FORAGER SUBSISTENCE REGIMES IN THE THAI-MALAY PENINSULA: AN ENVIRONMENTAL ARCHAEOLOGICAL CASE STUDY OF KHAO TOH CHONG ROCKSHELTER, KRABI

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ABSTRACT

FORAGER SUBSISTENCE REGIMES IN THE THAI-MALAY PENINSULA: AN ENVIRONMENTAL ARCHAEOLOGICAL CASE STUDY OF KHAO TOH CHONG ROCKSHELTER, KRABI

Environmental archaeology is a holistic approach to understanding human environmental intervention. This study examines a late-Pleistocene-to-Holocene archaeological rockshelter site in the Thai-Malay Peninsula, known as Khao Toh Chong Rockshelter (KTC). A mixed-method approach is applied to investigate human behavioral adaptation to a changing climate in the tropical environment of Peninsular Thailand. The changing subsistence regime at KTC describes the shift from hunting-gathering and foraging to opportunistic horticulture. The archaeological and multi-disciplinary methodologies utilized in this research include geoarchaeological sedimentary science, zooarchaeological analysis of faunal remains, and paleobotanical study of deposits of the stratigraphy of the rockshelter site.

The environmental archaeological study of KTC indicated that the hunter-gatherer and foraging groups that occupied the site exploited a wider array of fauna during the mid-Holocene (increasing diet breadth). The geoscience results of this research provided details about shifting from C_4 to C_3 photosynthetic plant ratios during the Holocene, which indicates that more fruiting plants were available during this time. The low pollen yield indicated poor organic preservation, whereas sedimentary analysis illustrated clay-rich deposits that were beneficial for material-culture preservation. Human environmental intervention at the rockshelter indicates that people began moving away from a hunter-gatherer and foraging lifestyle to a more sustainable practice of resource consumption during the mid-Holocene.

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List of Abbreviations

B.P.	Before Present
cf.	Compares favorably
df	Degrees of freedom
ICP-AES	Inductively coupled plasma-atomic emission spectrometry
KPD	Khok Phanom Di
KTC	Khao Toh Chong Rockshelter
LPS	Laser particle size
NISP	Number of identified specimens
NTAXA	Number of taxa
NTSH	Nang Thalee Hong Song coring site
MBS	Meters below the surface
MNI	Minimum number of individuals
p	p value
PKT	Phukhao Thong
r	Pearson's r
R.P.M.	Rotations per minute
SEA	Southeast Asia
XRD	X-ray diffraction

Chapter 1: Introduction to Tropical Environmental Archaeology

Introduction

The main objective of this chapter is to introduce how environmental study influences archaeological science and anthropological inquiry for tropical hunter-gatherer sites. This chapter also provides a framework for the theoretical discussion and the design of the research described in this thesis.

Background to the Research

Environmental archaeology is a holistic approach to understanding human and environmental interaction in the past. Throughout time, human and landscape relationships have been deeply intertwined, so much so, that the topic has been one of much scholarly debate in Southeast Asia (Anderson 1990, 1997, 2005; Dinacauze 2000; Hunt and Rabett 2014; Kealhofer 2002; Kealhofer and Penny 1998; Mudar and Anderson 2007; Penny and Kealhofer 2005; Sponsel 1998; White 1995; White et al. 2004). Anthropological inquiries about how humans persevered intense tropical storms; how hunter-gatherers and foragers adapted their foraging strategies in a changing environment; and how human behavioral response to changing conditions played an integral role in the success of foraging strategies are best answered through the combination of archaeological research and environmental science (Anderson 1997; Bailey et al. 1989; Endicott and Bellwood 1991; Kealhofer 2002; Maxwell 2001; Penny and Kealhofer 2005; Shoocongdej 2000; White et al. 2004). Human behavioral ecology theory and foraging theory provide a predictive framework of how and why human behaviors aid the survival of our species, especially under environmental constraints (Cronk 2003; Lupo 2007; Mudar and Anderson 2007). In this research, I investigate how hunter-gatherer and foraging practices were influenced by environmental conditions and the emergence of an agroecosystem during prehistory.

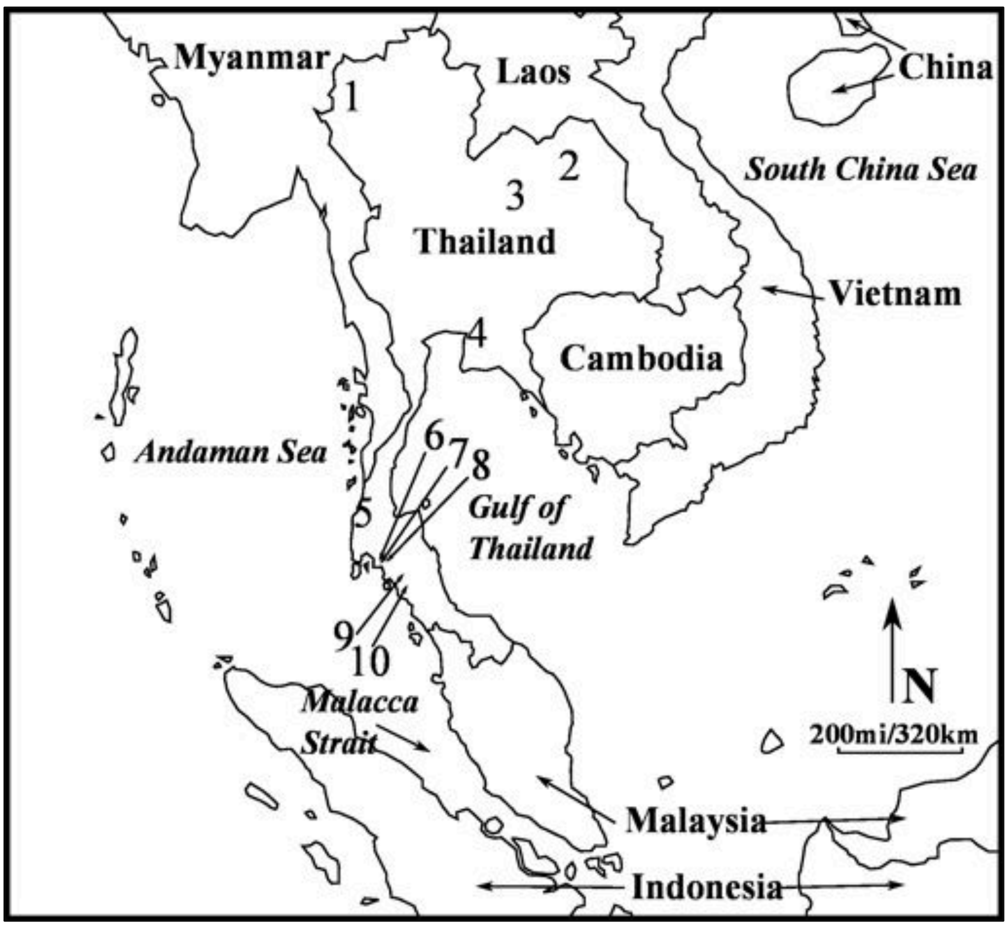


Figure 1.1 Map of Thailand, including (1) Spirit Cave, (2) Ban Chiang, (3) Non Nok Tha, (4) Khok Phanom Di, (5) Phukao Thong, (6) Lang Rongrien Rockshelter, (7) Khao Toh Chong Rockshelter, (9) Moh Khiew Cave, (10) Nang Thale Song Hong coring site.

Environmental archaeology and paleoenvironmental research use proxy data (e.g., fossil pollen, lithology, stable carbon isotopes) to consider human impacts on regional environments through time. Proxy data are often gathered within a general region and not always within specific environments encapsulating archaeological sites. For this reason, the proxy data explored are often circumstantial because caves and rockshelters have specific microclimates. A mixed methods approach was utilized in this research to consider as many aspects of human environmental intervention as possible, including the procurement of archaeological sediment samples for environmental proxy sampling. These methods include analysis of fauna exploited by hunter-gatherer groups, sedimentary science (sedimentology, mineralogy, and geochemistry) to illustrate how the site formed over time and preserved artifacts *in situ*, and analyses of fossil micrbotanicals (phytolith and pollen) to determine changes in plant matter at the archaeological site.

Region of Study

Southeast Asia is surrounded by tectonically active zones, the Sundaland and Sahul plates, that produce frequent earthquakes and volcanic activity; it is considered the most biodiverse region in the world (Wallace 1876) and the origin area of mangrove environments (Ellison et al. 1999; Heaney 1991; Van Welzen et al. 2011). The archaeological material utilized in this research was collected from a prehistoric (15,751-1,931 calibrated years before present) rockshelter site in the Krabi province of the Thai-Malay Peninsula, known as Khao Toh Chong Rockshelter and hereafter referred to as KTC (see Figure 1.1).

During the Pleistocene-Holocene transition (~10,000 years ago), there was a climatic shift from a glacial period to an interglacial period, leading to sea level rise and a general increase in global precipitation. This transition in Southeast Asia (SEA) is reported in numerous accounts (Sinaskul 1992; Maloney 1995; Marwick and Gagan 2011; Maxwell 2001; Tjia 1996). The amount of environmental change (e.g., diminished seasonal differences, changing coastlines and resource availability, and more intense tropical storms) that occurred during this period is reflected in both proxy data (e.g., lithology, carbon isotopes, and fossil pollen) and cultural deposits at archaeological sites (Anderson 1997). An increase in the level of precipitation occurred during this period because of stronger monsoonal rains and the rise in sea level. The present distribution of archaeological habitation sites is due to sea-level transgression, wherein early Quaternary dated sites lie buried within the continental shelf, causing a shift away from open sites to inland and highland archaeological habitation sites. These sites are often found in rockshelters and caves near estuary and river systems (Anderson 1997; Marwick et al. 2013).

Monographs and site reports from the excavations of cave and rockshelter sites in southern Thailand often present an abundance of charcoal deposits, which suggest both human occupation of these sites (as fire is not a naturally occurring disturbance in this wet environment) and generally well-preserved archaeological cultural deposits (Stott 1988). This evidence suggests the need for further investigation about site formation processes, stable carbon isotope testing, and analyses of fossil microbotanicals. Experts suggest the inclusion of palynological and phytolith methods within archaeological pursuits in SEA (Kealhofer 2003; Maloney 1991; Penny 2005; White et al. 1995). Because proxy data like palynology are sensitive to environmental changes, preservation of the microbotanicals is variable. Therefore, this research utilized three disciplinary methodologies (i.e., geoarchaeology, zooarchaeology, and geoscience) to compare environmental trophic levels deposited at KTC by the human occupants.

Aim and Research Question

The aim of this research was to investigate behavioral changes of human exploitation patterns during prehistory in southern Thailand. Changing trends in major climatic systems, plant communities, and the rise in sea level affected human populations in numerous ways yet the human adaptive responses to these changing systems is not well known (Horton et al. 2005). One such adaptive response to changing resources is the onset of cultivation practices. In Thailand, rice is the primary agricultural resource investigated under the predictive model, which suggests the adoption of cultivation to have occurred during the mid-Holocene (Castillo 2011; Kealhofer 2002). The origin of rice cultivation was in Indo-China and the Yangtze Valley of China approximately 6,000 years B.P. (Fuller 2006; Londo et al 2006). The emergence of cultivation practices, more specifically the emergence of rice agricultural, in southern Thailand has not yet been determined. This research provides insight to the transition of hunter-gatherers from foraging practices to a mixed foraging-horticultural subsistence regime due to the onset of opportunistic rice cultivation as a response to changing environmental conditions.

There are biological and physical constraints of rice cultivation: irregular rainfall and flooding, water shortage, low soil fertility, and pest menace. Constructing a freestanding rice paddy is a labor-intensive process, including the building of dikes, flooding the paddy, and mixing soils. Domestication of rice usually consists of a transition period from hunting-gathering and foraging to cultivation to the adoption of an agroecosystem (Fuller 2006; Kealhofer 2002; Maloney 1991; White 1995). Ethnographic evidence of groups in southern Thailand and northern Malaysia demonstrate the practice of hunting-gathering and foraging of food resources in an immediate economic return system, meaning there is no storage of food. Their societies are considered egalitarian and are reliant upon riparian and forest resources. Ethnoarchaeological records of rice cultivation describe the difficulties encountered during paddy preparation (Hayden 2013; White 1995).

If rice was introduced as a cultivated food source in southern Thailand during prehistory, then a shift is expected in the environmental proxies (stable carbon isotopes, phytoliths, and fossil pollen) as well as the exploitation of fauna (subsistence regime) deposited at KTC. The emergence of agricultural economies occurs when human diets broaden, meaning that more fauna is exploited (Zeder 2012). During prehistory, evidence of broadening diets and environmental change depicts the emergence of cultivation (Zeder 2012). Cannon (2001) and Broughton et al. (2010) effectively demonstrate how environmental change and broadening diets reflect the appearance of cultivation in the Mimbres-Mogollon region of Southwestern New Mexico.

The holistic approach to understanding these environmental and human behavioral changes depends on the radiocarbon chronology of KTC, stable carbon isotopic data, site formation processes, particle size analysis, and phytolith and palynological analyses, as well as the quantification of zooarchaeological data. Preliminary zooarchaeological results suggest exploitation patterns occurring during the mid-Holocene, earlier than previously observed (Van Vlack et al. 2013). In this thesis, I utilize three different methods to understand the changing biome through time, while elaborating on cultural activity in the region.

Paleobotanical research and study in Thailand extends only as far south as Phukhao Thong, a Metal Age site (2,500 years before present) located on the Thai-Malay Peninsula in the Rangon province, just south of Myanmar (Castillo and Fuller 2006; Castillo 2011). There is bias towards archaeobotanical research in the northern portion of the country due to lack of evidence in the south (Castillo 2011; Mudar 1995; White 1995). Previous archaeological research on this region offers insight into the cultural activity of everyday life, but it does not explore the transition of the hunter-gatherer and forager lifestyle to that of an agroecosystem (Anderson 1997; Higham 2002; Shoocongdej 2000; Pookajorn 1991).

Considering that Thailand is the largest exporter of jasmine rice (*Oryza sativa indica*) in the world, the lack of data reflecting the beginnings of agriculture and horticultural practices of this region is astounding (Kiatpathomchai et al. 2009). Southern Thailand is economically structured around seasonal rice yields because it is the only food-producing crop in the region (Kiatpathomchai et al. 2009). Farmers grow rice by either irrigation or rain-fed paddy systems. Research and study of how cultivation of rice came to be such an established crop in this region are questions yet to be answered. There are cosmological and creation myths about the spread of rice cultivation. However, scientific endeavors have yet to lend evidence to support such claims (Hayden 2013). Therefore, theoretical discussion and a multi-disciplinary approach to understanding this human environmental intervention will be explained and discussed throughout this thesis.

