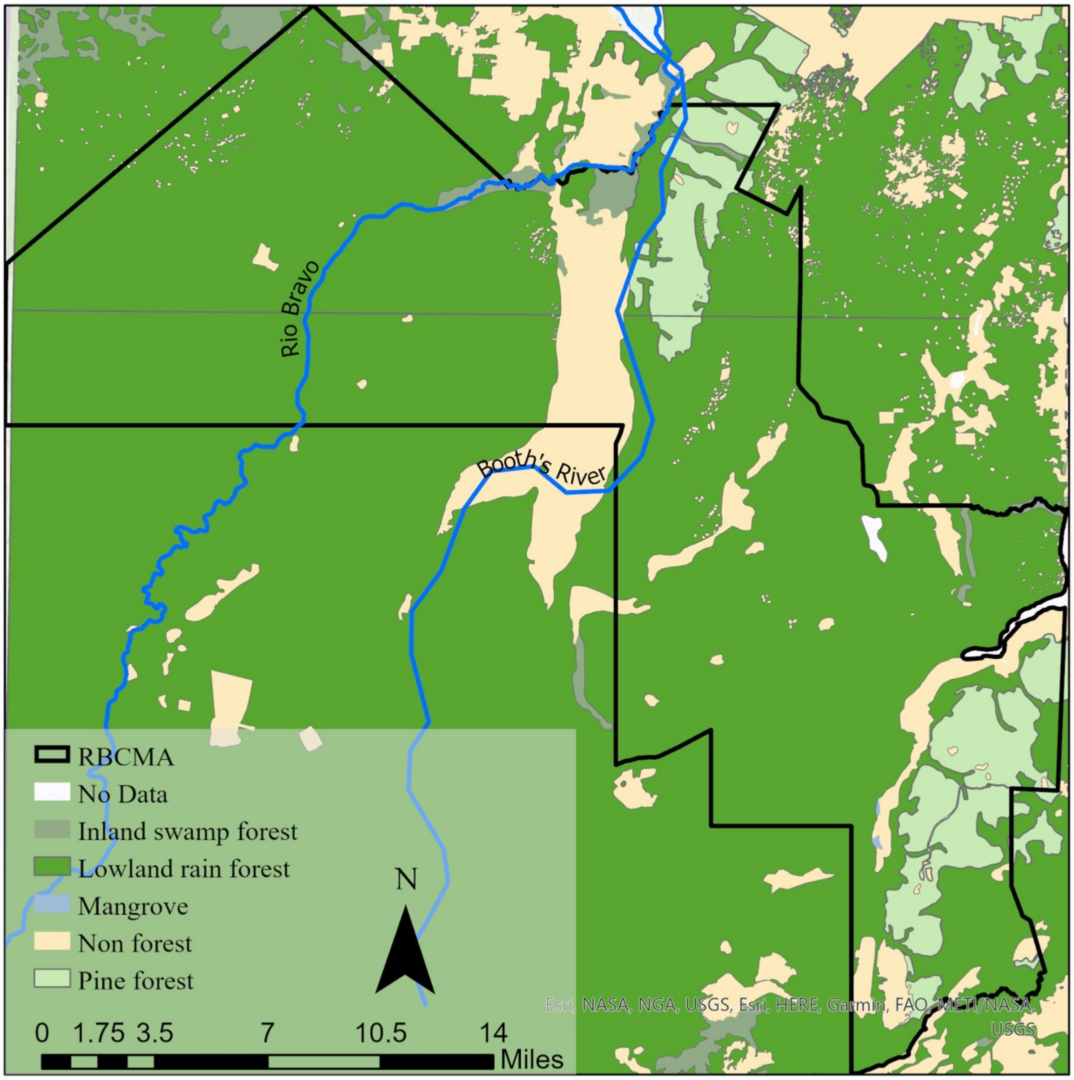
Map 1: Location of the RBCMA in Belize.



Map 2: Surface Geology of the Three Rivers Region. It is clear from this map that limestone is the most common surface formation in the region, with alluvium also covering portions of the landscape.

The main karstic features in the region are three escarpments, the Rio Bravo, the Booth's River, and the La Lucha escarpments (Moats 35). These escarpments are part of the Petén Karst Plateau and were formed by tension faulting, leading to differential weathering, which caused differences in the density, porosity, and elemental composition of the limestone bedrock (Brennan 3179-3180). In between the escarpments are seasonally inundated bajos, which have been studied by archaeologists as resource extraction areas. Residential structures and larger sites tend to have been built at the top of escarpments and hills, with agricultural terracing on the slopes (Brennan 1380).

The karst are characteristic of the weathering of limestone in the tropical climate of Belize. The RBCMA is classified as a Subtropical Moist Life Zone according to the Holdridge classification system (Shono 67). The conservation area covers more than 260,000 acres of rainforest and receives approximately 1500 mm of precipitation annually (Farnand 4). This rainfall is distributed between two seasons, a winter "dry season" between February and April receiving less than 100 mm per month, and a "wet season" with two peaks during the months of June/July and September/October in which over 200 mm of precipitation can fall per month (Farnand 4-5). The vegetation of the region varies with the terrain, ranging from dense upland forest to seasonal marshes and swamps in the bajos (See Map 3) (Valdez 258). Of the 240 species of tree recorded in this region, many, particularly mahogany, chicle, and logwood, have been logged for commercial purposes (Peedle 6-7, 19). The logging of mahogany, which lasted from the mid 19th century to 1982, had large effects on site disruption in the region as roads were cut and huge trees felled (Shono 68). The RBCMA also contains a wide assortment of animals, insects, birds, including jaguars, tapirs, and parrots, among many others (Peedle 19).



Map 3: Vegetation types in the RBCMA. Rainforest covers most of this area, but seasonal swamps – the bajos – exist throughout as well.

Archaeology and Culture History

Current archaeological investigation in the RBCMA is directed by the Programme for Belize Archaeology Project (PfBAP). The Programme for Belize was founded in 1992 to promote conservation, research, and biological diversity in Northwest Belize (Sullivan 8). PfBAP works under the direction of Dr. Fred Valdez Jr. and the University of Texas at Austin to study the economic, political, and social structures of sites associated with the major Classic period cities, such as La Milpa, in the greater Three Rivers Region (Sullivan 9). While the Three Rivers Region spans the Belize-Guatemala border, this modern political boundary is irrelevant to ancient settlement patterns, but highly relevant to the archaeologists who do research in this region. The border tends to force archaeologists to confine their research to sites on one side even though all sites within the region would have interacted with each other in some way, through economic, social, or political relationships.

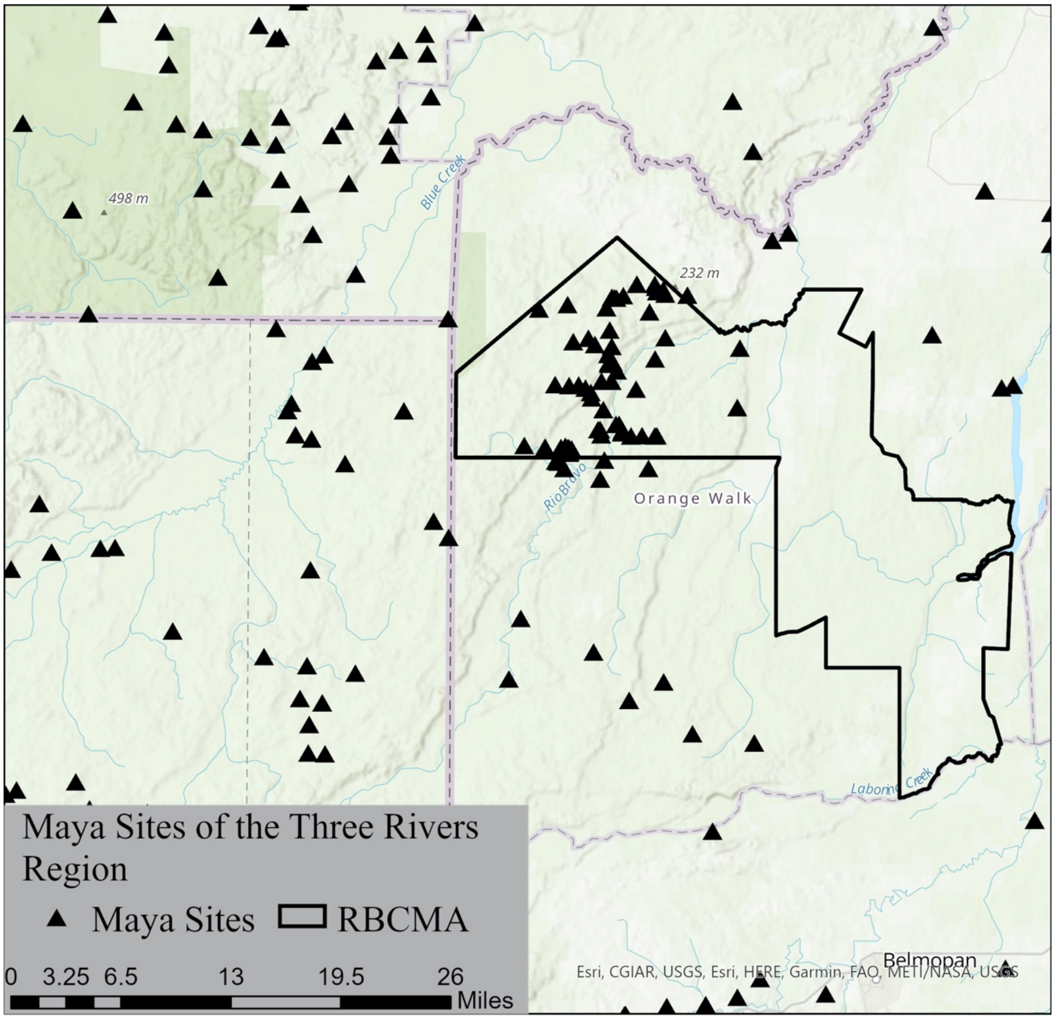
Cultural Period	**Date Range**
Preceramic	c. 3000-900 BCE
Middle Preclassic	c. 900-300 BCE
Late Preclassic	c. 300 BCE – 250 CE
Early Classic	c. 250-600 CE
Late Classic	c. 600-800 CE
Terminal Classic	c. 800-900 CE
Postclassic	c. 900-1400 CE

Table 1: Maya Chronology (Sullivan 40).

The central lowlands region, more specifically the Three Rivers Region, has been occupied to some extent since 3000 BCE (See Table 1), when data from fossilized pollen suggests human manipulation of the forest and more widespread deforestation by 2500 BCE (Sullivan 40). Evidence of Middle Preclassic occupation from La Milpa and Dos Hombres, both sites within the RBCMA, suggests that people lived in small, primarily agricultural settlements near water sources (Sullivan 42-43). Structures during this period were primarily wattle and daub, and construction of platforms, used to artificially level the ground on which to build and to raise structures above the ground surface, is seen towards the end of the Middle Preclassic (Sullivan 42). An increase in population and hierarchical complexity characterize the Late Preclassic, while settlements tend to remain near stable sources of water. The platforms on which residential structures were built were elongated and enlarged during this time period, and public architecture, such as temples or administrative centers, became more monumental (Sullivan 43-45).

The transition between the Preclassic and the Classic periods is marked by shifts in population and political power, primarily due to the emergence of Tikal as a regional power replacing, likely by force, former power Rio Azul in the Three Rivers Region (Sullivan 47). Populations were not evenly distributed throughout the area – people were more concentrated in a few sites in the western half of the Region whereas in the eastern half the population was more rural (Sullivan 48). The last century of the Early Classic is marked by the so-called Middle Classic Hiatus, in which populations declined, monumental construction stalled, certain major sites - like Rio Azul – were temporarily abandoned, and Tikal's influence in the area declined (Sullivan 48).

The onset of the Late Classic period brought population increase to its maximum level in the Three Rivers Region and an increase in architectural construction and styles (Sullivan 50-51). Images of war and the construction of defensive walls suggest that warfare between settlements was significant during this period (Sullivan 50, 53). The Terminal Classic was a time of societal reorganization, both class-based and regional. Abandonment and destruction of large sites was prevalent and the population seemed to concentrate in defensible areas such as cities or even migrated to the highlands (Sullivan 54). This population decline in the Three Rivers Region was finalized in the Postclassic. Most sites in the RBCMA show little to no evidence for occupation beyond the Terminal Classic (Sullivan 55). Because of this large-scale population shift, the "Maya Collapse" is considered to have occurred at the end of the Terminal Classic. Using the word collapse is a bit of a misnomer, as Maya culture did not cease with the end of the Terminal Classic, but the large-scale occupation of the central lowlands ceased after this point.



Map 4: Maya Sites of the Three Rivers Region. This map shows the total distribution of sites throughout the region without respect to time period.

Section 2:

Abandonment

An archaeological site is not formed in a single moment but by a series of events from the first human alteration to modern archaeological investigations. Forces of erosion and other factors make it difficult to observe and record every event or occupation that took place at a site. The latest phase of occupation of a site is typically the stage in a site's history with the best preserved information. This evidence can point to the reason for a site's abandonment.

Types of Abandonment

Site abandonment takes many forms, and at its most basic level is defined as "the process whereby a place – an activity area, structure, or entire settlement – is transformed to archaeological context" (Schiffer 89). Archaeological context is the opposite of systemic context, when a structure is actively part of a cultural system (Stein 39-40). Abandonment is the transition point between these two contexts. This definition is largely inclusive of all possible forms of structure abandonment, but it relies on the distinction between what is included in the archaeological record and what is not. This distinction is blurred where unoccupied buildings and spaces are mingled with occupied ones. In the Three Rivers Region, this distinction is clearer. While there is still active human influence in the RBCMA and even occupation at the PfBAP campsite and the neighboring ecolodge, those sites considered to be within an archaeological context, for the purposes of this research, are those that have been abandoned and overgrown by the jungle.

Abandonment is more complex than whether or not a space is occupied by humans at a given time. Abandonment can be categorized, for example, as temporary, meaning that occupants may return seasonally or after a relatively short length of time; or long-term, if the same group returns after years or generations or if a different group inhabits a site after a long period of no occupation. Permanent abandonment, on the other hand, refers to the definitive end of human occupation of a site caused by an event in the past with no subsequent occupations through to the present (Cameron 155 and Stanton 7). A site can undergo multiple types of abandonment within its history. For instance, a community may have intended to permanently leave a site, in which case it would have passed into the archaeological record, but after a few generations, the site is found by a different group who begins to build again, reusing some of the resources left at the site, before the site is truly permanently vacated due to collapse during earthquakes. In this case the site would be said to have experienced long-term abandonment before eventually being permanently abandoned. Evidence for multiple abandonments or stages of abandonment, or piecemeal abandonment, can be found in the archaeological record through excavations, but this thesis is primarily concerned with permanent abandonments or the final abandonment in a series.

Structure Use-Lives

Abandonment is frequently a slow, intentional process, except under circumstances that necessitate a rapid unintentional abandonment, such as war or natural disaster (Cameron 157 and Stanton 233). The decision to abandon rather than maintain or repurpose can be considered in terms of a cost-benefit relationship, that is, the cost of putting resources into continued maintenance of a structure must be considered worth the benefits of its continued use (Cameron 157). As modeled in Figure 1, the use-life of a structure has many possible paths and cycles before its introduction to the archaeological record. Understanding the different elements of a structure's life cycle is important to understanding why and how it became part of the archaeological record. The first important factor to be considered in relation to structure collapse and abandonment is its construction. The purpose of a structure, the materials used to make it, and its intended longevity may all play a role in its eventual destruction and/or abandonment, with the caveat that under extraordinary circumstances – namely destruction through human or natural means – the intentions behind a structure play little to no role. The logical conclusion can be drawn that the more effort and resources put into constructing a structure, the longer it is intended to last (Cameron 158-159). Structures with shorter intended use-lives are often built of perishable materials, such as pole and thatch structures that decay especially rapidly in tropical climates like that of Belize (Cameron 159). Perishable materials often denote lower status of the occupants of a structure as the materials tend to be more widely available and require fewer specialized skills to

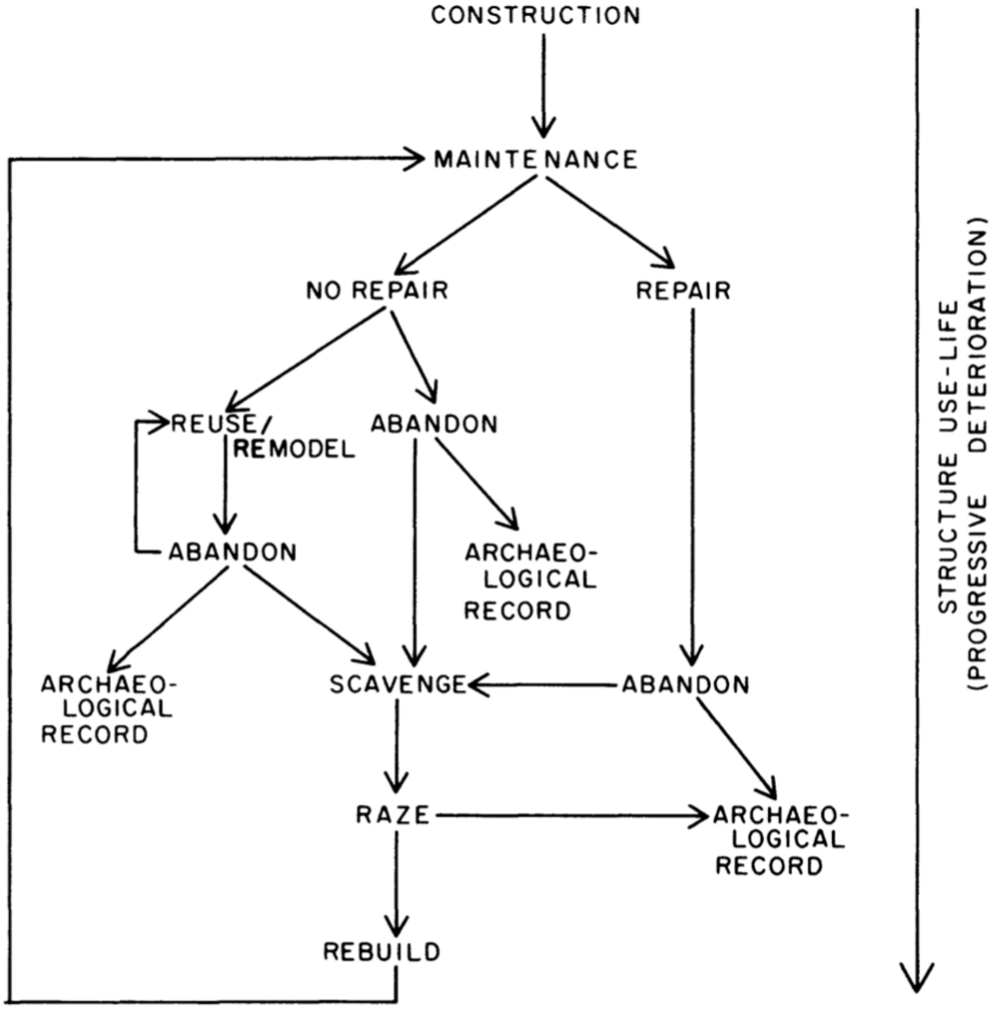


Figure 3: Structure Use-Life (Cameron 158)

manipulate. Stone may have been a primary construction material for larger and more elite structures, but clay and wood were essential to residential architecture, structural support, and construction fill (Wernecke 31-32). This correlation between building material and social status or wealth impacts what is preserved and studied. The archaeological record tends to bias elite material because elites have access to the resources to build structures with long use-lives, the same structures that tend to survive through the archaeological record, as well as the historical trend of archaeological studies to prioritize elite material over non-elite material. This bias on the part of researchers shaped much of the early history of archaeology as a discipline. Modern archaeological research works to confront this bias and investigate all aspects of the physical past and the lives of both elites and non-elites.