Previous archaeological endeavors investigating the emergence of agricultural dependence, domestication of crops, and the adoption of agroecosystems in the rainforests of southern Thailand have not had strong evidence to support claims about the chronology of horticultural practices. The transition from forager to farmer is considered to have been a southbound migration from China through Island Southeast Asia, based on linguistic patterns in root words of Austronesian language types (for example, domestic pigs and dogs, rice and ceramic) (Barker et al. 2005). Bailey et al. (1989) suggest that hunter-gatherer groups did not survive in the tropical rainforest without the assistance of agricultural neighbors, while Gorman (1971) suggests that hunter-gatherers on the Malay Peninsula relied solely on faunal exploitation. Macrobotanicals (e.g., mungbean, rice, fig seeds) are not often encountered during excavations because of data recovery techniques and issues with identification (Castillo 2011). Evidence of cultivation is often overlooked, while the methods for analyses of this transition from hunter-gatherer to horticulturalist are nuanced. Techniques for investigating cultivation practices in the tropics have advanced in the last decade, making research like this an important contribution to anthropological inquiries about the transition into an agroecosystem (Coil et al. 2003).

Based on the previous studies in southern Thailand, practices of hunter-gatherer and foraging groups during prehistory are not well known. What is especially rare about the KTC assemblage is the time period that it spans coupled with the availability of eco-artifacts. There have been many discussions about the appearance of rice agriculture throughout Asia (Castillo 2011; Fuller 2006; Gorman 1971; Higham 2002; Lekenvall 2011; Londo et al. 2006; Oka 1988; Pookajorn 1991; Stark 2004; White 1995). However, the appearance of rice paddy cultivation is not well documented in southern Thailand. If rice cultivation was introduced as a cultivation food resource to southern Thailand provinces during prehistory, then a shift can be expected in the archaeological data (e.g., geoarchaeological results, quantitative analysis of the zooarchaeology assemblage, and evidence in the paleobotanical remains). Theoretical models that inform on topics such as these are often found in zooarchaeological texts. The basis of human behavioral ecology suggests that human activity can change, or that humans will adjust behavioral practices for better survival.

The fine-grained prey choice model within human behavioral ecology theory states that humans adjust their practices to become more efficient within that given environment (i.e., optimal foraging) (Broughton 1994; Broughton et al. 2011; Cronk 2003; Jones 2013; Stephens and Krebs 1986). This means that humans will adjust hunting practices to collect the most caloric valuable food. Discerning calorically valuable food is based on post-encounter return rates, which are defined as a ratio of energy and time spent collecting food resources. The amount of time and calories spent foraging is considered efficient when hunter-gatherers limit time and collect as many calorically rich resources as possible (Bird and O'Connell 2006). In this predictive model, forager efficiency will decrease while diet breadth increases when an agroecosystem practice is adopted (Barlow 2002; Grayson and Delpech 1998). This is because rice is a lower ranked resource based on the post-encounter return rates when compared to hunting and gathering larger sized prey. Rice cultivation is a labor-intensive process that diminishes energy and time that may be spent hunting. Additionally, rice does not provide immediate caloric relief, as it requires preparation and processing before consumption (Hayden 2013; White 1995). The fine-grained prey choice model would predict that with the adoption of rice cultivation, foraging strategy would practice the collection of a wider array of fauna (usually smaller in size) because it is easier to access, process, and transport within a close range.

Research Design

The author designed this research study to examine floral, faunal, and sedimentary evidence deposited at KTC in order to understand trophodynamics of the environment. Environmental archaeology is dependent on the use of several, often multidisciplinary, methodologies. For this reason, studies that triangulate data sets allow for stronger results that consider all aspects of environmental change regarding a dynamic system (Dinacauze 2000; Penny et al. 2007; White et al. 2004). I use human behavioral ecology, mobility theories, along a mixed method approach for this thesis research. The research is designed to provide data on multiple trophic levels within the environment at the rockshelter in order to better understand human impacts during the transition from hunting, gathering, and foraging to that of an agroecosystem.

The author is using used two methods to collect micro-botanicals: phytolithic and fossil pollen extraction. These two methods provide fossilized botanical remains. Based on previous geoarchaeological analysis (Marwick et al. in progress) and zooarchaeological description of the site (Conrad et al. 2013), the author chose pollen and phytolith analysis to provide floral proxy data that are demonstrative of environmental changes through time. Additionally, the purpose of these methods was to provide chronological evidence of changing floral diversity within the Krabi region. Microbotanical fossil study, palynology and phytolithic analysis, may illustrate the environmental processes necessary for cultivation to occur, while providing a deeper understanding of the changing environment that may have lead to the adoption of agroecosystem practices in southern Thailand. A more detailed description and quantification of the zooarchaeological assemblage is an ideal pair to the paleobotanical methods employed in this case study to understand paleoecologial processes.

Summary of Contents

Chapter two in this thesis establishes the theoretical foundation of the research and author's perspective. The chapter will include environmental and archaeological case studies that support the framework of the research design carried out in this thesis. Human behavioral ecology, the fine-grained prey choice model, and mobility patterns of hunter-gatherers are the main theoretical arguments that will be discussed in this chapter. Environmental and archaeological case studies that are included in this chapter include sites that are close in proximity to KTC and were used to help design the research in this thesis. The archaeological sites that are included for consideration are Sakai Cave, Moh Khiew Cave, and Lang Rongrien Rockshelter. These three sites are well-documented, including some ethnoarchaeological work that has aided in understanding part-time horticulturalist practices.

Chapter three presents previous research at KTC, the selection of methods for this research, as well as the design of this case study. The methods of data collection, sampling, laboratory analysis, and data analyses are provided in this chapter. Such methodologies include radiocarbon dating, geoarchaeological techniques, zooarchaeological quantification, and microbotanical extraction. Explanation of how these methods inform on the development of the hypothesis and formation of the research question is discussed here along with previous research of Khao Toh Chong Rockshelter.

Data analyses and presentation of the results of these methods is presented in chapter four. Preliminary results of ceramic and flaked stone artifact mass (g) and counts are also reported. Presentation and description of the statistical analyses of the zooarchaeological assemblage are provided in this chapter, stating that the fragmentation and preservation of the assemblage occurs evenly throughout the stratigraphic layers. Exploitation patterns of the fauna are indicated, while some basic explanation of how these results came to be are discussed. The fossil pollen and phytolith results are also presented in this chapter. Trends in the subsistence regime at KTC presents a pattern of a broadening diet throughout the Holocene, a possible effect of the emergence of an agroecosystems.

Chapter five utilizes the fine-grained prey choice model as a predictive theory in discussion of the results and patterns of the preliminary ceramic and lithic analysis, faunal quantifications, and environmental pressures faced by the occupants during the late-Pleistocene and throughout the Holocene. The results are discussed considering human behavioral response to shifting environmental processes (e.g., increased monsoon strength, declined seasonality, and resource abundance). Behavioral adaptations include increased forager mobility in southern Thailand and the influence of estuary foraging on cultivation practices through the early-to-mid-Holocene.

The conclusive argument is discussed in chapter six. This chapter summarizes the research design and social theories (e.g., human behavioral ecology, the fine-grained prey choice model, and an emergence of an agroecosystems) associated with the analysis of the data sets. Implications of the research are discussed in brief, and recommendations for future environmental science in southern Thailand, as well as archaeological research of the KTC assemblage are explored.

Chapter 2: Human Behavioral Ecology Theory and the Environmental Archaeology of Mainland Southeast Asia

Introduction to the Chapter

The following discussion provides an explanation of human behavioral ecology theory, focusing on tropical rainforest foraging strategies utilized during prehistory. A background of how environmental science elucidates human behavioral response when utilized in archaeological research is explored. Geology and the environment of southern Thailand during prehistory is described to illustrate the background of the Thai-Malay Peninsula hunter-gatherer and foraging groups, while a description of previous archaeological research in the region is discussed. The main objective of this chapter is to provide a framework for the research design, as well as to provide insights for the theoretical discussion of findings in chapters five and six.

Theoretical Frames of Human-Environmental Intervention

Environmental archaeology is conceptually based on human ecological theory and often investigates human-environmental interaction and reconstruction of palaeoenvironments (Butzer 1982; Dinacauze 2000; O'Connor 1998). There is little definitive structure to environmental archaeology because the study has been used across varying disciplines, such as anthropology, geoscience, botany, and geology, to name a few (Watson et al. 1984). Using an interdisciplinary approach is not new to anthropological questions involving the environmental setting of archaeological sites.

The foundational notion that binds environmental archaeology in its array of use and disciplines is the theoretical basis of human ecology and more specifically the school of processual thought (Binford 1962, 1964; Butzer 1982).

> "Processual archaeologists attempt to explain human behavior in terms of ecological adaptation, emphasize cross-cultural regularities, and embrace a cultural evolutionary view of social change. They tend to epiphenomenalize culture and dismiss idiosyncratic cultural variability, such as is found in art styles, as being of little interest." (Trigger 2003:1)

In this research, environmental archaeology is best explained by human behavioral ecology theory because human behavioral ecologists employ theory to explain how modern humans have shaped humankind through behavioral choices. In this light, human behavioral ecology reflects the natural selection of our species, in that humans choose particular survival behaviors over others. For example, agricultural practices require more energy than is immediately returned when compared to hunting, gathering, and foraging. Human behavioral ecology theory is known by many other names, for example: evolutionary ecology, sociobiology, evolutionary biological anthropology, and evolution and human behavior studies. Research that embraces this framework often regards foraging patterns, redistribution, and reciprocity. All aspects of this theory emphasize sociocultural change— often regarding the spatial organization, hierarchal systems of the group, effects on technology, or sex differences in foraging regimes (Cronk 2003). Other topics immersed in human behavioral ecology theory are optimal foraging theory (diet breadth or prey choice), foraging locations (patch choice), and habitat or settlement choice. There is no reason to why human behavioral ecology cannot be applied to horticultural types of resource acquisition (Cronk 2003: 32). These topics will be explored in this study on the premise of previous hunter-gatherer and forager research in Southeast Asia.

Foraging Theory

Optimal foraging theory is a theoretical model usually applied to zooarchaeological assemblages because it allows researchers to evaluate what animal resources are being utilized in the diet. In Thailand, information regarding prehistoric zooarchaeological foraging models is limited, because these assemblages are not thoroughly analyzed using theoretical frameworks such as foraging theory (see Shoocongdej 2000 for alternative settlement-subsistence approach). Zooarchaeological data are often presented, however, not in full. The documentation usually provides a minimum number of individuals (MNI) and rarely reports unidentified specimen counts. Identification with comparative collections are often thwarted, wherein analysis is often done through faunal photography plates and previous regional documentation. This leaves much room for error and misidentification. Regardless, this thesis will utilize the fine-grained prey choice model to understand the zooarchaeological assemblage and foraging practices employed at KTC (Broughton et al. 2011; Conrad et al. 2013; Jones 2013; Van Vlack et al. 2013).

The fine-grained prey choice model is focused on understanding foraging efficiency and post-encounter return rates. For example, when foraging efficiency declines, the breadth in resources of the diet is predicted to widen. This means that foragers are no longer focusing on larger prey items (e.g., artiodactyls or Bovid), in turn spend their efforts collecting what is immediately available, and generally lower-ranked resources (e.g., Rodentia or mollusks). This is reflected in the zooarchaeological deposits at archaeological sites when specimens of larger-sized fauna become absent in cultural deposits. In turn there is an abundance of smaller-sized fauna. Foraging efficiency improves when this scenario is reversed: when smaller fauna becomes less abundant and larger fauna appears, this shift found in cultural deposits denotes the traditional prey-rank model.

The inclusions of horticultural practices are often discussed within the fine-grained prey choice model. The emergence of agricultural practices appear at varying points world wide, although this theoretical model improves the estimation of the transition from hunter-gatherer and foraging to the appearance of horticulturalism. For example, rice did not first appear as a domesticated crop until ~6,000 years before present (B.P.) in the Yangtze Valley of China (Fuller 2006). Rice requires a lot of time and effort to cultivate, manage, and harvest (i.e., higher post-encounter rates). Once harvested, rice must be soaked and cooked, which is also costly of time and energy. So, when we see higher ranked prey decline (e.g., larger fauna like deer or water buffalo) we can assume that the fauna is either no longer accessible in the forager diet or that foraging practices have shifted to gathering lower ranked food sources (e.g., rice, yams, or small game). Thus, identifying and quantifying zooarchaeological specimens provides data to estimate the transition from hunting, gathering, and foraging to cultivation.

There are some critiques of the fine-grained prey choice model, such as instances of mass-capture techniques (as is likely with mollusk specimens) or sex differential foraging. Bird and O'Connell (2006) refer to the use of body size as an index of prey rank in archaeofaunal applications as a "fragile" assumption, a conclusion that is very different from the one we reach later in chapter six. While Bird and O'Connell critique the utilization of body size indices, here I follow Broughton et al. (2011) in accepting this technique.

Mobility Theory and Settlement Choice in Southern Thailand

The landscape and formation of Thailand today is based on geomorphic evidence of plate tectonics, sea level change, and modern karstic environment. Dheeradilok (1995) describes the effects of water on the landscape, acting as a sculptor, carving out deep caves and depositing calcium carbonate that eventually formed limestone caves and rockshelters. One well-known human response to a wetter environment is the dependence on cave and rockshelter sites (Anderson 1997; Pookajorn 1996; Shoocongdej 2000). This response is neither new to prehistory, nor is it an identifying feature to Thailand. However, there are human response strategies to the tectonic uplift, damper climate, and stronger monsoons, among others, that still require investigation. The monsoonal activity in SEA has increased in strength throughout the Holocene (Maxwell 2001; Penny 2001). The southwest monsoon usually lasts May through October, while the northeast monsoon gathers moisture as it descends from China across Thailand. Seasonal rainfall varies throughout the country; southern Thailand usually receives about

4,000 mm of rain during the six to nine month rainy season. The upper mainland receives about 800 to 1,000 mm of rainfall.

Mobility patterns of hunting, gathering and foraging groups are a sign of physiological response to environmental stress (Brantingham 1991). During the late-Pleistocene to Holocene transition, it is possible that mobility of hunter, gatherer and forager groups increased along the Thai-Malay Peninsula due to the loss of coastal resources and narrowing of landward mobility. Brantingham (1991) discusses the residential and logistical models of forager mobility; his findings suggest that larger populations often travel shorter distances, while smaller populations can cover more terrain. Additionally, Brantingham suggests that typical foraging groups travel a median of 12 km in a single event.

In Thailand, foraging groups practiced a mix of two mobility models. The first model is the logistical model, where foraging groups are composed of skilled task groups that move from one site to another. Logistical groups move spatially and temporally with strategy to forage for specific resources. The second model is the residential model, where foragers rely on more permanent settlements and fan out to forage daily, monitoring resource accessibility and resource potential (Bindford 1980; Shoocongdej 2000). In Thailand, residential foraging is a strategy of seasonal environments (Shoocongdej 1996a). During the wet season residential foraging involves access to more resources such as water, flora, and fauna. The long-term residential model of foraging is indicated by specific artifacts found in archaeological assemblages, for example heavier stone tools such as stone cores and hammerstones (Anderson 2005).

In northern Thailand there are two major river systems. The Chao Phraya River is associated with Bangkok and the ancient city of Ayutthaya, while the Mekong River is associated with Angkor Wat, but it extends through China, Burma, Thailand and Cambodia. However, in Peninsular Thailand there are no major river systems. Along the peninsula there are a series of tributaries and streams that connect to coastal estuaries (see Figure 2.1). Northwest Thailand is considered the continental highlands, while the northeast is more flat and the location of the Khorat Plateau (Higham 2002). Peninsular Thailand is considered highland terrain with north-to south mountains spanning into Malaysia. The eastern side of the peninsula has broad lowlands extending towards the Gulf of Thailand.

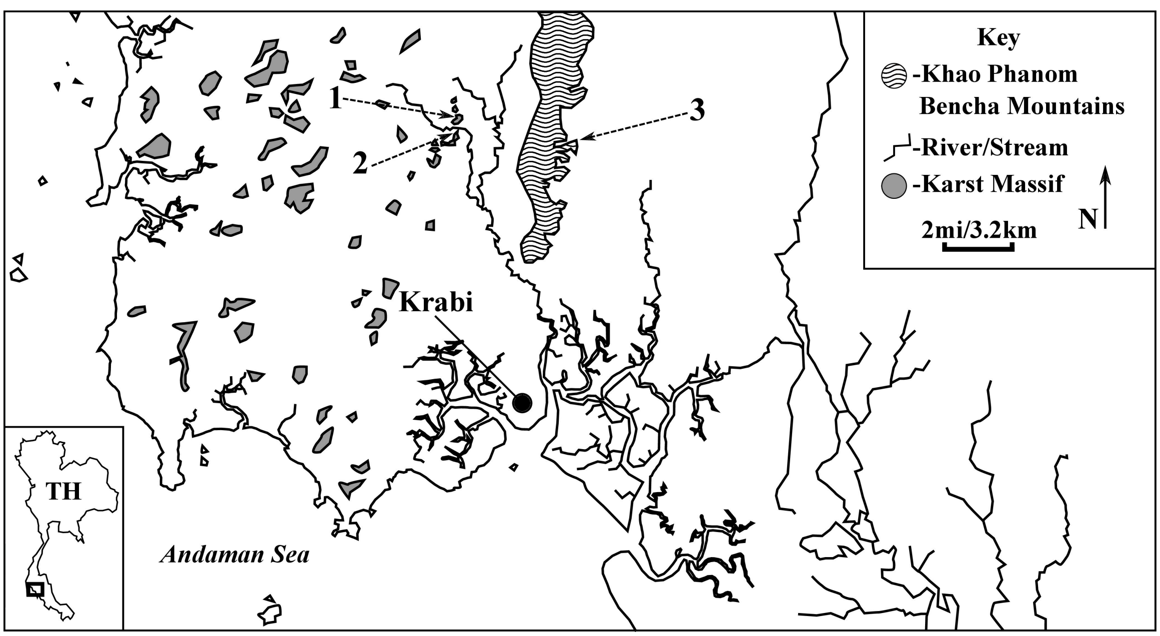


Figure 2.1 Map of the Krabi Province estuary and river system with (1) Lang Rongrien Rockshelter, (2) Khao Toh Chong Rockshelter, and (3) Moh Khiew Cave shown among the karstic environment.

Research of cave and rockshelter sites is an important contribution to archaeological research because of their rich assemblages and strong preservation of artifacts. During the time of occupation, this type of site would have provided shelter and a well-lit area for occupants, while providing an easy landmark during foraging practices (Anderson 199; Pookajorn 1988, 1984; Straus 1990). These shelters are natural formations in rock, often made of limestone, which can provide warmth in the cold weather or cool shade in the heat of the day- either way, protecting people from the elements. Settings such as these are also well ventilated, and so it is a common occurrence to find sleeping areas, and hearths, among other activity zones within the enclosures. These caves and rockshelters provide evidence of the mobility patterns of hunter-gatherer groups and the possible paleoecological niches utilized by ancient foragers (Anderson 1990; Higham 2002; Shoocongdej 2000). Anderson (1997) supposes that some of the prehistoric cave systems are now underwater due to the rising sea level (Horton et al. 2005; Tjia 1996). Other rockshelter and cave sites in the region of KTC include Lang Rongrien Rockshelter, Moh Khiew Cave, and Sakai Cave (Anderson 1990, 1997; Pookajorn 1991, 1996). Of these sites, only Lang Rongrien Rockshelter has a well-published record of archaeological activities.

Prehistoric hunter-gatherer and foraging groups in Thailand are mobile groups, which move from camp to camp seeking out resources and shelter (Pookajorn 1996; Shoocongdej 2000). By understanding the assemblages of these mobility sites, archaeologists can determine the seasonal use and chronology of site occupation (some of which are still seasonally occupied) and the motivation of site preference among others in the region. It is within these models of prehistoric social organization and mobility that theoretical paradigms come into play.

Shoocongdej (2000) investigated evidence of mobility as a behavioral adjustment in an ecological framework to understand prehistoric dynamics in Thailand. Her findings suggest that ancient peoples used a variety of cave or rockshelter networks when collecting resources. Under this pretense of mobility foraging patterns, Shoocongdej (1996a, 2000) was able to recommend seasonal traits between rockshelter and cave sites in this area – where certain models were reliant on the changing season, as wet or dry landscapes affected what the ecosystem was able to produce. The basis of her study was grounded on lithic analysis and sourcing, faunal and floral assemblages, ceramic data, chronology, and knowledge of the changing environment in northern Thailand.

Cave and rockshelter archaeology is becoming more studied in areas such as Thailand, where mobility camps were reliant on the features that rockshelters and caves can provide during monsoonal rains and tropical heat during prehistory (Bulbeck 2003; Pookajorn 1996; Straus 1990). Preservation issues to consider in archaeological remnants from cave and rockshelter sites include effects of trampling, site formation processes, and natural versus invasive biota (Dinacauze 2000; Farrand 2001; Huckleberry and Fadem 2007; McGrath et al. 2008; Straus 1990).

Archaeobotany in Thailand

In SEA archaeobotanical reports, there is often an overreliance on certain texts reporting on the origins of rice (e.g., Oka 1988). Fuller (2006) brings this to the attention of scholars, urging archaeologists to expand their resources and theoretical models to suit the archaeological assemblages often found in tropical settings. In part, expanding archaeological science in mainland SEA involves the utilization of environmental proxies to assist in the reconstruction of paleoenvironments. Butzer (1982), a human ecologist, encourages scientific rigor when studying environmental systems, which may yield stronger inferences about environmental processes. This is made possible by using updated methodologies, which may present various parts of a trophodynamic ecosystem. Determining whether humans have significantly altered or manipulated environmental settings has been an issue of much debate, primarily because there are several areas of research that need to be improved (Dinacauze 2000).

Depending on the yield of data from an archaeological site, data sets may be prioritized differently, either by interest-base or availability of study. For example, tropical microbotanicals in southern Thailand have not been an area of high scholarly investment. This is likely because of a lack of comparative collections, and preservation biases (White et al. 2004). The use of environmental proxies can enlighten many areas of archaeological interest; for instance, precipitation values, plant communities, landscape manipulation, food residue analysis, site formation processes, are among some uses that archaeologists employ proxy data to fulfill.

In Thailand, there are about twenty-nine sites with archaeobotanical specimens of rice, found by way of flotation, phytolithic analysis, rice temper or impressions in pottery (Castillo 2011). However, Castillo (2011) reports that there are many discrepancies in the level of study and identification of rice, including claims about rice domestication.

Phytolithic analysis from sites in north and central Thailand suggest that rice may have been cultivated as early as the mid-Holocene (Castillo 2011; Kealhofer 2002). Determining domestication of rice by phytolithic analysis is problematic, although some scholars believe it is possible (Saxena et al. 2006; Zhao et al. 1998). Phytolithic analysis analyzes the presence of silicate plant remains, in this case rice silicates, from archaeological sediment and lake cores, which provides a broader understanding of human environmental intervention by way of landscape manipulation (Castillo 2011; Fuller 2006; Fuller and Qin 2009).

Khok Phanom Di (KPD) is an archaeological site located near the coast of central-northeastern Thailand. Analysis of macrobotanicals deposited at KPD suggest the first evidence for rice domestication in Thailand (~4,000-3,500 years B.P.) (Thompson 1996). Weeds associated with cultivation and domesticated-type rice spikelets are the two indications used for determining the status of domesticates over wild cultivated crops (Castillo 2011). Londo et al. (2006) suggests that there were two domestication events of rice, the origin being in the Yangtze Valley of China and the Indo-China Valley. Evidence of the spread of rice in the Thai-Malay region suggests that *Oryza sativa indica* is the variety born from cultivation and domestication events. This variety of rice is commonly known as jasmine rice, and grows best in rain-fed environments (Castillo 2011; Londo et al. 2006).

> "The cultivation practices inferred from prehistoric sites in Thailand and one in the Thai–Malay Peninsula ... differ from the lowland paddy field agricultural system that was in place at the centre of origin in the Lower Yangtze when rice spread outwards to other regions ca. 4000 BCE (Fuller and Qin 2009). This difference may be because wetland paddy field agriculture in Thailand developed later. Although the earliest paddy field agriculture is found in China, it is during the first millenium CE that *indica* together with wetland systems of cultivation may have been introduced into Southeast Asia from India as a result of exchange networks." (Castillo 2011: 117)

The macrobotanical evidence during the metal age (400-200 BCE) at Phukhao Thong (PKT) suggest that *O. sativa japonica* was domesticated in this region. PKT is an archaeological site located at the narrowest point of the Thai-Malay peninsula (Castillo 2011). The analysis that determined this variety of rice was done through macrobotanical measurements, as *japonica* produces a smaller rice grain than *indica*. Additionally, the *japonica* variety is typically associated with domesticates found in China (Londo et al. 2006). Hayden (2013) reports that domesticated rice grains often produce more grains per panicle in contrast to wild varieties. Rice gathering and cultivation is generally agreed among scholars (e.g. Hayden 2013; White 1995) to be a counter productive foraging practice; meaning, cultivation requires more energy output to harvest, dry, and separate the grains from the panicle in addition to cooking time than, for example, foraging for yams and other alternative crops often used by hunter, gatherer and foraging groups in Southeast Asia (e.g., lotus root, prickly water lilies, peaches, etc.). The process from initial cultivation practices of rice to the eventual domestication of the species would have taken about 1,000-1,500 years (Fuller 2006). The absence of documenting the process of rice cultivation in archaeological accounts is discernable, while the approach of environmental archaeology actively seeks out periods of transition throughout human history. Londo et al. (2006) identified rice domestication regions in a phylogeographic approach, resulting in domestication events for two varieties of rice: *O. sativa indica* in the southern Himalaya mountain range, and the other being *O. sativa japonica* in southern China. *O. sativa indica* continue to be domesticated throughout Myanmar and Thailand. However, the process of cultivation to full domestication is still uncertain.

Mungbean (*V. radiata*) and horsegram (*M. uniflorium*) are species that both originate in India but are found wildly in Thailand during prehistory. Castillo (2011: 118) claims that "…genetic studies have shown that the modern Thai domesticated mungbean is more closely related to wild progenitors found in India than the native Thai wild progenitor" (Castillo and Fuller 2010). Millet is not commonly found in archaeological sites, which is often attributed to preservation biases because of its size. While, rice is the most often reported archaeobotanical remain in SEA. Castillo (2011) suggests several reasons why rice is so notable in archaeological records of Thai prehistory: the first being that rice is easily identifiable, and because scholars have also dedicated more efforts to clarify the history of rice – as it is as economically important today as it was during prehistory.

Human Environmental Intervention by Proxy

Penny et al. (2007) and White et al. (2004) use palynological core samples to reconstruct palaeoenvironments to understand environmental change over time. Their work provides an excellent example of the mechanisms for change and preservation biases that occur in archaeological assemblages and sediment samples in SEA. Penny et al. (2007) uses palynological data to contribute a broader scope of how ancient hydrological practices were prioritized through the succession of kingships at West Mebon, a reservoir near the Bronze Age site of Angkor Wat, Siem Reap, Cambodia (9th to 15th century AD). This case study reconstructs plant communities and water management practices using fossil pollen and lithology. In doing so, Penny et al. (2007) relies on Angkor Wat's well-known epigraphic chronology of royal succession to understand how the West Mebon water reservoir was prioritized throughout the reign of varying kings.

The plant communities at West Mebon were reconstructed through the identification and analysis of fossil pollen. These plant communities varied in organic material and taxa, allowing for Penny et al. (2007) to investigate the ecological conditions that would be necessary to support the vegetation. The volume and depth of the water within the reservoir could be estimated, as well as precipitation levels and monsoonal cycles. Penny et al. use the radiocarbon sequence of the samples to align them with the well-known epigraphic chronology of the Angkorian kingships. A palynological approach to environmental archaeological research provided evidence of the how the kings managed the reservoir and provides an exemplar case study of how human-environmental intervention can be addressed using proxy data and archaeological inference.

White et al. (2004), like Penny and colleagues (2007), used the organic material from the core samples to determine radiocarbon dates. White et al. used three coring sites throughout Thailand near significant late-Pleistocene archaeological sites to examine environmental change. Two of the three coring sites are located in northern Thailand, with the third in peninsular Thailand. The southern coring site, Nang Thalee Song Hong (NTSH), is located in the Trang province and was ideal for coring due to the closeness in range to Lang Rongrien Rockshelter and Moh Khiew Cave (White et al. 2004). The NTSH core sample demonstrated disturbance of the soil strata as well as poor organic preservation. However, the phytolithic analysis provided indications about the landscape during the terminal Pleistocene to early Holocene (Kealhofer 2003; White et al. 2004).

> "Kealhofer (2003) notes that the burnt phytoliths (identified by the presence of black (charred) organic material encased in the phytoliths) predominantly derive from grasses, suggesting the presence of a woodland savannah that was burned regularly... [a] period of unambiguous agricultural occupation in the region [that] coincides with a decrease in arboreal indicators in the phytolith record and an increase in burned wood (see Kealhofer, 2003)." (White et al. 2004: 114)

In Thailand, and throughout Southeast Asia, it is often the case that environmental studies are exclusively geoscience based. The incorporation of palynology and sedimentary studies of archaeological sites provides much needed ecological data for a portion of the biota. However, the thorough investigation of fauna deposited at the site demonstrates direct ecological and cultural activity through time. Together, the suite of methods can exhibit human impacts on the full spectrum of available fossil biota rather than parts of the whole. Additionally, proxy data are often circumstantial; thus the application of a mixed method approach provides a holistic and multidisciplinary perspective to environmental and ecological study of the human past.

"Successful description of human paleoecologies entails not only integration of all available information from both organic and inorganic components, but its interpretation [must exemplify a] sophisticated awareness of both the potential and limitations of recovered data sets" (Dinacauze 2000: 498). Using this statement as the guideline by which other paleoecological studies are assessed, the widespread misappropriation of paleoecological methods and general terms of interpretation is indeed understandable. Dinacauze (2000) reminds us that environmental archaeology is not a certain science, but is one that can enlighten and provide application of human-environmental interactions.