Part of the cost of building and maintaining a structure is the expense in terms of both energy and time put into obtaining the materials to be used. Material and labor cost in a stable community are typically low enough that maintenance and repair are preferable to abandonment or destruction during a structure's intended use-life. The length of this use-life is determined by multiple factors, one of which being the rate of deterioration. Stone as a building material has the longest use-life, as it is the most difficult to weather or rot, but stone constructions are subject to the quality of their construction, the amount and quality of mortar used, and the mass of the structure itself (Cameron 161). Even among stone structures some are longer-lasting than others, such as pyramids, which efficiently distribute weight across a base, assuming that base is stable. Other materials decay at a more rapid pace. Mud, fired into bricks or otherwise, is particularly susceptible to erosion by water (Cameron 160). Plaster, when applied over mud walls, can increase its longevity, but cracks must be attended to quickly so that moisture does not accumulate behind the plaster (Cameron 161, 163). Organic construction materials, such as wood or grasses, have the shortest use-lives. They are subject to biological agents of destruction, such as insects, bacteria, and fungi, as well as water damage (Cameron 159-161). Even the most insect and rot-resistant woods are subject to total disintegration within fifty years without maintenance or replacement (Wernecke 73).

If maintenance and repair no longer suit the needs of the people using a structure, or its original purpose has become obsolete, a decision must be made to either reuse the structure for a new purpose, destroy the structure and rebuild, or abandon it and rebuild somewhere else (Cameron 163). Reuse for a secondary purpose can conserve resources and still provide a function to the structure, especially when land or resources may not be readily available or reasonably acquirable (Cameron 168). Reuse of structures or at least their components is also common when populations increase (Cameron 165). Reuse of a space can occur without the destruction or exact reuse of the original structure that stood there. The potential for reuse is not based on practicality alone. Even in occupied areas, structures may be abandoned due to a stigma or strong belief that is attached to them. Houses where someone has died or been extremely ill are often abandoned or destroyed rather than salvaged or reused (Cameron 167). Thus, it is a tradeoff between the need for usable space and the power of belief or strength of a stigma.

Causes of Abandonment

While maintenance and reuse can elongate the use-life of a structure, my thesis is concerned with structures that are now a part of the archaeological record, those that have been permanently abandoned. The causes of abandonment are varied and the processes differ from site to site, because even if the environment or social pressures are similar at sites within a region, people will react differently to every case (Valdez 256 and Moats 4).

Up to this point, I have made the argument that structures, at their most basic level, are defined by their utility, and that this utility is the sum of a structure's purpose, both practical and cultural, the cost of construction and maintenance, and the benefit that the structure provides to a person or community throughout its use-life. Some structures may lose their usefulness over time and be left to decay without interference, while others are abandoned due to an event or series of events that necessitate abandonment over continued use for the safety of its inhabitants or other reasons (Valdez 262).

The natural and societal causes of abandonment are varied and often mingle with each other to build conditions that necessitate abandonment more than one factor alone could. In some cases, abandonment is truly caused by only one factor, typically in the case of extreme natural disasters. Natural catastrophes can destroy structures and force the relocation of entire populations (Cameron 178). These disasters include fires, floods, earthquakes, volcanic eruptions, and, particularly in the Caribbean region, hurricanes (Cameron 178 and Peedle 24). These events can render structures and their components unusable or unsuitable for reuse. Repeated events can discourage resettlement leading to the permanent abandonment of an entire area (Linn 361). Another natural phenomenon that can preempt abandonment is climactic change, especially drought. Droughts can range from short-term dryness that is inconsistent with local weather patterns to drastic shifts in the amount of precipitation resulting in water emergencies and significant crop losses (Valdez 256). In the case of drought it is typically the reactions of the people that determine whether a site will be abandoned, because different groups have been shown to react differently to the same level of environmental change and thus have different abandonment patterns (Valdez 256).

Changes in social structure are often the most influential factors for abandonment. Regional conflict and challenges to social hierarchy tend to have the effect of displacing populations and abandoning structures and even whole settlements. Usually instigated by a combination of factors, including economy and environment, deterioration in societal structure is a main avenue towards abandonment (Moats 56). Challenges to social hierarchy can lead to the abandonment of elite-associated spaces. In these cases there tends to be evidence of violence or destruction as connections to the elites that utilized such spaces, homes or even religious spaces, are erased (Moats 31-32). Challenges to elite authority can be consequences of large-scale relocations of populations to elite controlled areas like cities. Shifting populations can lead to the abandonment of peripheral sites while populations at regional centers surge, leading to the illusion of total population decline (Eppich 92 and Valdez 260). These people could be fleeing warfare, disease, or natural disaster, but the ultimate result is abandoned sites with high densities of left-behind artifacts (Stanton 233). Regional warfare can push people from towns and villages to shelter in easily defensible urban centers (Eppich 92). Sites abandoned during times of warfare can be sacked, burned, and otherwise destroyed, leaving them sometimes permanently abandoned.

Abandonment in Process

Abandonment as an event is the liminal space between systemic and archaeological contexts. The circumstances leading to abandonment have direct influence on what happens as a site is abandoned. If an abandonment is planned people are likely to remove all or most of their belongings and salvage usable materials from the abandoned structure or site before moving on and rebuilding. If an abandonment is sudden, people may not have time to gather their things, thus leaving a larger quantity of artifacts to the archaeological record and leaving the structures in question to the processes of nature (Stanton 233). Some intentional abandonments are marked by physical changes to the space that can be studied in the archaeological record (Moats 4). In sudden abandonments, one might expect that most artifacts are left in their original context, as if people had to pick up and leave in an extremely short amount of time, taking only what is necessary (Stanton 233). It can be expected that a usable space is kept relatively clean and organized, at least to the point where a person could maneuver through the space without difficulty (Stanton 230). In a violent abandonment, where structures are sacked and people leave in an unorganized fashion, debris, possibly burned or broken, may cover the floors of structures haphazardly, but in this case these materials would still have belonged in the space originally (Stanton 233).

When many kinds of artifacts, usually broken ceramics that do not form whole vessels, bones or cooking refuse, and mundane litter, are found together in a deposit, it is often interpreted as a midden, or trash heap (Stanton 234). The physical differences between a terminal deposit and a midden in the archaeological record are context and content. Middens are often found separated from occupied structures and usually contain the refuse of daily life rather than artifacts with associated value, such as precious stones, carvings, decorated ceramic, and even human bone (Stanton 230, 237-239). The purpose of a termination activity or ritual is to literally or symbolically change the purpose or meaning of a space from active use to "abandoned" (Moats 15). In this context, "abandoned" does not necessarily indicate that no one lives near or knows of the space, as some abandoned structures are regarded as sacred, and while they are no longer physically maintained, they may be visited as a potentially religious or cultural site where the deterioration increases the symbolic importance of the space (Stanton 14-15 and Moats 51).

Termination events that occur directly prior to permanent abandonment are the most prominent in the archaeological record, as the physical remains of them are never cleaned up in order to reuse a space (Stanton 237). The contents of termination deposits are related to the events and context that formed them. Destructive events like fires, both intentionally and accidently set, would result in cracked masonry, burned pottery, and ash layers (Degryse 219). Other natural disasters might similarly leave structural damage, scattered and broken artifacts, and layers of debris. Unlike deposits associated with termination rituals, deposits from abandonment due to natural disaster would be expected to be spread out, whereas termination ritual deposits are more concentrated to a single structure or part of a structure. These deposits often bar entrance to or block off use of a structure so that it must be abandoned (Valdez 264). Some termination rituals or events involve displays of violence. These violent actions may be related to sacking, which is practiced around the world, in which structures are destroyed, people killed, and valuable items looted, among other things.

Factors Post-Abandonment

Up to this point, I have discussed structures while they are part of a human cultural system both in systemic context and the liminal state that exists prior to their entry into archaeological context, where they are subject to the transformations of site formation processes (Stein 39-40). These processes are both anthropogenic and natural, and physically transform the structure through degradation, conservation, and the movement of elements – including relocation, removal, and addition (Stein 40). The three temporal categories of abandonment - seasonal, long-term, and permanent - induce different extents of physical deterioration, particularly because of the ratio of human to natural influence each category implies. Most natural deteriorative processes require longer lengths of time to make significant impacts on a structure than anthropogenic processes. In seasonally abandoned structures, these natural impacts, typically no more than a buildup of sediment, some vegetation growth, and small-scale structural damage, would be routinely cleared away or fixed. In a long-term abandonment, the impacts of nature are greater but would still be cleared away when the structure was reoccupied. In both these instances, the human impact on the structure is greater than the impact of nature after its initial abandonment, because it is reoccupied and cleaned. Permanent abandonments imply a much greater impact of non-human phenomena compared to the impact of humans post-abandonment. Nothing is cleared away or repaired, leading to a natural accumulation of material that may eventually fully cover the structure.