Cave and Rockshelter Sites in Southern Thailand

Pookajorn (1991; 1996) concisely describes Moh Khiew Cave and Sakai Cave, both of which are located on peninsular Thailand near KTC and Krabi province. Both sites show evidence of changes in human occupation during the Holocene, a behavioral pattern related to environmental shifts in the region (Chaimanee 1994). Moh Khiew Cave was sourced for palynological testing that revealed a floral record dating back to 30,000 years B.P. (Pookajorn 1996). The proxy records described a seven thousand year period (between 30,000-23,000 years B.P.) where climatic conditions were cold relative to the tropical setting today (Ha Van Tan 1985). There are other sources of data that are consistent with these findings in SEA, specifically in Vietnam (Ha Van Tan 1985).

Palynological data from archaeological sediments does not always yield abundant and identifiable samples, and so archaeologists interpreted environmental change using fauna as a proxy for environmental interpretations excavated at both cave sites (Pookajorn 1996).

Sakai Cave is a rare site because the Mani people who inhabited the site were open to anthropological inquiry and archaeological excavations. The ethnographic history of this tribe was recorded and published alongside the site report (Hongo and Auetrakulvit 2011; Pookajorn 1991, 1996). Sakai Cave is an early to mid-Holocene radiocarbon dated site, located in the Trang province of southern Thailand (Pookajorn 1996). The Sakai Mani people had continuously occupied the cave, and analyses of the archaeological assemblage from the site indicated a hunter, gatherer and forager subsistence regime that were reliant on the faunal rainforest resources supplemented with opportunistic gathering of botanical foods. The palynological analysis of the sediment from the site indicated the use of medicinal plants, often associated with shamanistic practices. Evidence of floral foraging for subsistence was not recorded in either the site report or in the fossil pollen record, and reasons to the lack of this data is unspecified. Ethnographic evidences about wooden traps, digging sticks, blow pipes and poison dart hunting, and subsistence regimes – which, include cultivation practices – were documented. The current Sakai Mani people focus their foraging practice on the arboreal hunting of primates (Chaimanee 1994; Hongo and Auetrakulvit 2011).

Ethnographic accounts of subsistence regimes in southern Thailand have been documented in ethnoarchaeological projects at Sakai Cave, while there are several ethnographic and participant observations about cultivation practices documented from northern Thailand (Hongo and Aeutrakulvit 2011; Pookajorn 1991; Trankell et al. 1995; White 1995). Trankell (1995: 99-100) discusses riparian resources utilized in the Thai diet, stating that wet rice ecosystem species of fish and other aquatic animals make up the main part of everyday food. Daily cooking involves fish and rice, as they complement one another, and have underlying meaning about the origin of rice.

The archaeological record provided spatial analysis at the site, determining sleeping areas, hearths, and food processing areas. The use of wooden tools in SEA has been a topic of much debate, as there has been some evidence of bamboo cutmarks on faunal bone, however, there is no known preservation of bamboo tools found in archaeological contexts (West and Louys 2007). Pookajorn (1996) uses the ethnographic data from Mani tribe at Sakai Cave to interpret the foraging strategies in terms of both sourcing for food and also to gather information on the utilization of tools and tool technique. There are known survivals of bone and bamboo tool technology currently in use today by these hunter, gatherer and forager groups (Rabett 2005).

Lang Rongrien Rockshelter and KTC are both located in the Krabi River Valley, about twelve kilometers from coastal mangrove forests. The archaeological assemblage from Lang Rongrien Rockshelter included artifacts of the Hoabinhian technocomplex. There are numerous flaked stone tools, chord marked pottery (sherds and complete pots), as well as some identifiable faunal remains. The faunal assemblage at Lang Rongrien Rockshelter included larger prey (e.g., bovid, Rhinoceros) as well as smaller faunal remains (e.g., mollusks, Testundines, various small mammals), but the level of faunal identification was not fully reported in the 1990 monograph. The Pleistocene dated strata where these faunal remains are deposited are not unlike the Holocene zooarchaeological assemblage at KTC (presented in Appendix D). Evidence of bamboo technology (e.g., wooden traps or blow darts) was not apparent at Lang Rongrien Rockshelter.

> "Turtles and tortoises are a significant component of the Lang Rongrien sample, but the meat contribution of turtles and tortoises is relatively small in proportion to the number of elements identified. The ubiquity of turtle and tortoise bones in cultural features suggests, however, that turtles and tortoises were a constant element of the diet while at the cave and may have been a fairly reliable source of food, at least seasonally. Thus turtles and tortoises may have been a significant resource for maintaining levels of dietary protein in comparison to the erratic success of hunting mammals by active pursuit. Relatively easy to capture, especially if encountered on land, turtles and tortoises may represent the contribution of children and elderly people to the diet." (Mudar and Anderson 2007: 328)

This model of environmental interpretation is an important contribution to the region because it provides a record for which comparable zooarchaeological analyses can be applied. Of the archaeological sites mentioned here, Lang Rongrien Rockshelter is the closest in proximity to KTC, in addition to the similarity in faunal remains (Conrad et al. 2013; Van Vlack et al. 2013; Marwick et al. in preparation). Although the site chronology differs, the preliminary zooarchaeological analyses of Sakai Cave and Moh Khiew Cave do not provide enough information for thorough comparison. The analysis of mammalian faunal remains from Moh Khiew Cave was completed by Dr. Prasit Auetrakulvit for his Ph.D. dissertation, but access to the original dissertation was not possible. More recently, the reptilian assemblage excavated from Moh Khiew Cave is currently under further analyses (Supalak, personal communication 2014.).

Chapter 3: Research Design and Explanation of Methodologies

Introduction to the Research Design

This chapter provides an explanation of the methodologies utilized to explore the environmental archaeology of Khao Toh Chong Rockshelter (KTC). A description of the site is provided in this chapter, and previous archaeological study of KTC is discussed in detail. Description of the radiocarbon dating, geoarchaeological analysis, and the post-excavation analysis of the collection are discussed in this chapter. The explanation of quantitative zooarchaeological methods for data analyses, phytolithic extraction, and palynological study of the sediment collected from KTC is illustrated in this chapter.

Environmental Archaeological Case Study of KTC

Case studies are primarily used to investigate phenomena using a particular research method (Fidel 1984: 273). In this research, KTC is an excellent case study for environmental archaeological techniques in southern Thailand. There are several reasons why this site was chosen, the first being access to the assemblage. KTC has a diverse array of artifacts that allowed for a multidisciplinary approach to understanding the data sets. Several sites in the area have employed aspects of environmental archaeology; however, the variety of methods utilized in this thesis has not yet been combined in SEA archaeological research until now. Among the various factors at this site, especially considering the preservation, artifacts deposited at KTC were complete enough for in-depth analyses of the paleoenvironment and cultural transitions through time.

Additionally, studies in southern Thailand often exclude palynological testing or are thwarted by inconsistent data. Thus, it is imperative to research and report the findings of this method, and the occurrence where procuring samples for analysis is possible. The analysis of sediment procured from Sakai Cave in the Trang province exhibited fossil pollen. In addition, there are several accounts for procuring fossil pollen from archaeological sediment in karstic environments (Dimbleby 1985; Pookajorn 1996; Bhattacharya et al. 2011). The possibility of palynological research at Sakai Cave indicates that there are no basic laws stating the ideal relationships and processes involved in preserving fossil pollen in karstic environments in SEA.

This research accomplishes this feat by utilizing KTC as a case study for future work in the region. In order to determine which methods to use in this multidisciplinary measure of human-environmental intervention, various means of data collection were utilized and observed during the initial excavation of the archaeological rockshelter site. Charcoal was abundant during excavations as was the faunal assemblage. This gave precedence for further analysis of both zooarchaeological quantifications, as well as a deeper look into the geologic processes encountered at this rockshelter site. These evidence present a profile of cultural activity throughout the late-Pleistocene and Holocene. Site formation processes, carbon isotope data, and pH values showed an ideal setting for fossil pollen and phytolithic components at the site. The presence of the faunal, floral, and sediment history at the site allowed for a deeper look into the paleoenvironmental changes at KTC. The region that KTC is in has not yet undergone these methodologies to understand the life ways and foraging habits during prehistory.

Data Collection at Khao Toh Chong Rockshelter

KTC was surveyed by Mr. Theranand Krailer in early 2011 (see Figure 3.1). During his survey, ceramic pot sherds, flaked stone, and many different molluscan species were found on the surface of KTC. With this knowledge, Mr. Krailer contacted two local teachers Mr. Niwat Wattanayamanaporn and Mr. Suthep Chantara to acquaint them with his findings. The two schoolteachers informed the Regional Office of Fine Arts Department at Phuket. Thereafter, KTC was excavated June through July in 2011 by a field school under the direction of Drs. Ben Marwick (University of Washington), Rasmi Shoocongdej and Chawalit Khaokhiew (Silpakorn University), Boonyarit Chinesuwan (Fine Arts Department of Thailand) and Cholawit Thongcharoenchaikit (Natural History Museum, National Science Museum, Thailand). The field crew consisted of an international group of students, ranging from the United States, Myanmar, Cambodia, Indonesia, Korea, The Philippines and Vietnam (Marwick et al. 2013).

KTC is an ideal case study for using environmental archaeological practices to understand shifting subsistence regimes of the hunter, gatherer and foragers to that of an agroecosystem for several reasons. The first reason is that the chronology of the site indicates continuous human occupation spanning this transition. Second, the faunal assemblage deposited at KTC is well-preserved, while preliminary results have suggested a shift in the foraging regime. And lastly, the geographic settlement of KTC is located near the Krabi River and subsequent tributaries, as well as in close proximity to other cave and rockshelter sites.

Figure 3.1 Beneath this karstic massif is Khao Toh Chong Rockshelter.

The rockshelter provides about ten meters of shelter from the base of the karst to the dripline (refer to Appendix A for photographs of the site). The massif is about thirty meters long, and extends about forty meters above the ground. The site consists of fine sediment and little signs of disturbance. This is likely an effect of trapping wind blown and sheetwash sediment (Marwick et al. 2013: 132).

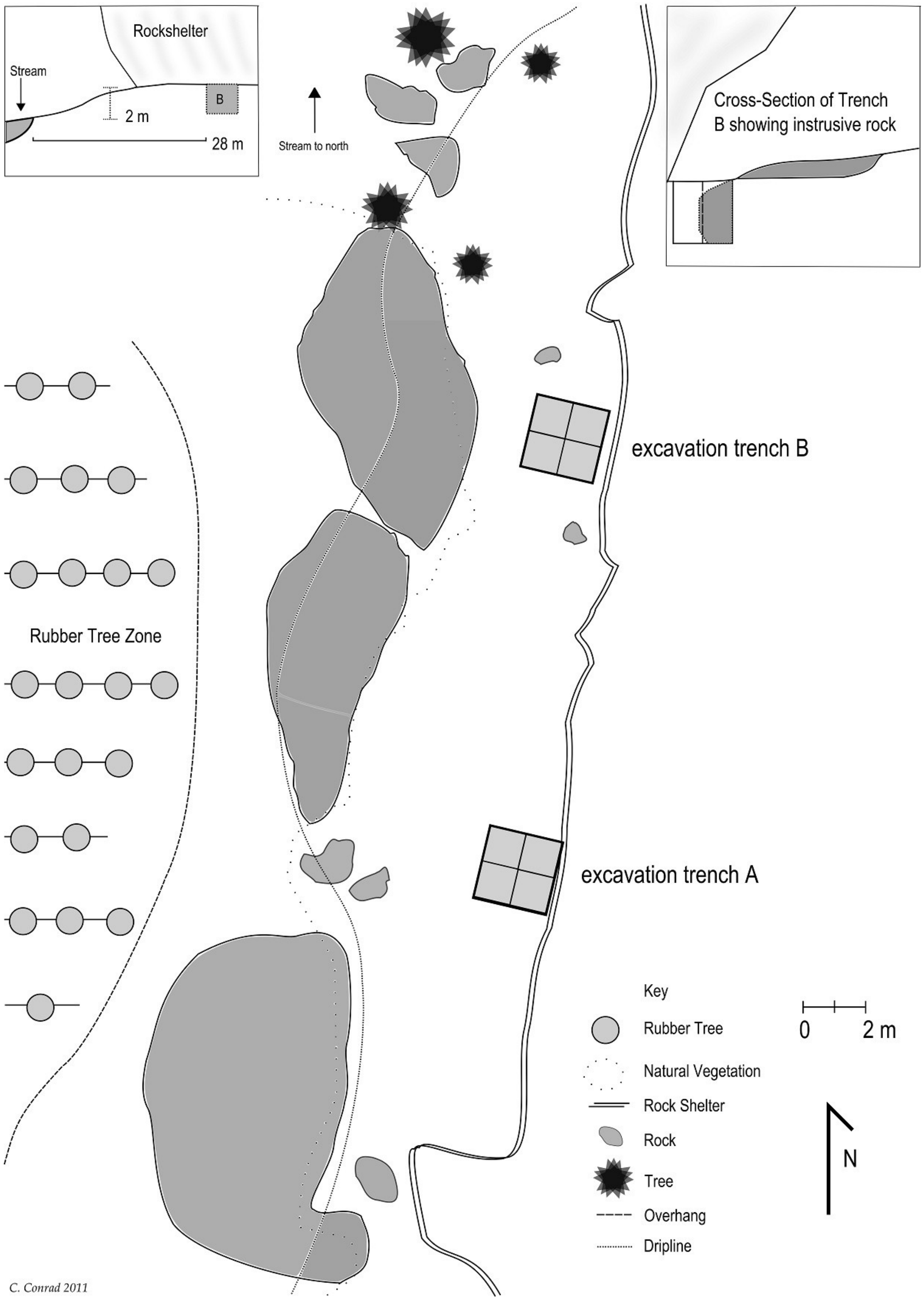


Figure 3.2 An aerial view of Khao Toh Chong Rockshelter.
Image source is courtesy of Marwick et al. (2013).

The field crew also provided preliminary analysis during the 2011 field season. Students, such as myself, were trained in modern methods of archaeological excavations, using small tools such as trowels, wooden picks, and brushes (Mitchell 2005). The details of the excavation were recorded in several ways. Each student was provided a field journal to record major findings, jot notes about tasks and analyses, among other notes and insights into this prehistoric site. These notes, drawings, and records provided in-depth discussion between the field crewmembers each day. Additionally, a Harris matrix was used to keep track of features throughout the site stratigraphy. All units, features, and intact artifacts were recorded by means of digital spatial analysis (e.g., Total station), digital high-resolution photography, and analogue field records (e.g., context forms). The 2011 excavation of KTC explored two archaeological trenches (see Figure 3.2) within the rockshelter site (Trench A and B). Three teams were formed within the field crew, and each team rotated daily from three locations within the site (i.e., Trench A, Trench B, and the analysis lab; a small canopy, extension chord with a serge protector, and long table seating approximately twenty people was assembled by the property owners- this is where the bulk of analysis was done in 2011). Throughout the field season the rockshelter had many visitors: local school groups, Thai scholars, shamans, Buddhist monks, and an assortment of community members visited to spend time to learn about the excavation and show support (Marwick et al. 2013).

Radiocarbon Dating

Burnt organic matter and molluscan fragments were procured with limited handling during excavation in 2011 and during post-excavation analyses in 2012 (see Figure 3.3). Both sets of samples were shipped to DirectAMS in Bothell, Washington for preparation and radiocarbon testing (see Table 3.1). The results of the radiocarbon testing were calibrated on OxCal 4.1, IntCal 09 using a midpoint of 95.4% confidence (Bronk Ramsey 2009). The chronological sequence of KTC indicated cultural layers extending from the late-Pleistocene (15,751.0 cal. years B.P.) through the Holocene (7,866.5-1,931.5 cal. years B.P.), to present.

Figure 3.3 Samples of charcoal and organic material collected from Context 2 for radiocarbon dating.

Geoarchaeological Analyses

Geoarchaeological analyses were conducted for KTC by students of the geoarchaeological program at the University of Washington, Seattle, under the direction of Dr. Ben Marwick in 2012. The methods utilized in this research include sedimentology, mineralogy, and geochemistry.

Table 3.1 Details of the radiocarbon dating process, including a presentation of unit depths and material sampled for radiocarbon dating.

Spit-Unit	**Depth MBS**	**Context**	**Sample No.**	**^{14}C uncal. B.P. ±1δ**	**^{14}C cal. B.P.**	**Material**
1-1	0.03-01	Surface	D-AMS 1140	149 ± 25	142.5	charcoal
2-2	0.1					
2-3	0.08	2	D-AMS 1142	178 ± 26	144.0	charcoal
3-5	0.15					
4-5	0.15	3	D-AMS 1143	1,973 ± 27	1,931.5	charcoal
4-6	0.19					
4-7	0.19					
5-9	0.35	4	D-AMS 1151	2,846 ± 30	2,967.0	charcoal
5-10	0.35					
6-12	0.45	5	D-AMS 1153	5,592 ± 29	6,370.5	shell
6-13	0.4					
7-14	0.53					
8-14	0.6		D-AMS 1152	7,051 ± 50	7,866.5	
8-15	-	6				shell
9-16	0.65		D-AMS 1146	11,813 ± 42	13,636.0	
10-16	0.7					
11-17	0.75					
12-19	0.8	7H	D-AMS 1149	11,990 ± 50	13,860.0	shell
13-19	0.85					
14-19	0.9	8				
15-19	0.95					
16-21	1.0					
16-22	1.0					
17-23	1.05		D-AMS 1147	13,026 ± 45	15,751.0	shell
18-25	1.1	7L				
19-27	1.15		D-AMS 1148	11,236 ± 42	13,121.0	charcoal
20-26	-					
20-27	1.25					

These analyses included pH, electrical conductivity, color, organic and carbonate matter content, magnetic susceptibility, X-ray diffraction (XRD), inductively coupled plasma-atomic emission spectrometry (ICP-AES), and laser particle size analysis (Marwick et al. in preparation; refer to Appendix C). Additional analyses of the sediment from KTC included a carbon isotope analysis. Bulk sediment samples were collected from each of the natural soil horizons (see Figure 3.4), consisting of nine sediment samples (i.e., surface sample 1, 2, 3, 4, 5, 6, 7H, 8, and 7L). Each context includes a variety of spit-units; a spit is an arbitrary measure of a volume of sediment excavated and recorded for better resolution of spatial analyses of the trench. A unit is feature within the spit. At KTC, the spit-units were recorded at 5 cm intervals. Context 8 is a naturally occurring feature between context seven, which is contextualized here as 7H (high) and 7L (low).

The geoarchaeological analyses of KTC revealed evidence of environmental change, human occupation, and site formation processes (see Appendix B; Marwick et al. in preparation). Additionally, carbon isotope data revealed evidence of vegetational change at the site. Laser particle size analyses provided a basic understanding of how KTC has formed over the past 13,026 years. There are varying periods within this timeframe that show evidence of both colluvial and aeolian deposits, meaning that the sediment at the site was brought in by wind and sediment falling off the rockshelter face onto the surface below. Because of the large boulders that follow the drip line of the rockshelter, the sediment is a well-preserved record with limited disturbances. XRD and ICP-AES allows researchers to understand and describe the aspects of water activity at the site, including precipitation, by using clay sized particles and minerals. In contexts 5 and 6, X-ray diffraction and ICP-AES exhibited evidence of increased precipitation or water activity in site deposits. This is likely due to the strengthening of the Asian-Monsoon (Maxwell 2001).

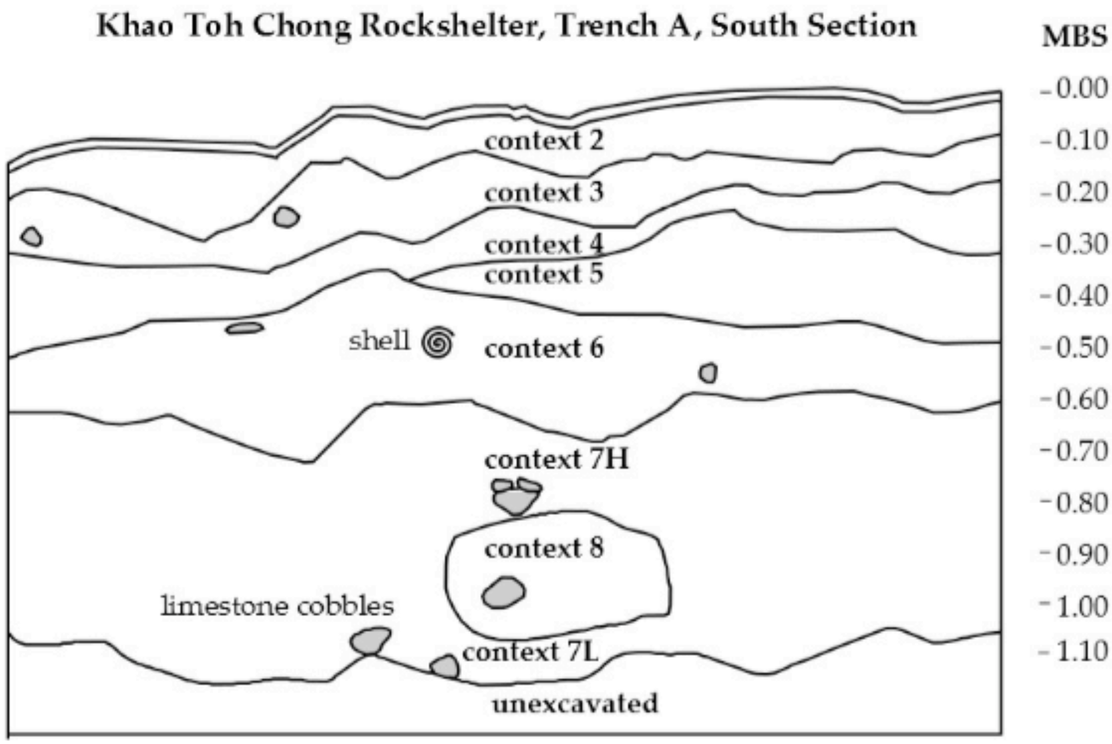


Figure 3.4 South wall profile from Trench A at KTC, displaying the natural strata labeled 'context.'

ICP-AES results provided data on site stabilization, weathering of the sediments, and soil formation processes. Magnetic susceptibility informed on the fire activity within the deposits and provides insight into occupational periods of the rockshelter. The results of this indicate that the rockshelter was inhabited continuously throughout the late-

Pleistocene and Holocene; however, detail as to greater periods of occupation within this timeline is yet to be discussed. The organic and carbonate matter and pH values at KTC generally describe the stability and preservation of sediments at the site (Marwick et al. 2013; Marwick et al. in preparation). The carbon isotope data suggests an increase in C_3 plants (e.g., plants that photosynthesize with sunlight and tend to be in more temperate climates, for more detail please refer to Appendix B).

Post-Excavation Faunal Data Collection

In 2012, the author and a colleague returned to Silpakorn University in Bangkok, Thailand where the archaeological assemblage is currently stored. The aim of the analyses in 2012 provided preliminary data of the archaeological assemblage excavated from the southwest unit of trench A during the 2011 field season at KTC. These results were presented at the 2013 Society for American Archaeology Conference and were later published (Van Vlack et al. 2013; Conrad et al. 2013). Research and analyses of artifacts were limited by time and access to the collection. Therefore, the focus of analyses prioritized artifacts that were deposited where the radiocarbon samples and the sediment samples were procured. The southwest unit of trench A was analyzed in order to determine identification and quantification of zooarchaeological remains, ceramic mass (g) and counts, charcoal mass (g), as well as lithic mass (g) and counts of flakes (see Figure 3.5). During excavation, a 0.05 mm sieve was used to separate cultural material from sediment.

Zooarchaeological analysis was carried out in the Digitation of Archaeological Archives Laboratory at Silpakorn University, Bangkok, throughout the month of July in 2012. Mollusk taxa were identified using the comparative collections from the National Science Museum of Thailand, and additional mollusk references manuals were used to understand habitats that these species are commonly found (Claassen 1998; Swennen et al. 2000; Sri-aroon and Harada 2006; Jiwaluk et al. 2007; Sucharit and Panha 2008). Mammalian, reptilian, and fish taxa were identified by the investigators using standard zooarchaeological reference manuals (Bunsong and McNeely 1977; Auetrakulvit 2004; France 2009; Ankel-Simons 2000). Without mammalian, reptilian, and fish skeletal comparative collections, identification of the former was generally broad based in order to limit identification error and provide a basis for further analysis. Avian taxa were absent from this unit of the KTC assemblage. Mammalian and reptilian identification assistance was provided by Dr. Prasit Auetrakulvit, associate professor of archaeology at Silpakorn University in Bangkok, Thailand. Both Cholawit Thongcharoenchaikit, an archaeologist and paleontologist for the National Science Museum of Thailand (Bangkok), and Dr. Sakboworn Tumpeesuwan, a paleontologist in the department of biology at Mahasarakham University, Thailand, aided in the identification of the molluscan assemblage.

Figure 3.5 Data entry during zooarchaeological analyses of KTC artifacts, July 2012.

A digital palm scale was used to record the mass of identified elements to the nearest 0.1 grams. Counts were recorded, standardized dimensions were taken in millimeters when applicable, and human modification of the fauna was noted when present in the assemblage. In addition, identifications of cutmarks and burning were noted for both mollusk and vertebrate remains. Photographs of complete mollusk specimens were taken using a Canon EOS60D digital camera (see Figure 3.6). Statistical analyses of the faunal assemblage followed the paleontological quantification standards of Lyman (2008). The focus of this research required an understanding of biases within the sample size, as it represents the whole assemblage. Additional quantification of the rate of faunal fragmentation within the assemblage was considered and statistically analyzed.

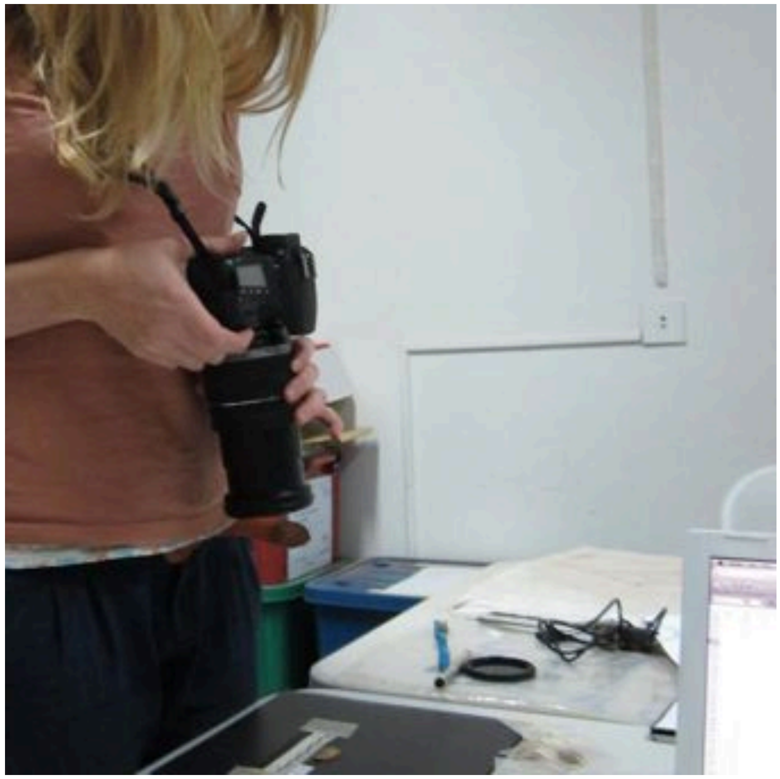


Figure 3.6 Photography station for analysis of KTC artifacts, July 2012.

Zooarchaeological Quantitative Methods of Data Analyses

The zooarchaeological assemblage at KTC was quantified in three ways. First, the number of identified specimens (NISP) was calculated as the primary measure of taxonomic abundance at the rockshelter site (Lyman 2008). This is an ordinal scale measure, quantifying all the identified skeletal elements either collected by hand during excavation or through sieving (0.5-0.3 mm). After preliminary analyses of the site in 2012, a reinterpretation of the site stratigraphy presented different results of the NISP values at KTC than previously recorded in the Conrad et al. (2013) article. Based off of the NISP count, the minimum number of individuals (MNI) was calculated following the standards of Lyman (2008). Taxonomic richness (NTAXA) was also calculated for quantification purposes.

The composition of the faunal assemblage (see Figures 3.7 and 3.8) was quantified in two ways: analysis of the sample size and rate of fragmentation (Lyman 2008: 144-151, 222-232; Cannon 2013). This was done in order to understand biases in the archaeological assemblage. Biases of the archaeological faunal can be affected by taphonomic processes during deposition of the faunal skeletal material, such biases may affect the ability to identify the remains by element or taxon. Additionally, addressing the sample size allows the researcher to understand if the assemblage can significantly represent the whole of the archaeological faunal collection.

Figure 3.7 Mollusk specimens from early Holocene deposits (*Neoradina prasongi*).

In order to examine changes in the subsistence regime over time, dietary evenness was quantified (Magurran 2004; Lyman 2008; Jones 2004; Jones 2013). Simpson's evenness and Shannon's evenness were calculated using taxonomic richness (NTAXA) and the NISP. In a perfectly even assemblage (values approaching 1) all taxa are equally utilized (i.e., abundant). In an uneven assemblage, all taxa are unequally utilized (i.e., values approaching 0).

Figure 3.8 Burnt artiodactyl distal third phalanx (muntjac deer).

Nestedness is a measure of the presence or absence of faunal specimens through time; this analyzes the possibility of faunal remains being subset populations of one another. For example, the fauna in context 8 at KTC should represent a smaller subset of the fauna from the context of 7L (in a perfectly nested assemblage). A perfectly nested assemblage is 0, while a not nested assemblage is 100 (Lyman 2008; Jones 2013; Jones 2004; Atmar and Patterson 1993). A broad diet should be represented by a larger diversity of fauna found at the archaeological site. Nestedness provides a quantifiable way to examine the change in diet breadth over time. Nestedness (nested overlap and decreasing fill index) was calculated by using the open-source software program called ANINHANDO (Almeida-Neto et al. 2008; Guimaraes Jr. and Guimaraes 2006).