When maintenance stops, the materials making up a structure begin to break down. Organic materials decay the fastest, being broken down by biologic agents, such as bacteria and insects, and damaged by moisture (Cameron 159). Even the most insect and rot-resistant woods are subject to total disintegration within fifty years without maintenance or replacement (Wernecke 73). Inorganic construction materials are subject to the agents of weathering and erosion. There are three types of weathering, physical, chemical, and biological. Physical weathering is the breakdown of rock from applied forces – called stresses - both internal and external (Degryse 215). Chemical weathering describes processes that breakdown rock through chemical reactions, including dissolution, where minerals are dissolved in water, and hydrolysis, where water molecules react with molecules in the rock to form hydrates (Degryse 215). In the case of limestone, carbonation is the dominant chemical reaction, taking place between the calcium carbonate in limestone, water, and carbon dioxide. Biological weathering describes any weathering process, either physical or chemical, that is caused by a living thing, such as roots enlarging cracks, organic acids from plant material dissolving minerals, or lichen and algae growth on rock surfaces (Degryse 215). Weathering and erosion of stone act much more slowly than the decay of organic materials, sometimes with only a few millimeters of surface being removed in a few years depending on the intensity of the weathering agents and the rock type.

Agents of weathering and erosion are the physical things and environmental conditions that exert forces or facilitate dissolution of rock, such as climate, temperature, vegetation, and animal and human activity. Water is a primary agent of weathering and erosion. It is both a transport mechanism for erosion and a cause of weathering, particularly of chemical weathering. Another important agent is wind, both abrading stone with carried particles and removing weathered particles (Degryse 225). Weather patterns, in particular seasonal weather patterns, are agents of weathering, allowing for cycles of alternating conditions, particularly a freeze/thaw cycle or wetting and drying (Linn 367). Different types of environment lead to different preservation conditions for different materials. A tropical climate, like that of Belize, is extremely destructive, as the combination of heavy rains, acidic soil, thick vegetation, and large animal and insect populations exacerbates deterioration, especially when acting on a relatively weak stone like limestone (Renfrew 58). While weathering and erosion can be seen as constant processes, the rate at which they occur changes over time as conditions change and new agents are added or equilibrium is reached in a chemical reaction (Inkpen 37). Because of this, the effects of each agent and process cannot be considered independent of each other. As with causes of abandonment, certain circumstances or contexts, when isolated, may not be enough to cause substantial change, but have that capability when combined with others.

Chemical weathering is influenced by climate, rainfall, soil acidity, and soil carbon dioxide levels – especially when considering limestone carbonation – among other things (Trudgill 26). For exposed rock, as one would expect newly abandoned structures to be, rainfall and climate are the most important of the factors that influence chemical weathering. After a structure has collapsed or soil cover has begun to form, the chemical properties of that soil become much more important. Chemical weathering is typically apparent as surface modification that penetrates into the stone but can also act as a shield for future weathering, thus allowing an equilibrium to be reached (Purdy 212). Two mechanisms that act on the surface of materials are selective leaching, the removal of specific elements or ions from the surface layers, and matrix dissolution, where the entire surface, no matter what elements or components it contains, is broken down (Purdy 215-217). Another chemical reaction that can occur is hydrolysis, where hydrogen or hydroxide ions replace mineral ions in the surface layers of a rock (Degryse 215). All three of these surface reactions either tend to or have to take place in the presence of water, and when that water has a low pH, like that of acid rain, weathering happens at a higher rate (Trudgill 36). These reactions are influenced by factors such as angle, surface texture, and water flow rate, because the longer water is in contact with a surface, the greater the chance a reaction will take place (Trudgill 40).

Chemical weathering caused by organic acids produced by plant material is considered part of biological weathering processes. Lichens growing on stone, particularly limestone, produce acids that weather the rock and allow water to remain in contact with the stone surface for longer (Degryse 215-218). Clusters of plant roots growing near a structure, moving closer when the structure is abandoned and the landscape no longer maintained, can also retain water in the soil, weathering structure foundations (Ghestem 875). Accumulation of decomposing organic materials such as fallen leaves and the microbes responsible for that decomposition releases CO_2 and impacts the precipitation of minerals from surface weathering (Yarwood 383).

The forces that cause physical weathering are numerous and the extent of their effects are determined by the physical properties of the rock on which they act. For example, at the level of individual grains, different heat transfer capacities lead to different amounts of granular expansion and contraction with temperature change and this in turn causes granular disintegration (Degryse 215). The porosity of stone is also an important factor in its deterioration, as stones with higher porosity are able to hold more water, which breaks down the stone from the inside as well as from the outside (Purdy 245). Joints, faults, and bedding planes are all areas of weakness where weathering and erosion agents, particularly water, are able to enter and further deteriorate the rock (Trudgill 12). In a limestone formation known as a pavement, weathering is concentrated in the joints that cover the pavement surface (Trudgill 54). The physical phenomena of joints, faults, and bedding planes in large-scale rock units are paralleled in stone constructions as the places where one building block meets another. The introduction of water into these spaces and any cracks that form during collapse exacerbates the deterioration of structures (Wernecke 94). All rock types have an inherent strength, a product of their molecular structure, that must be overcome for the rock to break or crack. This strength is overcome by a net force, the combination of all forces acting on a point or stone. In the case of a stone wall, the inherent strength of the stones is greater than that of the mortar used between them, but once the mortar is compromised, the wall as a whole becomes unstable – the stones themselves do not need to be compromised for the whole wall to collapse.

The most destructive forces of weathering are those that exert forces in vulnerable areas of a structure or rock and induce movement of particles. Water that undergoes freezing and thawing cycles can quickly enlarge cracks in a rock and, if it inhabits and internal cavity in the rock, break it from within if enough pressure is gathered (Wood 333). Similarly, clay-rich soils hold water and expand, in some areas undergoing seasonal expansions and contractions that mirror increases and decreases in rainfall (Wood 352). Clay used as a binding agent or part of a mortar in construction could expand when allowed to absorb a lot of moisture, putting pressure on the stones it holds in place, sometimes enough pressure to crack the stones or push them out of place in the wall (Degryse 224). Roots, as a part of the physical side of biological weathering, also inhabit and expand cracks in stone (Linn 365). Expanding the cracks allows for more water to pool, which both erodes the stone further and helps the roots continue to grow (Ghestem 874).

Structural weaknesses caused by abandonment and weathering can mount to such a point that the structure begins to collapse. Collapse can be piecemeal, with blocks falling one by one; gradual, as walls and foundations slump; quick, via catastrophic structural failure and rockfall; or a combination of one or more of these rates. All forms of collapse are dependent on gravity outweighing the forces keeping the wall standing. Because of this dependency on gravity, collapse of stone structures can be modeled by geologic mass wasting processes. Collapse is sometimes a direct consequence of physical weathering, particularly where water, expanding clays, or plant roots push blocks in a wall out of place. Natural disasters can also cause collapse. Earthquakes can destabilize structures to collapse them, sometimes instantly, and heavy rains can cause stones to fall from walls (Linn 361). In Belize, the most destructive natural disasters are hurricanes, damaging both modern and ancient structures (Peedle 24).

If a wall is modeled as a cliff, with bedding and jointing running through it where blocks meet each other or where cracks exist in the stone, when a stone or piece of stone falls or is pushed off the wall, it will behave as if it had fallen off a cliff, albeit a relatively small cliff. It is important to note that structures that already have sloped sides, such as pyramids, will not collapse or form mounds in the same way as those with vertical or near-vertical walls. It is only vertically-sided, stone structures that are being considered in this current discussion. This “cliff” will degrade to a slope in a relatively short amount of time, as compared to the geologic time scale (Kirkby 349). These slopes are essentially the collection of fallen stone debris, which is another reason why a comparison can be made between structure collapse and geologic collapse. The properties of slopes formed from cliff rockfall are dependent on the type of rock, the size of the falling pieces, and the height from which they fall (Sæter 6-7). Tall cliffs tend to form a talus that has a straight upper slope which transitions to a concave slope at the bottom (Sæter 7). On a smaller scale, such as the height range of stone structures, the concave section is minimal or non-existent, leaving a relatively straight slope (Statham 51). This slope is referred to as a scree and is caused by noncohesive debris falling from a cliff (Kirkby 349). Screes tend to extend up the entire cliff once equilibrium is reached, creating one continuous hill that is at a relatively stable angle of repose (Statham 43).

I will consider two basic qualitative categories of rubble that make up the talus, though in reality, the stones and particles exist on a continuum. The first category is weakly weathered stones, primarily including whole blocks from the wall and large chunks of stone easily identifiable as having come from the wall by rock type or shape. The second category is highly weathered material: all of the other eroded material that makes up the slope. Considering the first category of rubble, because it is relatively nonweathered, it would have fallen off or out of the wall soon after abandonment, before the agents of weathering have been allowed to work for a prolonged period of time. Thus, large pieces of rubble will make up the initial wedge at the base of the wall (Bloom 189). Natural examples of this on approximately the same scale occur because of faulting or river erosion, which leave an area unstable by removing supporting material or decreasing the internal strength of the rock (Bloom 189). All of the varied causes of this instability can be boiled down to one concept: collapse is instigated by an unbalanced force, which, in the case of mass wasting, is gravitational.

People tend to build structures to resist the pull of gravity, however, as previously discussed, maintenance is required to combat unrelenting forces of natural deterioration. In a vertical wall, the force of gravity compresses stones laid on top of one another, and is met by the normal force, directed up, which each stone exerts on that directly on top of it, preventing it from sinking downward (Figure 4A). As long as this equilibrium is maintained, a wall will stand. Either internal or external forces can disrupt this equilibrium. As shown in Figure 4B, such an external force may be from fill settling behind a retaining wall. Settling introduces an unbalanced horizontal force on the wall. Other sources of unbalanced force come from erosion of soil around the base of a structure, or even vegetation growth, particularly root growth. Large tree roots can grow under foundations or wall and cause uplifting of the soil and disruption of the wall, or they can grow in cracks or between blocks where mortar has been eroded away expanding that crack over time and forcing the blocks to shift (Ghemstem 870).