Geoscience Methods

Two methods of archaeobotanical analyses were used in this research in order to understand the floral diversity at KTC. The first method, phytolith extraction, is a subfield within paleoethnobotany (Pearshall 1989). The second method used is a subfield of geoscience and botany known as palynology (Faegri and Iversen 1989). Both methods focus on fossil microbotanicals (Pearshall 1989). In this thesis, the phytolith extraction involves the removal of silicate plant cell structures from sediment deposited at KTC (Pearshall and Piperno 1993). These silicate plant fossils can be identified based on their morphology, allowing for a deeper understanding of landscape change and floral exploitation. Palynology is the study of fossil pollen (Faegri and Iverson 1989; Pearshall 1989). This method can be used to understand plant communities in a given region, while providing data for paleoenvironmental reconstruction and climatic conditions of those environments (Penny et al. 2007; Pearshall 1989). Both of these fossil microbotanical methods provide information about plant exploitation and landscape manipulation when used in anthropological capacities (Pearshall and Piperno 1993).

Phytolith Extraction

Phytolithic extraction was initially selected to test for botanical and organic matter within the KTC sediments samples. The processes of extracting phytoliths from sediment involves the use of mostly non-toxic chemicals, and with the small number of samples taken from KTC they were processed within one day. The author of this thesis participated in an internship at the paleoethnobotany lab at the University of California, Berkeley, under the direction of Rob Cuthrell, a doctoral student in the archaeology department. Instruments needed to process phytoliths required a laboratory equip with a chemical fume hood, basic instruments (e.g., 15 mL polypropylene test tubes, copper pot, syringes, 100 mL beakers, 500 mL beakers, glass dropper, microscope slides and slide box, vortex, centrifuge, and a hot plate). The chemicals used in this process are included in description of the methodology.

I used four steps to extract phytoliths from sediment and clay particles. The steps include (1) deflocculation; (2) removal of calcium carbonate; (3) removal of humic acid; (4) gravity separation and phytolith extraction (Coil et al. 2003; Piperno 2006). To alleviate the issue of cross contamination between sediment samples, the author rinsed hands prior to handling each sample. Instruments that came in direct contact with each sample were utilized for that sample alone. All processes were recorded via laboratory notes and excel spreadsheet. For each sample, 2.0 g of a homogenous mix of sediment was collected; the mass (g) was recorded and poured from the weigh-boat into a labeled 15 mL polyethylene test tube. There were nine samples total for this process.

Step 1. Deflocculation of particles

Each sample received 10 mL solution of deflocculation solution (sodium bicarbonate). This process allows for samples to be neutralized of electrical charges that may aggregate particles. Each sample was vortexed for several minutes to ensure saturation of sediment in the deflocculation solution. Then each sample received a water bath ranging in temperature from 75-83ºC for five minutes. Once the samples were removed from the water bath, samples were centrifuged at 1000 R.P.M. for ninety seconds. The supernatant was suctioned off the sample with the corresponding syringe, the remaining pellet was treated with 5 mL of deionized water, vortexed and then centrifuged again (see Figure 3.9). This allows for any deflocculation solution to be diluted, and for the remaining water to be removed in order to successfully treat the samples during the clay removal step.

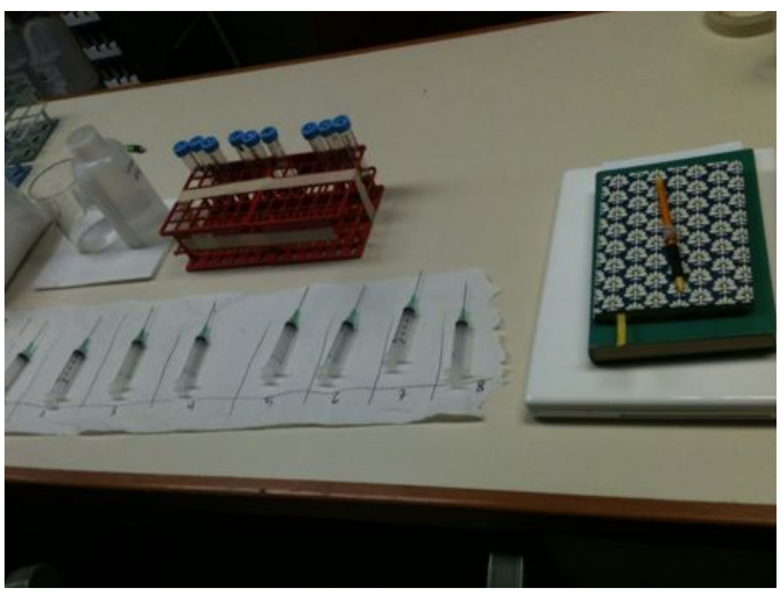


Figure 3.9 KTC sediment samples, syringes for chemical processing, and lab note set up at the University of California, Berkeley Archaeological Research Faculty wet lab.

The sample taken from context 7L was selected to check if the deflocculation was successful. To do this, 1 mL of the sample solution was removed and mounted on a slide to look at under a microscope (400x magnification) to check if clay particles were stratified or evenly distributed across the slide. Since the result of this test was an even distribution of particles, repeating this step was not necessary.

Figure 3.10 Centrifuge used during phytolithic extraction, University of California, Berkeley Archaeological Research Faculty wet lab.

Step 2. Clay removal

For this step, the fume hood and personal protective equipment was used to ensure laboratory safety. A 10% solution of HCl was added to each sample slowly. Because the sediment samples were collected from a calcium carbonate rich environment, HCl was added in drops to anticipate samples that would react stronger than others. Five drops total were added to each sample, followed by an additional 10 mL of the HCl solution to each sample. The samples were stirred, vortexed for a homogenous mixture, and then centrifuged at 3000 R.P.M for three minutes (see Figure 3.10). The supernatant was distilled into a baking soda solution, while the samples were treated again with deionized water, vortexed, and then centrifuged two more times to dilute any HCl remaining in the samples.

Step 3. Carbonate dissolution and organic digestion

For this step a water bath was used to heat sample, treated with 5 mL of KOH. Samples were placed in the water bath (78-85ºC) for ten minutes. It is normal for the samples to change color during this step. Samples containing more humic acid will darken to a blackish-brown.

Figure 3.11 Fume hood used during phytolithic extraction of KTC sediment; University of California, Berkeley Archaeological Research Faculty wet lab.

After removing the samples from the waterbath, each sample was vortexed and centrifuged at 3000 R.P.M. for three minutes. Once the centrifugation was complete, samples were decanted of their supernatant into an Acetic acid, glacial solution.

Step 4. Heavy liquid flotation

For this step the author used smaller test tubes to help control the amount of sodium polytungstate solution used for gravity separation. Sodium polytungstate was chosen to use in this step over bromoform because it is a non-toxic chemical alternative to bromoform. Gravity separation will separate the botanical remains for a brief period of time. The phytoliths and starches will be floated into the light fraction supernatant. The supernatant was poured into the newly, and properly, labeled polyethylene test tube. The heavy liquid flotation solution was added in 4 mL quantities to each sample. The samples were stirred, vortexed, and then centrifuged at 3000 R.P.M. for three minutes. When centrifugation was complete, removal of the supernatant of each sample for light fraction material was extracted. To mount slides, a dropper with 1 mL drop of saffranin stain was placed one each sample slide.

Phytolith analysis can indicate the occurrence of site use or alteration based on the proportion of phytoliths deposited at the site (e.g., plant refuse deposited in archaeological sediment). Phytoliths require no special conditions to become fossilized, however, the diversity of the phytolith yield may be lower than the diversity of a palynological study of the same site (Piperno 2006). Analysis and interpretation of phytoliths have been modeled after pollen studies, so many of the techniques are shared among the disciplines. Plant communities can be developed based on the phytolithic assemblage, also the size of phytolithic deposits can inform on environmental reconstructions (Penny and Kealhofer 1998; Kealhofer and Penny 2005). Phytolithic studies present data on percentages, concentrations, accumulation rates, in addition to the identified taxa and age-depth information on phytolith diagrams designed on TILIA and TILIA GRAPH programs (Piperno 2006: 123). Phytoliths are identified based on their shape that reflects the gross morphology of the particular plant.

Palynology

In this research, the author relied on the palynological standard practice of liberating fossil pollen from archaeological sediments (Faegri and Iversen 1989). The sediments used for this methodology were collected initially for geoarchaeological analyses explained previously in this chapter. The author was invited to work alongside Dr. Dan Penny, a geoscience professor at the University of Sydney, Australia. His expertise in Southeast Asian palaeoplaynology made this collaborative project ideal for this research. In this way, the KTC sediment samples were relied on as a repository for the fossil pollen. Some studies have suggested the possibility of this in karstic environments, especially those which environments have limited access to wetland eco-systems typically resources for geologic coring (Dimbleby 1985; Bhattacharya et al. 2011; Pookajorn 1991; White et al. 2002). There may be low counts of pollen in the sediment samples because of the karst topography at KTC. In which case, to reach saturation it may be necessary to use anywhere from two to five microscope slides depending on the variation of flora. For analytic purposes, it is better to express pollen in absolute numbers and not by percentages. When a percentage for one taxon goes up another may go down; this can be misleading about the abundance of flora at the site. Therefore, the samples will be counted in absolute numbers. Insect pollinated floras are usually in low abundances, whereas windblown pollen is likely more abundant. The pollen present at the site may suggest the flora, which existed at the site or grew close in proximity, rather than carried there via vector.

There are six steps involved in extracting the fossil pollen from sediments. The first stage is to remove coarse grain material (>100 μm) from the sediment samples selected for testing. The second stage involves adding HCl to the samples for the removal of $CaCO_3$. HCl was added to the sediment samples for the removal of calcium carbonate from the samples. Then, the sample was sieved (100 μm) to remove coarse materials. HF was added to the samples to remove silica, after which the samples should only consist of organic matter. The next step was to remove the polymers from the sample.

Step 1. Sample preparation

The Geoscience Water Analysis Lab at the University of Sydney, Camperdown was used to measure the volume and gather the mass (g) of the samples. Beakers containing the sediment samples were labeled by arbitrary sample numbers and recorded based on their archaeological context; the beaker labels varied chronologically 1 through 18 for organizational purposes (see Table 3.2). Each sediment sample will have two beakers to use for pollen extraction. A pre-cut syringe was used to take a core from the sediment sample collected from KTC. Samples were weighed in 100 mL beakers on a Mettler AE 160 scale to account for the nearest thousandths of a gram.

Table 3.2 Record of KTC sediment samples used for palynological chemical digestion and analysis.

Sample Label	**Sediment Sample (KTC11)**	**Volume**	**Mass (g)**	**(A) >250 µm, and (B) 250-106 µm**
1	B-N 1	2.0 cm^3	2.1977	1A, 1B
2	B-N 1	2.0 cm^3	2.2017	2A, 2B
3	A-S 2	2.0 cm^3	1.7631	3A, 3B
4	A-S 2	2.0 cm^3	2.0175	4A, 4B
5	A-S 3	2.0 cm^3	2.2360	5A, 5B
6	A-S 3	2.0 cm^3	2.1848	6A, 6B
7	A-S 4	2.0 cm^3	2.4882	7A, 7B
8	A-S 4	2.0 cm^3	2.0485	8A, 8B
9	A-S 5	2.0 cm^3	2.7909	9A, 9B
10	A-S 5	2.0 cm^3	2.6161	10A, 10B
11	A-S 6	2.0 cm^3	2.6713	11A, 11B
12	A-S 6	2.0 cm^3	2.7705	12A, 12B
13	A-S 7H	2.0 cm^3	2.4235	13A, 13B
14	A-S 7H	2.0 cm^3	2.8425	14A, 14B
15	A-S 8	2.0 cm^3	2.1084	15A, 15B
16	A-S 8	2.0 cm^3	2.5089	16A, 16B
17	A-S 7L	2.0 cm^3	2.4855	17A, 17B
18	A-S 7L	2.0 cm^3	2.7953	18A, 18B

Approximately 50 mL of sodium hexametaphosphate (50 g/L) was added to each of the 18 samples. This allows for the sample to be treated more effectively with other chemical reagents, because sodium hexametaphosphate breaks apart clay particles so that the material is more easily dispersed and neutralized (see Figure 3.12). The samples were stirred at 120 R.P.M., and were left over night to mix. Lycopodium spores [batch 1031] were added to the samples at this stage to control for the affect of the chemical reagents, which may alter the total pollen count (Maher 1981). Two tablets of Lycopodium spores were added to each sample. It is easier to add Lycopodium to the samples prior to the chemical digestion of silicates because the spores act as a control when counting the fossil pollen. If they are not needed they can be ignored during microscopic identification and analysis.

Figure 3.12 Disaggrating clay and mineral particles, and dissolving Lycopodium spores into the samples; Chemical Digestion Lab, at the University of Sydney, Camperdown.

Step 2. Coarse material separation

Each sample was sieved to remove coarser material. This material is kept and sorted by two different fractions, >250 µm and 250-106 µm. The samples of the coarse grained material (<106 µm) is where the fossil pollen is located within the sediment sample, and this faction of sediment was stored in the 100mL beakers for futher chemical digestion. Tropical pollen grains are about the same size (under 100 µm) and are quite robust. The two fraction sizes used for coarse grain removal may contain seeds, sand, and charcoal particles (see Figure 3.13). Charcoal size can be indicative of how close a fire was to the site (e.g., large particles of charcoal may be a closer fire than smaller particles of charcoal), and so these fractions were separated, dried, and sealed in polyethylene bags for future study.

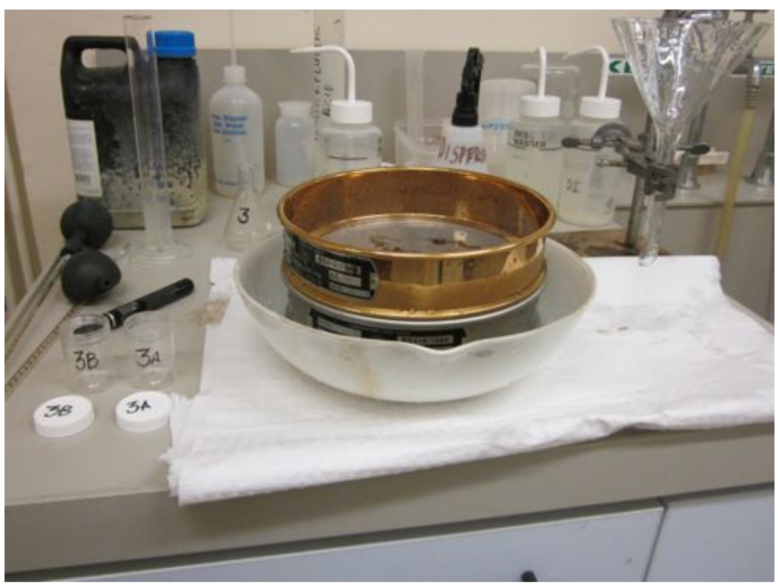


Figure 3.13 Separation of coarse particles of KTC sediment, Chemical Digestion Lab at the University of Sydney, Camperdown.

Step 3. Removal of Calcium Carbonates

The samples <106µm were weighed to the nearest thousandths of a gram, and this information was recorded in Table 3.2. The samples received 50 mL of HCl and stirred on the shaker at 120 R.P.M. for approximately three hours. Upon removal of the shaker, the samples were treated with 15 mL of HCl for ensure $CaCO_3$ digestion. The samples were treated with the solution and heated in a water bath (80ºC) for three hours. Humic acids produced a color (e.g., green or dark brown; see Figure 3.14) that stain sediments because they are organic rich and provide excellent conditions for pollen preservation. The HCl acid was diluted with 30 mL of deionized water, spun at 3000 R.P.M. for five minutes, and decanted (this process can be repeated if more HCl is used to digest the $CaCO_3$).

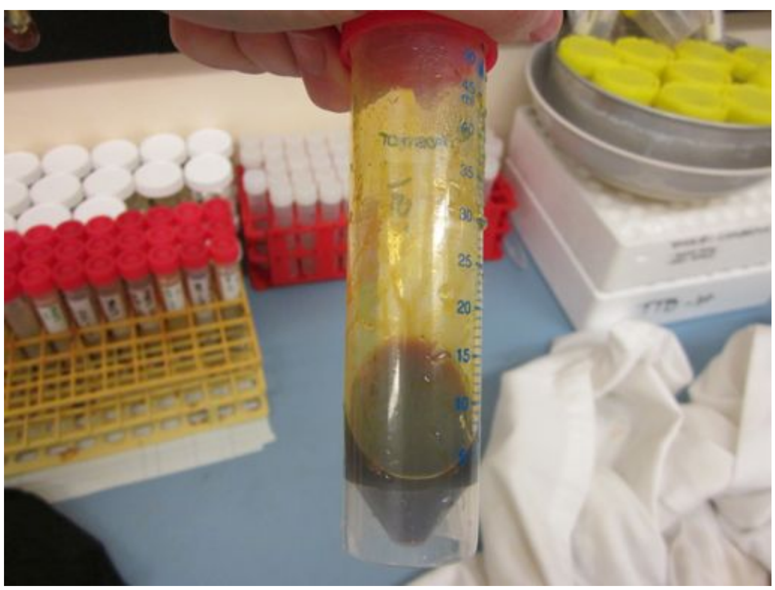


Figure 3.14 Examination after removing humic acid from KTC sediment; Chemical Digestion Lab, at the University of Sydney, Camperdown.

Step 4. Removal of Silicates

The most important step is eliminating silica from the sample. Silica is a mineral, and by ridding the sample of it the sample will be cleaner for pollen identification. To do so, 10 mL of HF was added to each sample and then each sample was heated with a water bath at approximately 60ºC for five to six hours (see Figure 3.15). Samples received 30 mL of deionized water, and were centrifuged at 3000 R.P.M. for three minutes. The supernatant was decanted. This step was repeated for samples that exhibited silica presence (i.e., a white ring around the pellet) until the silica was no longer visible. After silica is removed the samples become slippery, and they will need to be centrifuged for longer. Once the samples finished centrifugation and decantation of the solution, the author added 10 mL of 15% HCl and vortexed the samples for a homogenous mixture of sediment and solution. This step removes the precipitants (silica fluorides).

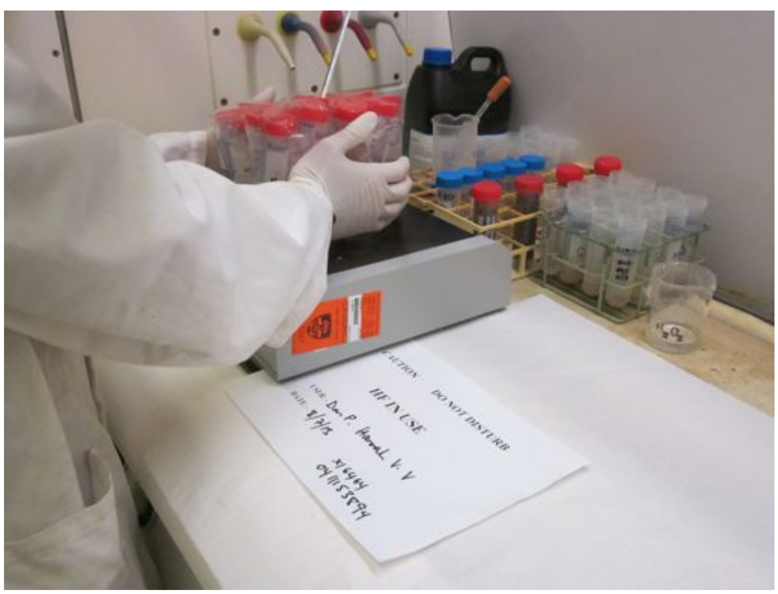


Figure 3.15 Waterbath of the KTC samples, treated with HF; Chemical Digestion Lab, at the University of Sydney, Camperdown.

Step 5. Acetolysis

Glacial acetic acid was added to the samples to get rid of the water from the test tubes. Water and anhydric acid mixed with sulphuric acid is highly combustible, and so the glacial acetic acid was used to remedy this catalytic process. For safety purposes, 10mL of glacial acetic acid was added to each sample, vortexed until the pellet was mixed, and centrifuged at 3000 R.P.M. for five minutes, then the sample was decanted leaving the pellet of organic matter behind. This step was repeated twice. After decantation, the samples received 10 mL of acetic anhydrate sulphuric acid to undergo the process of acetolysis. The chemical acid solution contained one part sulphuric acid (20 mL) and nine parts acetic anhydrate (180mL). Ten mL of this solution was added to each sample, vortexted, and centrifuged at 3000 R.P.M. for five minutes. The samples sat for ten minutes in a sonaphon, a process that uses ultrasonic vibrations. The vibrations are sent through the samples at a high resolution in order to shatter the samples at a molecular level. The combination of anhydrate acid and sulphuric acid produces a thermal reaction, and so a heated water bath can catalyze this process. Without this step the sample may appear foggy on the slides.

The samples were centrifuged at 3000 R.P.M for five minutes, decanted and then 10 mL of glacial acetic acid was added to the samples (see Figure 3.16). This allows for the samples to be rinsed from the chemicals without a combustible reaction. The samples were vortexted and centrifuged for five minutes at 3000 R.P.M. and decanted. Thirty mL of deionized water was added to the samples for several hours.

Figure 3.16 Centrifuge at the University of Sydney, Camperdown Geoscience Department.

Step 6. Slide Preparation

The pollen slides were mounted using a 1 mm dropper and glass microscope slides. Five mL of glycerol was added to each sample in order to aggregate the sample for identification purposes, which prevented pollen from collecting in one area. The pollen slides were sealed with paraffin wax (see Figure 3.17). The slides will be stored at the University of Washington in three slide boxes. There are three sets of samples for each slide: A, B, and C. Three slides were produced for each sample to assure saturation within the fossil microbotanical assemblage.

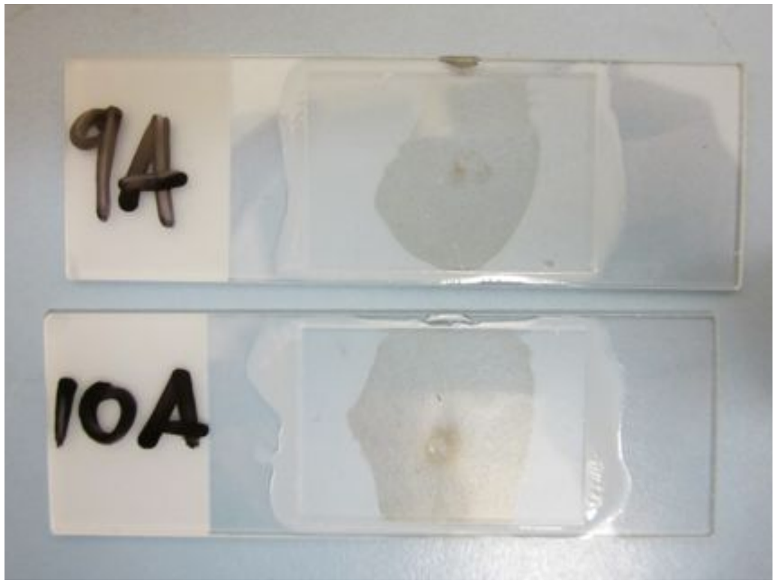


Figure 3.17 Paraffin wax was used to seal the glass slides containing the palynological data.

Chapter Summary

This chapter provides a description of the research and methods carried out on the KTC assemblage, including the previous archaeological study of the site. The radiocarbon dating, geoarchaeological analysis, and the post-excavation analysis of the KTC assemblage are discussed in this chapter. An explanation of quantitative zooarchaeological methods for data analyses, phytolithic extraction, and palynological study of deposits collected from KTC are explained thereafter. The environmental archaeological study of KTC is designed to illustrate a spectrum of environmental processes encompassed at KTC. The continuous human occupation of the site during the late-Pleistocene and throughout the Holocene provides cultural and environmental evidence that provides insight into the transition from hunter, gatherer and forager to that of an agroecosystem.

Chapter 4: Data Analysis and Results

Introduction to the Results

Analysis of the KTC assemblage provides evidence of trends in resource exploitation and technological advances throughout the Holocene. Preliminary results of ceramic and lithic counts and mass (g) are presented in this chapter, in addition to the possible motivations behind the chronology of their occurrence in site deposits. The results of quantitative and statistical measures of the faunal assemblage is presented in this chapter and suggests that hunter, gatherer, and foragers utilized a system of complex foraging to procure a specific faunal population. Changing climatic and environmental conditions appear to be the primary reason for changing exploitation patterns over time. The fossil microbotanical analyses indicated periods of wetting and drying at the rockshelter, which was not ideal for fossil pollen preservation. The pilot study of phytoliths indicated an emphasis for future analyses of fossil silicate microbotanicals.

Results from the Lithic and Ceramic Analyses

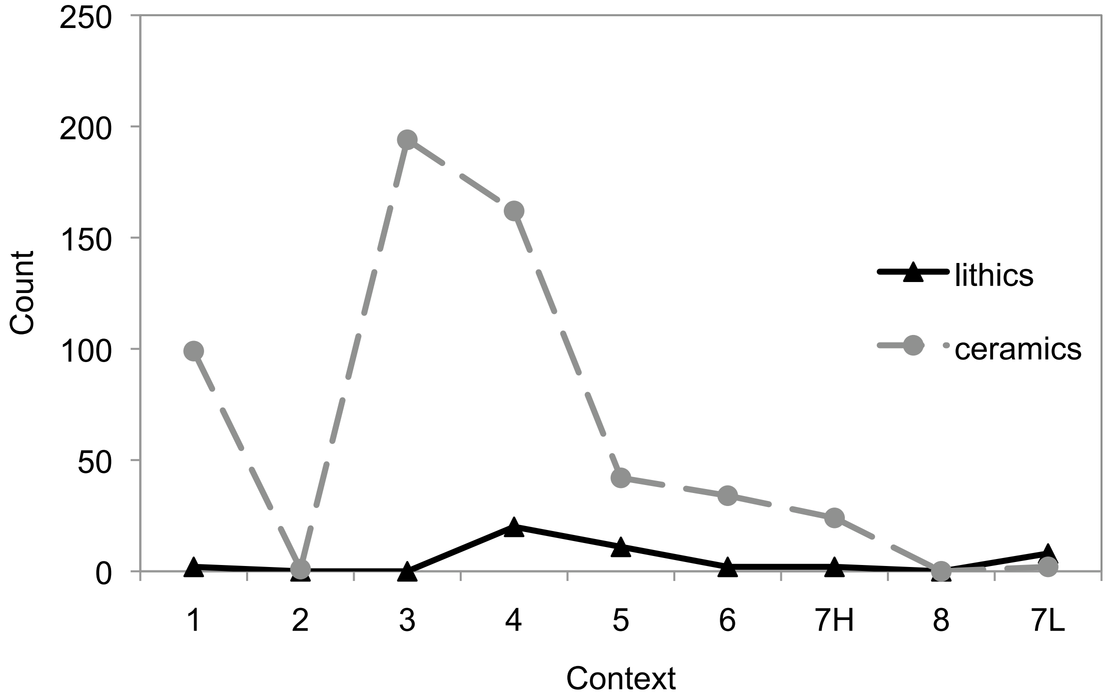
Counts of the lithic and ceramic artifacts were analyzed to investigate trends in the cultural activity at KTC. The results can be seen in the graph below. The analyses of the lithics and ceramics counts and mass (g) show some preliminary results. Ceramic counts and lithic flakes both increase during the mid-Holocene at KTC (5,592 years BP). The ceramic counts continue to increase throughout the late-Holocene. During this period, it is likely that bronze and iron technology was utilized as a main tool resource over stone technology (Higham 2002: 113). However, bronze and iron tool technology was not discovered in either the 2011 excavation at KTC or in the 2012 post-excavation analysis of the assemblage. The occurrence of rice chaff located in ceramic temper was found at two archaeological sites, Ban Chiang and Non Nok Tha, which suggest “that the earliest bronzes were being cast within a period of 1,500-1,000 BC” (Higham 2002:112). It is likely that the cause in the subtle drop of lithic flakes during this period, approximately 2,967.0 cal. years B.P, is due to the adoption of metal tools in the region.

Figure 4.1 Flaked stone artifact (left) deposited at KTC Rockshelter, excavated in July 2011. And red chord marked ceramic (right) artifact, collected during excavations in 2011.