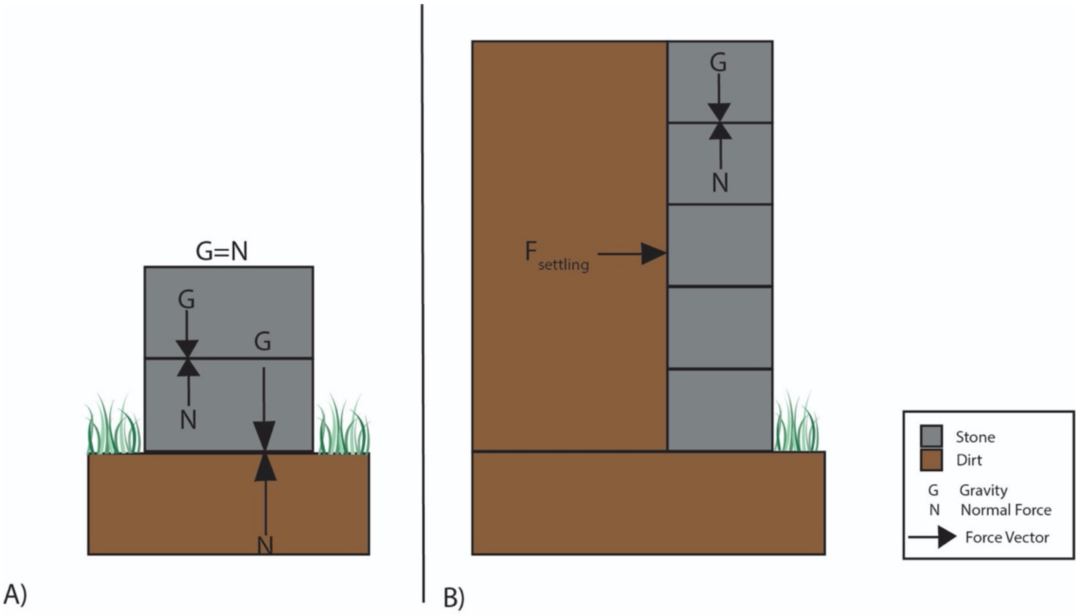


Figure 4: Simplified free-body diagrams of walls. A) A free-standing wall showing balanced forces. This wall is stable and will not collapse. B) This diagram shows a retaining wall or a wall that runs along the outside of a filled foundation, like those built by the Maya (Wernecke 56, 58). As the fill settles over time, it exerts a force on the wall that is not balanced.

While Figure 4 portrays the force of a settling foundation as having no counter-force, this is very simplified. A main counter force is the force of friction, both friction between the blocks and friction between the ground and the wall. The force of friction, F_f, is calculated by multiplying the coefficient of friction (μ), a constant dependent on the materials, by the normal force, N=mg.

$$|F_f| \leq \mu |N|$$

The idea that F_f is less than or equal to $\mu|N|$ is imperative to the idea of balancing the forces and resisting collapse. F_f will be equal to the external force, balancing it, until F_f equals μN, the upper limit of the friction force. Once this point is surpassed, movement will begin, though friction does not go away. Rather, it changes from static friction to kinetic friction, each with a different coefficient. The coefficient of static friction, μ_s, is always greater than the coefficient of kinetic friction, μ_k. Once the F_f becomes kinetic, the blocks in the wall will begin to move. Because the normal force is dependent on mass, it increases moving down the wall. Thus, because the total mass above the bottom blocks must be supported, friction is greatest between blocks at the bottom of the wall and the blocks at the top of the wall will move most readily. As these top blocks move horizontally, the location of their center of gravity becomes critical. As long as the block remains moving solely horizontally, it will remain a part of the wall, albeit pushed out from the face of the wall, until the center of gravity reaches the face of the wall (Figure 5A). At this point, the block will begin to pivot, with the force of gravity being stronger than the reduced normal force on the block (Figure 5B). Gravity will eventually cause this block to fall to the base of the wall, forming the beginning of the talus.

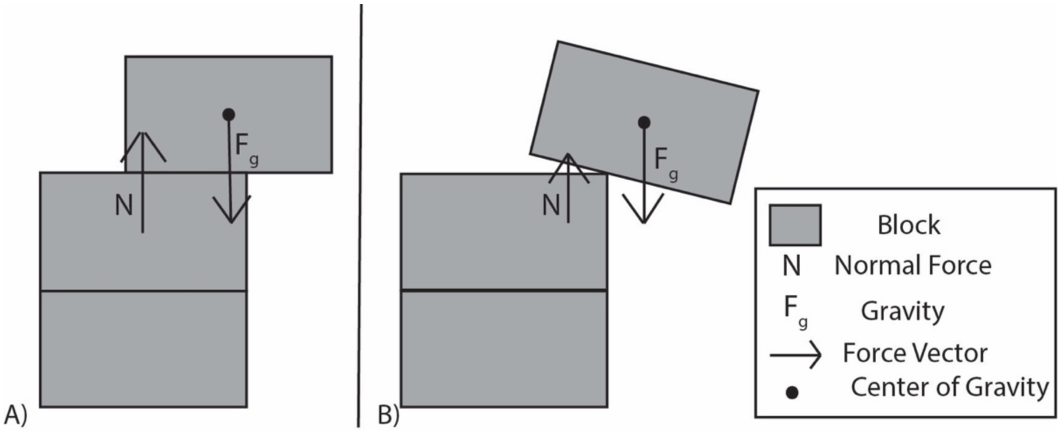


Figure 5: Free Body Diagrams. Free body diagram demonstrating the change in normal force magnitude based on the position of the center of gravity of the above block.

At this point, the second category of rubble is largely in play. The first wedge of large debris will pile up quickly, within a few months or years, then the weathering and erosion processes discussed above will take over the formation of the hillslope (Bloom 189). After, or even as a debris slope forms, soil will be produced that can eventually cover the entire hillslope and what is left of the structure. Soil formation is dependent on five variables, the parent material or type of rock, topography, climate, vegetation, and time (Dincauze 273). The process of soil formation tends to begin with the colonization of exposed stone by lichens, which are then colonized by mosses (Trudgill 66-67). This moss feeds on the lichens, weathers the stone, and produces humus, an organic-rich soil layer that, combined with the moss, is able to support grasses and small plants (Trudgill 67). This growth will happen so long as the stone on which it occurs remains still and is exposed to enough moisture, which can happen after a structure has fully collapsed, or stone by stone as they reach their final resting place in the collapsed pile (Trudgill 67). In addition to moss and lichen generated humus, large deposits of organic material, such as falling leaves and animal dung, or any organic material left behind by the previous inhabitants, will contribute to soil formation. As the humus increases in volume and the parent material continues to be weathered, a soil layer rich in minerals will begin to form under the humic layer (Payne 131). As more weathering occurs, multiple layers can form in the soil, aided by water moving through and gravity drawing heavy particles downward (Payne 130-131). Soil is not just formed in place at archaeological sites, and it is most common for sites to be buried gradually under soil and sand carried by the wind (Renfrew 52). This wind-carried sediment is incredibly important as part of the history of the site as it can provide data on climate and regional events such as volcanic eruption or drought.

There is no condition where soil is left undisturbed after it forms. Pedoturbation is the process of physical and chemical soil mixing (Wood 317). Animals and insects both contribute organic material to soil through decomposition and disturb it while alive through burrowing (Wood 318-320). Vegetation, in particular root growth, presents a contradicting example of pedoturbation. Roots can both mix soil layers and hold soil in place (Ghestem 870). Roots can channel water flow on a slope, preventing large scale erosion (Ghestem 869). Gravity is also majorly influential of soil movement on slopes, resulting in greater accumulation downhill (Day 499). Soil can be carried downslope by water or gravity alone. When large amounts of soil gradually move as one down a hillslope without a transport agent such as water, it is a type of mass movement called creep (Wood 346). When this process happens quickly, it is a landslide, but the process of creep is much different. Swelling of clays, freeze/thaw cycles, and wetting/drying cycles cause the ratchet-like movement of the upper layers of soil, perpendicular to the slope then vertically downward, resulting in a net downslope movement (Wood 347-349). This movement has profound effects on the visible landscape, most notably bent tree trunks or leaning fence-posts (Wood 349). Under the surface, creep will carry any loose artifacts in those mobile soil layers out of their original context and may have enough force to continue to dislodge stones from buried structures. In addition to creep, water will carry large amounts of soil downhill, resulting in the hill profile showing high levels of erosion at the top and large amounts of deposition at the bottom (Trudgill 47). The result of these downslope movements, from creep, water transport, and others is that the maximum height of the hill and its angle decrease in a measurable way. The diffusion equation

$$\delta y/\delta t = c(\delta^2 y/\delta^2 x)$$

tells the rate at which the elevation of the hill is changing given the local slope curvature and c, the diffusion constant (See Figure 6). Because the rate of creep has been shown to be proportional to the tangent of the slope, as the slope decreases over time, so does the rate of change in elevation (Bloom 189).

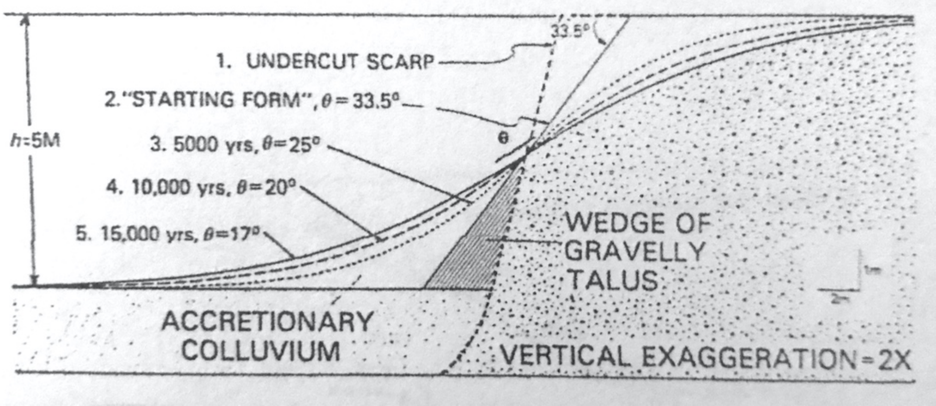


Figure 6: Hillslope Diffusion. This demonstrates five points in the diffusion of a hillslope from the initial straight slope and decelerating diffusion through 15,000 years, and how both angle and curvature change through time. The diffusion constant (c) used in this scenario is $12x10^{-4}$ m^2/yr. (Bloom 189)

Creep tends to act once a hillslope has been established, meaning that there is a relatively stable layer of soil cover. Soil development, weathering, erosion, and collapse will continue as long as a structure remains exposed to nature. In some cases, it will become totally buried. Not every site will reach this point, some large structures will remain partially exposed for thousands of years.

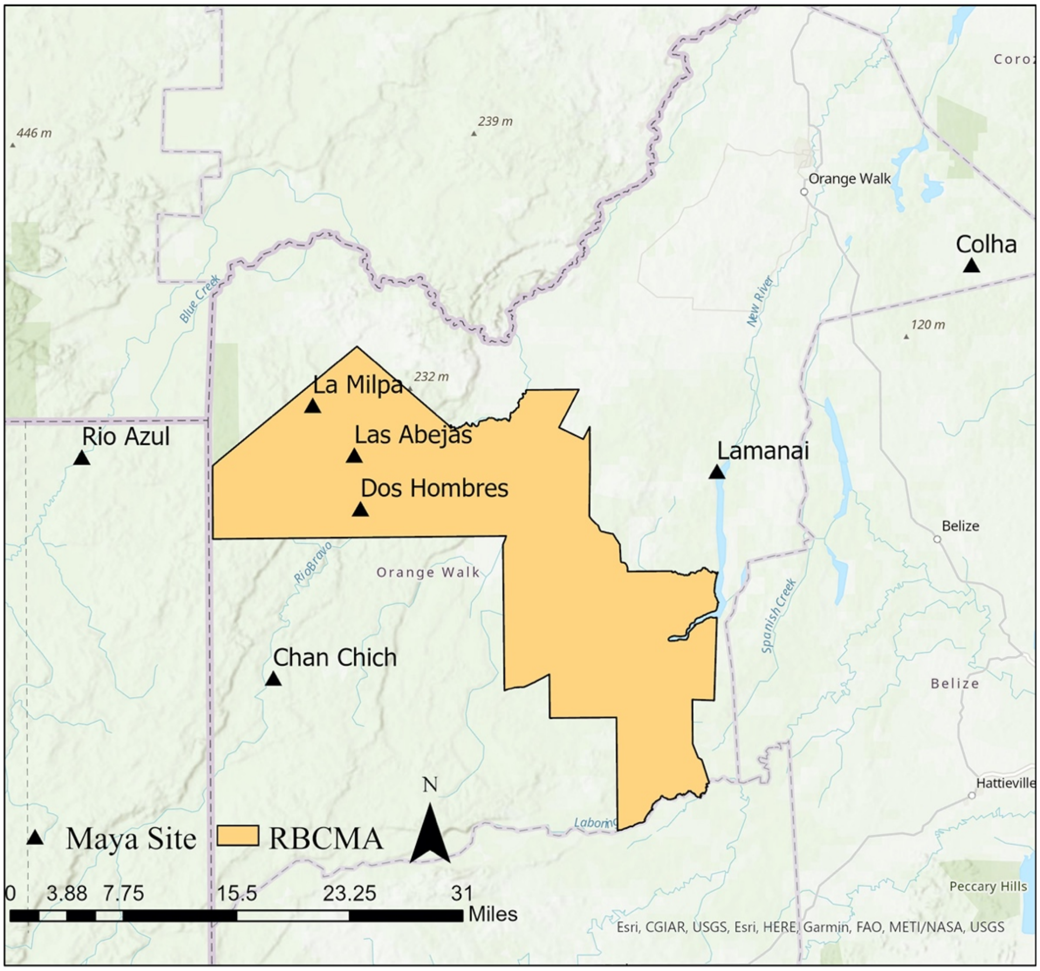
Burial is not just a physical phenomenon. It plays into abandonment in a more anthropocentric way. While many sites remain known by the ancestors of their inhabitants and modern people living in the region, the individual structures and their original functions can be forgotten, particularly when they now exist in hard to access areas, like the jungle. This is a less literal form of burial, where structures become buried in the past – even if they are still visible from the surface of the earth.

To fully understand the anthropogenic impact on sites post-abandonment, it is necessary to return to those moments concurrent with and immediately after a site is permanently abandoned. Materials that are still viable for use, such as wood or stones, are often collected from a building as it is being abandoned for reuse in other structures. This tends to exacerbate natural physical deterioration post-abandonment (Cameron 163). If people remain in the area, abandoned structures see continued use as play sites for children, sources of material for scavengers, or preserved as areas of religious significance or used as burial sites (Cameron 171, 182, Stanton 4). At any point after abandonment, so long as it remains physically accessible, a structure may be occupied by squatters, or people living in a structure without the knowledge or consent of its original owners (Stanton 234). If squatters remain in an area and begin repairing or rebuilding structures, they are technically no longer abandoned. This return to occupation via squatting can be seen as a "reclamation process" for structures, where they return, albeit temporarily, to systemic context from archaeological context (Schiffer, 99). The circumstances of the original abandonment must be significantly changed, be they social, economic, or environmental, for the abandoned site to be reoccupied for a long period of time (Valdez 268).

Human land use in modern and ancient times has an immense impact on the deterioration of sites. Clearing land for farming leads to increased soil erosion rates. Farming itself overturns and mixes soil, destroying the context of artifacts and sometimes destroying sites themselves. Modern chemical fertilizers can damage stone. Construction of buildings, towns, and cities on the sites of buried structures can destroy whatever of those structures was left buried. Deforestation and logging have massive impacts on sites, sometimes destroying them directly with machinery, uprooted trees, and by cutting roadways through forests, leveling sites. Removing the protective trees can expose sites to increased natural weathering and erosion and influence the regional climate.

Another group of human behaviors that disturb sites after they have been abandoned are those that seek to find what is concealed at a site. This can take two opposing forms: archaeological work and looting. Looting destroys structures, artifacts, and the natural environment (Renfrew 55). In order to find and collect artifacts of supposed “value” looters will sometimes cut directly into structures. Archaeological research and investigation can also be destructive, particularly excavation. Exposing physical remains that have been buried long enough to come into equilibrium with their environment that has protected them from further deterioration, reinvigorates that deterioration (Linn 367-368). In order to do as little damage to a structure or site as possible after excavation, archaeologists must either take steps to fully preserve the exposed site or refill the excavation pits. Conservation and preservation are time consuming and expensive projects, so backfilling is more commonplace. Tourism often mitigates the cost of conservation, but having crowds walking through a site can cause damage to the materials and promote soil deterioration (Linn 370).

The Three Rivers Region as a Case Study for Abandonment



Map 5: Specific Maya Sites as Examples. The sites pictured on this map provide the basis of examples used in this section. Not shown – Chichen Itza in the Yucatan; Tikal and El Mirador in Guatemala.

Sites in the Three Rivers Region (See Map 5) provide a case study of abandonment as ample research has been done – and continues – in the area and environmental protections have been enacted that help to preserve many sites from urban development. I will follow the order of the previous subsections, discussing evidence for different types of abandonment, causes of abandonment events or "collapses," the specifics of Maya termination rituals and abandonment events, and finally, a post-abandonment Three Rivers Region.

Types and Causes

Short-term, long-term, and permanent abandonments are all shown in the occupation history of Dos Hombres, where excavations have indicated multiple abandonment events at different times, which influenced the reoccupation and then abandonment of structures or areas within the site during the Terminal Classic (Moats 24, 27). Different levels of intentionality concerning abandonments are also represented in the region The Maya primarily used locally available materials for their construction, primarily limestone, clay, and wood (Wernecke 9-10, 15). Limestone is a relatively weak stone, which makes it easy to work with, when compared to rock types found around the world, so it was often used in conjunction with plaster coatings and maintenance to increase the use-life of structures (Wernecke 16). A mortar made from slaked lime was used between limestone blocks to hold them together, and plaster or stucco was used on the interior and exteriors of structures to prevent erosion and water damage (Wernecke 17, 23-24). Because there is little evidence for building foundations, the construction of flat platforms, often built of clay or fill behind a stone retaining wall, were essential to the stability of Maya architecture (Wernecke 56, 58).

The Maya utilized resources near construction sites, sometimes directly adjacent to the site, proximity of resources being something which likely influenced site location in the first place, thus the cost of collecting these resources was low (Wernecke 9). However, the temporal cost of maintaining certain structures was great. The platforms built by the Maya may have required almost daily maintenance because of the environment in which they lived (Wernecke 59). Certain structural problems existed in these platforms as well that often led to collapse before the intended end of the structure's use-life, primarily differential settling of fill material and uneven load distribution which placed pressure on the retaining walls and caused them to buckle or slump (Wernecke 62, 90). Attending to these problems would have been a time consuming and nearly constant concern, so in a situation where resources were thinning or populations are moving, maintaining every platform may no longer have been a priority. Many Maya structures, particularly monuments and temples, were built directly over older structures (Wernecke 54). While this may have saved time, space, and resources as opposed to constructing an entirely new structure, this practice could be detrimental to the stability of the new structure. Any accumulated moisture in the fill between the two layers could concentrate and erode the bottom of the new construction, leading to instability from within (Cameron 161).

. For the Maya, the question of whether to reuse or abandon a structure was not only one of practical use, but one concerning cultural beliefs. Maya structures were "the ideological centers of blood, household, ancestors, lineage, and identity," which suggests that a lot of consideration went into any decision to abandon a site that may have been linked to such ideologies (Stanton 14). The strong association of households to ancestors and identity among the Maya, due to the fact that the dead were often buried in association with households, would have increased the likelihood of structure maintenance and reuse over destruction or abandonment (Stanton 14). Maya structures were sometimes purposefully left to fall into ruin while still being part of an occupied settlement. In this case, the purpose of the structure may have changed from one of practical usefulness to one of cultural significance and symbolic meaning, particularly of reverence to the past or to ancestors (Stanton 5). At sites like Lamanai, in Belize, which have been occupied from Preclassic to modern times but still have structures that have been "abandoned" to the archaeological record, the process of permanent abandonment is blurred by different factors. While structures at Lamanai were purposefully left unused or unoccupied, their significance and potential for interaction with humans continued.

The Maya lived through many cycles of societal change which resulted in periodic site abandonments and population shifts. Most archaeological data for these shifts is centered on the collapse of the elite system and the end of large-scale building projects, which suggests changes in the economy and a lack of centralized ruling systems (Renfrew 482). Many of the Maya "collapses" were concentrated in regions or within the control area of a few major sites rather than affecting the entire Maya population and resulted in population shifts rather than disappearance or loss of population. The Mirador region of Guatemala is thought to have been largely abandoned by 150-200 CE, and the population in this region never resurged to what it had been in the height of the pre-classic (Renfrew 482). Drought may have played a role in the abandonment of sites such as El Mirador during this time period (Valdez 259). Not all sites were affected equally, however, as the Central Lowlands region, including the Three Rivers Region, thrived during the subsequent Classic period, developing new architectural and pottery styles (Valdez 259).

Northwest Belize is situated in the Central Lowland region and had its major decline in the Terminal Classic, approximately 760-930 CE (Valdez 260). Several droughts have been investigated as indicators of abandonments or societal shifts in the Maya world. However, social upheaval during these time periods seems more influential in the abandonment of sites than drought, though the drought may have played an instigatory or inflammatory role. The sites in this region show evidence of the many variables that impacted their abandonment. While each variable alone may not be enough to cause the decline and abandonment of a site, they amplify each other to create a "perfect storm" in terms of lack of resources, sociopolitical instability, and economic downturn. Population growth may have necessitated agricultural intensification, which depleted natural resources and ultimately caused food shortages (Eppich 91). If this overuse of resources were combined with changes in climate or drought, the effects would be even more acute. Debate continues as to the extent of drought in the Terminal Classic, but geologic evidence of increased soil erosion and decreased rainfall indicate that a drought did happen during this time period (Eppich 91). When resources are scarce and the economy is suffering, social disparity becomes very evident and can lead to a breakdown in power structure and control of a site (Moats 56). As elites tried to hold on to their power, competition within and between sites increased, sometimes resulting in war (Valdez 263). Warfare between major sites drove some to be abandoned, as well as encouraging population concentration in defensible areas, like city centers (Eppich 92).

While these factors influenced the region as a whole, they did not equally impact individual sites. Sites were abandoned throughout the region at different times and in different ways due to the individual conditions at each resulting in both sudden and planned abandonments. Planned abandonments existed around El Perú-Waka', where people moved to the site center from the periphery for protection from attack (Eppich 92). Other settlements in the area were abandoned suddenly because of those attacks, having been fortified, then sacked and burned (Eppich 92). In the Three Rivers Region, La Milpa, having been largely influenced by the politics and economy of Tikal, fell into economic decline after the Early Classic Hiatus, c. 534-589 CE, when Tikal lost power in the region (Moats 49-50). The result of this economic downturn and possible environmental changes was a gradual and intentional abandonment of the site, as people moved to increase their chances of survival (Moats 50).

The Terminal Classic marked a general "political demise" in the Central Lowlands rather than a cultural one, as some sites continued to thrive when others around them were abandoned (Moats 11). Lamanai is the primary example of a Lowland site that continued to thrive through and after the Terminal Classic.

While there is little evidence of hardship incurred at the site during the Terminal Classic, it is unlikely that Lamanai totally avoided the effects of the region's turmoil. Because occupation continued, residents likely cleaned up the residue and continued on with their lives (Valdez 265). Some of Lamanai's ability to withstand the troubles of the Terminal Classic may be attributed to its location near a large fresh water source, the New River, which would have allowed its residents to weather droughts and continue to grow sufficient amounts of food for the population, lessening the effects of social inequality and possibly even war (Valdez 268). While the Central Lowlands may have largely declined in the Terminal Classic, the Yucatan and the northern lowlands became the new center of population in the post-classic, centering in sites such as Chichen Itza (Renfrew 483).

Maya Termination Rituals and Abandonment Events

Distinguishing between middens and termination deposits in the Maya region has been controversial because deposits that were once interpreted to be from post-abandonment "squatters" are being re-examined as termination deposits (Stanton 233-234). These termination deposits are typically found on the floors of elite structures or in areas that block access to a space (Stanton 235). At Dos Hombres, in Belize, a deposit in an elite courtyard that marked the entrance to the acropolis held a wide variety of "elite" objects or "special finds," which indicates that this was not a midden but a termination deposit (Valdez 263). By placing these deposits, the intention was to "ritually 'kill' an object, structure, person, or place" in accordance with the belief that buildings and spaces were essentially alive while in use and held connections with ancestors (Stanton 235). At Chan Chich, a site in Belize, deposits of ceramics, obsidian blades, stone tools, and other artifacts, the combination of which indicated that this was not a midden, or trash deposit, were found blocking stairways, presumably to prevent access to the structures (Moats 25-26). In contrast to Chan Chich, a similarly placed deposit at La Milpa changed the function of a structure from that of occupation to visitation rather than blocking access to it altogether (Moats 139).

At Colha, unrest in the Terminal Classic resulted in the execution of thirty or more elites whose skulls were all buried together in a pit (Valdez 260). The structure over this pit then collapsed, likely due to intentional burning, and preserved the skulls (Valdez 264). Similarly, termination rituals at El Perú-Waka', also in the Terminal Classic period, concentrated on an ancestral shrine aimed to destroy the ties of the elite rulers to the site (Stanton 5). The difference between the concept of sacking and the Maya termination events is the lack of randomization in the actions of the Maya (Stanton 236). The evidence of desecratory termination rituals include burning, intentional structural damage, deposits of sharply broken pottery, white marl, and large concentrations of elite artifacts out of the context of their typical use (Stanton 237-238).

Post-Abandonment

The weathering and erosion of sites in Belize are conditions of the environment and obey the chemical and physical principles laid out above. Of particular importance when considering weathering is that limestone is the most prevalent construction stone. Thus, chemical weathering of sites in Belize can be expected to be prominently carbonation – the reaction between water, carbon dioxide, and calcium carbonate in limestone, all of which are abundant (Trudgill 32-33).

The anthropogenic activities that occur post-abandonment are more specific. Logging was a particularly large problem in the destruction of archaeological sites in Belize, being the top industry while it was a British colony, and continuing through the 1900s until areas like the Rio Bravo Conservation and Management Area were created as concessions with logging companies (Shono 68, Peedle 6).

In Belize, local site formation processes have switched between natural jungle regrowth, human influence, and a return to jungle growth (Brennan 3180). Each site has undergone individual processes that have shaped its modern manifestation. For example, evidence at La Milpa shows that it was regularly visited during the Postclassic as part of pilgrimages meant to honor the ancestors (Moats 51). Such evidence here and at other sites may include *incensarios*, or incense burners, and evidence of feasting in elite structures after sustained occupation has ceased (Stanton 15). Certain regional processes, however, exist across sites. In regard to building materials, the limestones used by the Maya were not particularly resistant to weathering or erosion, so once the protective plasters were no longer applied or maintained, the structural integrity of the wall would decrease dramatically (Wernecke 93). As previously mentioned, logging threatened many sites in Belize, both by direct destruction and providing easier access to sites for looters. Drug trafficking through the Belizean jungle, particularly around the borders also threatened archaeological sites, particularly when drug traffickers doubled as looters (Peedle 11-13).

Section 3:

Mathematically Analyzing Mound Formation

Abandonment of a structure creates the conditions that allow for the formation of the deposit I refer to as a mound. The formation of this deposit is really the transformation of a structure in systemic context to a mound in archaeological context via an abandonment event. This transformation is tracked in patterns identifiable in the mound. I am focusing on one pattern in particular: the shape of the mound. Studying change through time is known as diachronic analysis. I have established that it is reasonable to approximate the behavior of a structure post-abandonment as a cliff that is being continuously weathered and eroded into a hill. In studying how a hill changes over time, it is impossible to measure the exact amounts of material being added or subtracted over time, but its shape changes in predictable ways, particularly height and profile. Translating this approach to a mound indicates that the original structure is most likely to have been taller than the mound and would have had vertical or close to vertical walls. As discussed, the wall will decay over the span of a few years into a hillslope with a relatively straight slope (Bloom 189). Once that straight slope is established, the subsequent changes can be described by the diffusion equation discussed in the previous section.

$$\delta y/\delta t = c(\delta^2 y/\delta^2 x)$$

This equation models slopes using a quadratic equation, which, to create a 3D model of a hillslope, is rotated around a vertical axis (Bloom 192). The same approach can be used with mounds, but would need to be applied in sections, as the likelihood that the original structure was a perfect circle or even ovoid is low. It is most likely that the original structure was rectangular or close to rectangular, thus would form four hillslopes that join at the corners. Looking at one section of the mound can still yield results when considering the change in height of the whole unit.

Use of the diffusion equation presents two potential problems: the value of c and determining the best quadratic equation to represent the mound. C is dependent on the soil properties and the climate of the region in question and can range from approximately $4\text{x}10^{-4}$ to $4000\text{x}10^{-4}$ m^2/yr (Fernandes 1310). If the value of c has been previously calculated for the soil type and climate in the area of study, that value can be researched and used for calculation, however, if it has not been researched, additional data collection would have to be done. C can be calculated by measuring the profiles of hillslopes of known ages (Bloom 189). In an archaeological context, this would mean measuring the profile of mounds whose contents have been dated. One could do this in the field, but a more cost-efficient way would be utilizing excavation profile drawings of previous excavations that extended into mounds. The second problem, determining the best quadratic equation to represent the mound, is a result of the individuality of every slope, but is easily resolved through additional data collection in the field. After identifying the base of the mound, several points can be measured on the profile of the mound to be given x- and y-coordinates with respect to the base reference point. These points can then be plotted in a graphing program such as excel or R and a best-fit quadratic equation identified. Once c and the quadratic equation are identified, the diffusion equation can be used to predict the approximate age of the studied mounds (Bloom 189). Because the initial wedge and straight slope are formed relatively quickly, i.e. within a few years, the approximate age of the mound can be extrapolated to be an approximate age of collapse that can help date a mound to a period in the history of a region prior to excavation, where further dating can be done.

Surveys are crucial to determining where the best place to excavate is in order to answer archaeological research questions, and they provide data in several forms. First is the location of sites based on surface artifact density or a visible anomaly such as a mound or visible structure, or proxy evidence such as changes in vegetation growth. The second data category provided by survey is approximate dating. I say approximate dating rather than relative or absolute because the dating provided by analysis of surface finds is really both and neither of these types. A specific style of ceramic or other artifact found during survey can place occupation to the time period associated with that artifact, but does not offer a comprehensive picture of the occupation history. Mound analysis adds to this picture an approximation of when the structure was abandoned – an upper limit on dates of occupation. This method also provides dating when there are no surface finds on or immediately around a mound, or when the land surface is too obscured by vegetation to identify surface artifacts.

Section 4:

Enumeration of Methods

Should conditions allow field work this upcoming summer, I would collect data to test this proposal in the Three Rivers Region of Belize following the methods below.

In the field:

1. Identify an archaeological mound during pedestrian survey.
2. Mark corners of mound for use in planimetric survey and designate one corner to be identified by GPS coordinates for later mapping (see Figure 7).

Figure 7. A flagged mound. Top and bottom corners are marked by pink flags. Courtesy of the PfBAP.

3. Measure the distances between the marked corners of the mound, the angles between those corners, and the orientation of the mound.
4. Measure the height of the mound using a tape measure, string, and level.
5. Identify a reference point at the base of the mound. Do not use a corner. The ideal reference point would be at the midpoint of one of the sides of the mound.
6. Measure the height and horizontal distance away from the reference point for several locations (at least 7) on the slope of the mound. These data points should fall in one line perpendicular to the base of the slope. These will form the basis for identifying a best-fit quadratic equation to model the mound.
7. Repeat steps 2-6 for all mounds identified during survey.

Analysis:

1. Enter the slope profile points taken in step 6 into a data processing program such as excel or R.
2. Utilize the program to make a scatter plot for each slope profile and assign a best-fit quadratic equation to the data.
3. Consider the diffusion equation. If both sides are integrated with respect to δt, the resulting equation would be: $y=tc(\delta^2 y/\delta^2 x)$. By then solving for t, the length of time the hill has been decaying can be found. If c is known for the region, use that value in calculations.

If c is not a known value:

1. Identify previous excavations that have dated the final occupation of a structure or have dated its final abandonment and have published excavation profiles. It is important that the excavation was done perpendicular to the mound.
2. Identify a reference point where the ground appears horizontal or at the end of the profile.
3. Measure several points on the profile at the land surface for height and distance away from the reference point.
4. Plot those points in a data processing program and use that program to identify a best-fit quadratic equation for the data.
5. The knowns for using the diffusion equation are now y, t, and ($\delta^2 y/\delta^2 x$). Solve for c for all of the excavation profiles and average the results to obtain an approximate best value for c. This value can now be used in the previously described analysis.

Additional steps to establish precision and accuracy:

1. In order to confirm that the use of the diffusion equation provides precise results, a slope profile can be measured on each of the four sides of a mound and t calculated for each side. Because all four sides exist in the same environment they should diffuse at the same rate, so each value of t should be approximately equal.
2. Eventual excavation of mounds analyzed with this method would be able to confirm the calculated value of t.

Section 5:

Conclusion

Patterns are the basis of the physical world. All objects on earth are subject to its gravitational field and thus behave in predictable ways – in patterns. Human behavior may seem random at times, but in many ways it is equally as predictable under certain circumstances. Abandonment is the result of people acting in predictable ways under a set of circumstances. While I showed in Section 2 that the causes of Abandonment are varied, the steps taken to get there are predictable. A structure is built, used, maintained, and eventually abandoned based on whether or not it remains useful to its occupants. A combination of stimuli, including warfare, lack of resources, and environmental change, illicit a decision: abandon or remain. The pattern seen here is the relationship between costs and benefits: an abandonment takes place when the cost of remaining outweighs the benefits. Abandonment is the point of transition between systemic context and archaeological context, but in reality it is not just a single moment. In Maya structure abandonments, a great deal of purpose is often associated with the abandonment of a structure, as seen in the archaeological record via termination deposits, meant to kill the structure and permanently end its use. The permanence of some abandonments, as opposed to reoccupations of structures, allows them to move into archaeological context, where a new set of stimuli act on the structures.

The changes undergone by the structure after abandonment are primarily directed by natural forces such as weathering and erosion. While human actions are relatively unpredictable, nature almost exclusively follows patterns, and scientists are often able to use equations to describe those patterns. Thus, after permanent abandonments, where human interaction with the abandoned structure is made indirect, the changes to the structure are predictable and can be traced using a geological approach. A mound forms from a structure in an analogous way to a hill forming from a cliff. Weathering and erosion act on stone elements of the structure and any organic material contributes to the formation of soil cover. In modeling an archaeological mound as a hill, the changes it undergoes through time are modeled by the diffusion equation [$\delta y/\delta t = c(\delta^2 y/\delta^2 x)$]. The method I propose utilizes this equation to calculate the approximate age of the slope, which is also the age of collapse and indicative of the time at which abandonment occurred. Although this method is designed for execution in Belize the governing principles – that collapse and mound formation due to structure abandonment can by analyzed via hillslope diffusion – are applicable to archaeological remains throughout the world. The use of this method during survey would provide an upper limit for when a structure may have been occupied based on when it was abandoned and left to collapse. This can supplement analysis of surface finds to establish a relative chronology of a site based on information from survey prior to excavation.

The field portion of this method does not add significant amounts of time or equipment to standard survey methods. Perhaps a few extra minutes at each mound must be dedicated to measuring the slope profile, but most of the time would be spent on analysis after data collection. In terms of equipment, this method requires a line level, 2 tape measures, and a protractor or plumb bob, all of which are already part of a surveyor's tool kit. This method requires at least two people, one to hold the vertical measuring tape and one to hold the horizontal measuring tape. In all, this method is not impractical or costly. If proven to be accurate and precise, this method could provide additional data on dating that can be used in combination with survey data to better describe population distribution and land use in ancient times without costly and destructive excavation.

Despite the straightforward application of this method, it faces several potential limitations. Because I was unable to collect data, these limitations, much like the method itself, can only be addressed theoretically. First, in the attempt to establish precision through redundancy, it is possible that when calculating t for multiple sides of the same mound, a different value is found. This could happen for multiple reasons. Differential weathering based on the orientation of the sides can occur, but would be evident in all mounds in the area. This discrepancy could also result from error in measuring or plotting the mound surface, or could indicate a failure of the method to accurately calculate the time since collapse. A second limitation would come after the fact, if the structure is found through excavation to have been abandoned at a significantly different time than suggested by the diffusion equation. If t is greater than the actual time since abandonment, it could be due to a previous collapse or the shape of the structure altering the shape of the mound so that it is not consistent with what can be modeled by the diffusion equation. If t is less than the actual time since abandonment the structure may have stood for a longer than expected period of time after the point of abandonment before it collapsed and the slope began to decay. A third potential limitation may be reoccupied structures. While it is likely that, in order to reuse the structure or the location the structure once stood, people would have demolished previous remains, fixed the old structure, or at least cleaned it up, it is possible that multiple occupation periods may skew the results of the diffusion equation. If this is the case, the method may only be applicable to structures with only one occupation prior to permanent abandonment. The only way to confront these limitations is to take data in the field and confirm it via excavation and establishing a date for the final abandonment of a structure from multiple lines of evidence.

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Map Information and Data Sources

Geographic Coordinate System: WGS 1984 UTM Zone 16
Projection: Transverse Mercator

Map 1 Data Sources: ISBER/MesoAmerican Research Center University of California, Santa Barbara, belizetest, GfK Marktforschung, Michael Bauer Research, Environmental Systems Research Institute (Redlands, CA)

Map 2 Data Sources: Eco-Regional Plan of the Maya, Zoque and Olmeca Forests, - a joint effort formed by Conservación Internacional (CI), El Colegio de la Frontera Sur (ECOSUR), Fundación Defensores de la Naturaleza (FDN - Guatemala), Programme for Belize (PFB), Pronatura Península de Yucatán (PPY), The Nature Conservancy (TNC), and Wildlife Conservation Society (WCS). ISBER/MesoAmerican Research Center University of California, Santa Barbara, GfK Marktforschung, Michael Bauer Research, Environmental Systems Research Institute (Redlands, CA)

Map 3 Data Sources: ISBER/MesoAmerican Research Center University of California, Santa Barbara, University of Florida. GeoPlan Center, Paseo Pantera Consortium, US Agency for International Development, GfK Marktforschung, Michael Bauer Research, Environmental Systems Research Institute (Redlands, CA)

Map 4 Data Sources; ISBER/MesoAmerican Research Center University of California, Santa Barbara, FAMSI (Foundation for the Advancement of Mesoamerican Studies, Inc.) http://www.famsi.org/research/MayaGIS/index.html

Map 5 Data Sources; ISBER/MesoAmerican Research Center University of California, Santa Barbara, FAMSI (Foundation for the Advancement of Mesoamerican Studies, Inc.) http://www.famsi.org/research/MayaGIS/index.html