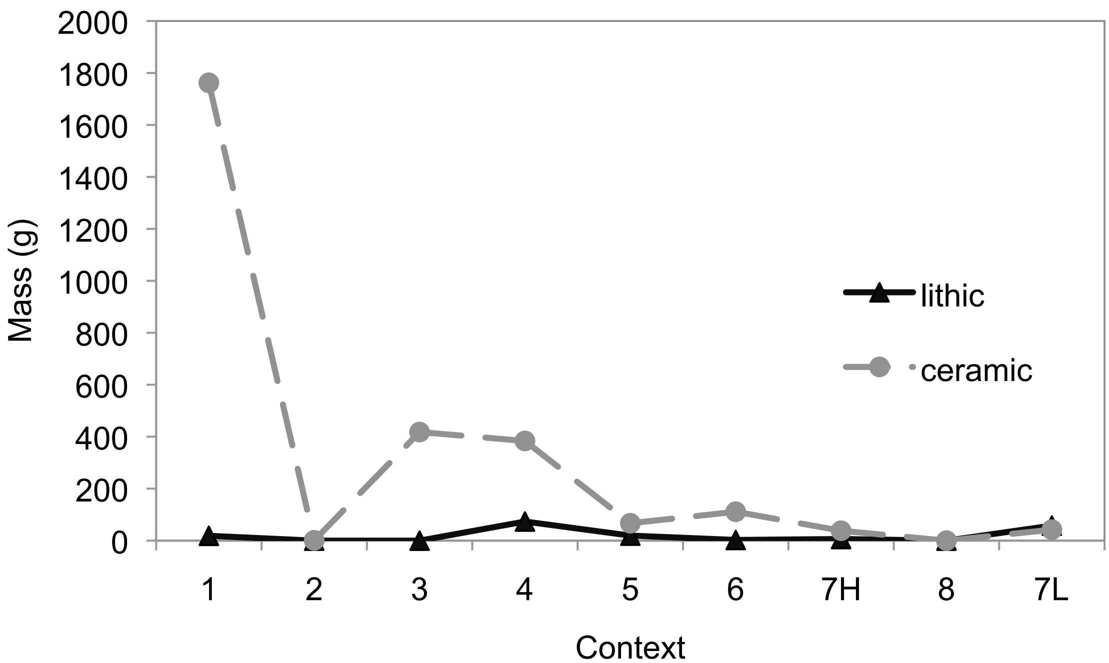
Evidence of ceramic use in Malaysia does not appear until the mid-Holocene, which may suggest that there is either a fair amount of trampling and vertical displacement of artifacts occurring within the sediments at KTC; or, ceramic vessels were introduced to Thailand, which later spread south through the Malay Peninsula (Bulbeck 2003). Lang Rongrien Rockshelter suggests that ceramic vessels associated with human burial post-date 4,000 years B.P., while evidence at KTC suggests an earlier time period for the appearance of ceramics in southern Thailand (Anderson 1997; Marwick et al.

2013; Marwick et al. in preparation). Lambert et al. (2003) states that Spirit Cave, Thailand sees the appearance of ceramic use in 3,042±37 cal. B.P. to 2,995±40. Examples of the ceramic and lithic technology collected from KTC cultural deposits can be seen in Figure 4.1, while a visual reproduction of lithic and ceramic counts can be seen in Figure 4.2.

The ceramic and lithic technology at KTC showed distinct changes through the chronological sequence of the site. Polished fine-grained sedimentary rock was found in the mid-Holocene layers of the site while large flaked cores of coarse-grained metamorphic rock were found in the late-Pleistocene to early-Holocene layers of the site. The ceramic assemblage changes from black sherds found in the mid-Holocene layers to thicker, red ceramic sherds with incised decoration found in the late-Pleistocene to early-Holocene layers. The changes in the lithic and ceramic technology deposited at KTC suggest a critical transition from hunter, gatherer and forager subsistence pattern where food is collected on an immediate return rate to a regime where surplus food is stored. The appearance of ceramics, the artifacts that dominate the material-cultural side of the assemblage at KTC, suggests that food storage is being practiced. Heavier flaked stone artifacts and the abundance of ceramics also suggest a more sedentary group during the mid-Holocene.



Counts of Lithic and Ceramic



Lithic and Ceramic Mass (g)

Figure 4.2 These graphs represent the total counts ceramic and lithic (above) and the mass (g) of lithic and ceramic (below) excavated from Trench ASW at KTC in 2011.

Results from the Zooarchaeological Analyses

Quantification of zooarchaeological remains from KTC were recorded in three ways using the lowest possible taxonomic level (Lyman 2008; refer to Appendix C): the number of identified specimens (NISP), taxonomic richness of the assemblage (NTAXA), and the minimum number of individuals (MNI). A two-tailed linear regression test was run to analyze the statistical significance between logNISP to NTAXA, and logNISP to MNI. The test between logNISP to NTAXA provides a statistical measure of sample size. Testing between logNISP to MNI provides a statistical measure of fragmentation (Lyman 2008). The statistical findings produced a significant result for logNISP to NTAXA ($r = 0.91$, two tailed $p = 0.0007$, $df = 7$; see Figure 4.3). This test for the preservation of sample size indicated that processes affected each context similarly, implying that the faunal assemblage from KTC is not biased.

A regression analysis of logNISP to MNI was utilized to decipher if the level of fragmentation for faunal remains affected the faunal assemblage during decomposition and deposition (Lyman 2008; Jones 2013). Results from this regression indicate that fragmentation of the faunal assemblage occurred equally throughout all contexts of site strata, although with relatively weak significance ($r = 0.601$, $p = 0.0436$, $df = 7$). This result is likely driven by the abundance of one shellfish species (i.e., *Neoradina prasongi*). Taphonomic processes may be one factor in the absence of other vertebrate species, while other factors such as complete carcass processing, trampling, and the presence of rodent scavengers is likely to have occurred at this site affecting the faunal biodiversity of the assemblage. *Neoradina prasongi* dominates the total mollusk specimens in the assemblage by a striking 85.2% of the total NISP.

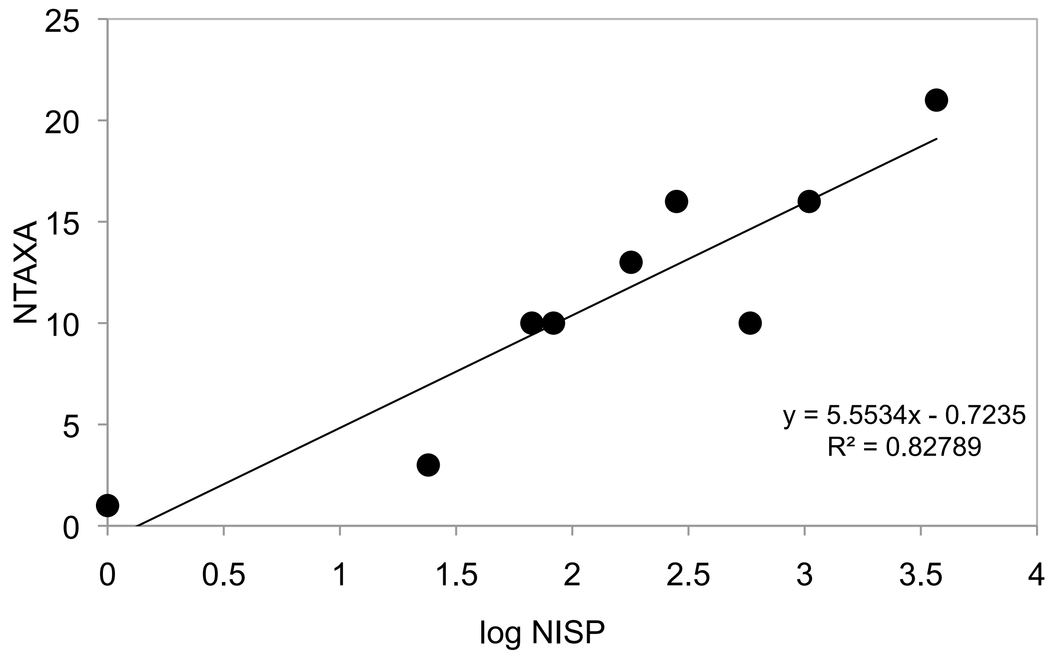


Figure 4.3 Relationships between log NISP and NTAXA of the faunal assemblage from KTC per context with a best-fit regression line ($r = 0.91$, $df = 7$, $p = 0.0007$). Faunal material from Trench B and units SE, NW, NE of Trench A have not yet been studied.

There is a huge abundance of fragmented specimens, which supports the concept that taphonomic decomposition is largely impart to biases in the sample size. Large zooarchaeological assemblages in Thailand are not common, often due to increased decomposition and taphonomic processes from acidic sediment in these karstic environments. KTC is a rare site because of the well-preserved faunal skeletal remains, likely a result of the basic to neutral pH range in the soils (7.6 - 9.3; refer to Appendix B). For this reason, zooarchaeological collections are few and far between, while documentation of the surrounding sites does not give precedence to this area of expertise. At Moh Khiew Cave there were perhaps 65,000 specimens recovered from excavations of the archaeological site, but only 34% of the taxa was identifiable (Auetrakulvit et al. 2012). The sample of zooarchaeological remains collected from the southwest unit of trench A reflects an accurate reflection of the fauna at KTC.

Table 4.1 Species richness of KTC zooarchaeological assemblage representing the dietary evenness at KTC. The assemblage appears to have shifting evenness values over time, suggesting complex foraging.

Context	^{14}C Dates cal. Years B.P.	1/Simpson's	Simpson's E
1	142.5	1.29	0.43
2	144.0	-	-
3	1,931.5	2.28	0.23
4	2,967.0	1.75	0.13
5	6,370.5	2.27	0.23
6	7,866.5-13,636.0	3.95	0.25
7H	13,860	1.18	0.06
8	-	1.14	0.11
7L	15,751-13,121	2.29	0.14

The results of testing for evenness suggest varying trends over time. The reciprocal of Simpson's and Simpson's E were calculated to examine the statistical significance of dietary evenness: the quantification of abundance and richness of taxa (see Table 4.1). For Simpson's E, if the assemblage is uneven and dominated by a single species then the values will be closer to 0, while an even assemblage in which all taxa are equally abundant will present values closer to 1. The reciprocal of Simpson's E is not susceptible to the dominance of a single taxon, thus the values appear to be greater than Simpson's E.

In context 7L diets are broad and relatively even, but in contexts 8 and 7H the faunal assemblage is less even. This is an indication of narrowing diet breadth, likely due to the environmental changes that occurred during the melt of glaciers during the Ice Age. During the late-Pleistocene, when the environment around KTC was an open-grassland savannah, large artiodactyls were abundant and exploited for subsistence purposes. In this context, bivalves and gastropods were also found among the faunal assemblage. The exploitation of these types of resources may indicate sex differences in foraging strategy likely driven by resource availability in this changing environment.

In context 6, diets became broader. Radiocarbon dates of context 6 indicate that the fauna was deposited in the transition of the late-Pleistocene to Holocene. During this transition, sea level began to rise, pushing foraging groups landward towards the Krabi highlands. It is likely that diets began to broaden during this period due to the onset of cultivation practices.

Contexts 5 and 4 occur during the mid-Holocene. Diets continue to be broad. The data indicates that foragers are exploiting a variety of fauna. However, the reciprocal of Simpson's suggest that the faunal exploitation that took place during the mid-Holcoene began to narrow in comparison to the overall pattern. It is likely that this result is driven by several factors; during this period, the monsoonal storms became seasonal, affecting the region with more strength (Maxwell 2001). Also, the increase in storms may have influenced a rise in the occupation at KTC, while foragers in the region likely became more skilled to hunting, gathering, and foraging in the dense jungle-like estuary.

Context 3 becomes relatively more even than contexts 5 and 4. This is an indication that late-Holocene foraging existed amid agriculture in the area. Context 2 and 1 reflect the historical use of KTC. Historically, there may have been some foraging and food processing at KTC, while there is little ethnographic data of hunting, gathering, and foraging in the Krabi region, this data sheds light on the possibility of modern foragers.

Nestedness is an analysis of species distribution within a habitat; it is commonly used in the environmental science and studies of biodiversity (see Table 4.2; Atmar and Patterson 1993; P. Guimarães Jr. and P. Guimarães 2006; Lyman 2008; Jones 2013). The results of the nestedness analysis show that the assemblage is relatively nested (NODF = 28). Values that indicate a perfectly nested assemblage range from 0 to 49, while the range of 50 to 100 are considered a not nested assemblage. This was calculated using the ANINHADO software (Guimarães and Guimarães 2006). Following Lyman (2008), Spearman's rho was quantified to measure the strength between contexts and NISP. Since the assemblage is relatively nested, a significant Spearman's rho relationship is expected if NISP decreases through time relative to the context. The rank order relationship is significant ($r_s = 0.92$, $p < 0.05$): an indication that hunter-gatherer and forager subsistence practices are driving these results.

Table 4.2 Presence (+) and absence (-) matrix for the nestedness analysis (Spearman's *rho* = 0.92, $p < 0.05$).

Taxa / Stratigraphic Context	**Surface**	**2**	**3**	**4**	**5**	**6**	**7H**	**8**	**7L**
Neritidae gen.	-	-	-	+	-	-	-	-	-
Nerita balteata	-	-	-	-	+	+	-	-	-
Cyclophorus sp.	-	-	-	-	-	-	+	-	-
Cyclophorus cf. *saturnus*	-	-	-	-	-	-	-	-	+
Cyclophorus malayanus	-	-	-	-	-	+	+	+	-
Cyclophoridae gen. indet.	-	-	+	+	+	+	+	+	+
Rhiostoma jalorensis	-	-	-	+	+	+	+	+	+
Rhiostoma sp.	-	-	-	-	-	-	+	-	+
Filopaludina sp.	-	-	-	+	-	-	-	-	-
Viviparidae gen. indet.	-	-	+	-	-	-	-	-	-
Pila sp.	-	-	-	-	-	-	+	-	-
Ampullariidae gen. indet.	-	-	-	-	-	+	+	-	+
Neoradina prasongi	-	-	+	+	+	+	+	+	+
Telescopium telescopium	-	-	-	+	+	+	+	-	-
Muricidae gen. indet.	-	-	+	+	-	+	-	-	-
Plectopylis degerbolae	-	-	-	+	-	+	+	+	+
Amphidromus atricallosus	-	-	-	+	+	-	+	-	-
Anadara sp.	-	-	+	-	-	-	-	-	-
Arcidae gen. indet.	-	-	-	+	-	+	-	-	-
Pseudodon sp.	-	-	-	+	+	-	-	-	-
Amblemidae gen. indet.	-	-	-	-	+	+	+	+	+
Corbiculidae gen. indet.	-	-	-	-	-	-	+	-	-
Osteichthyes subclass indet.	+	-	-	-	-	-	+	-	-

Taxa / Stratigraphic Context	Surface	2	3	4	5	6	7H	8	7L
Testudines fam. indet.	+	+	+	+	+	+	+	+	+
Varanus sp.	+	-	+	+	+	+	+	+	+
Pythonidae gen. indet.	-	-	-	-	-	-	-	-	+
Primates fam. indet.	+	-	+	-	-	+	-	-	+
Macaca sp.	-	-	+	-	-	-	+	+	+
Trachypithecus obscurus	-	-	-	-	-	-	+	-	-
Rodentia fam. indet.	-	-	+	-	-	-	+	-	-
Rattus remotus	-	-	-	-	-	+	-	-	-
Cannomys badius	-	-	-	-	-	-	-	-	+
Atherurus macrourus	-	-	-	-	-	+	-	-	-
Carnivora fam. indet.	-	-	-	-	-	-	+	-	-
Tragulidae gen. indet.	-	-	-	-	-	-	+	-	-
Cervus unicolor	-	-	-	-	-	-	+	-	-
Muntiacus muntjak	-	-	-	-	-	-	-	+	+
Bovidae gen. indet.	-	-	-	-	-	-	-	-	+

Changes that are seen in the KTC zooarchaeological assemblage over time reflect what humans were collecting and utilizing to survive at the rockshelter. The fauna deposited at KTC is relatively nested with a significant Spearman's rho correlation (r_s= 0.92, $p < 0.05$). This means that the fauna deposited at KTC was derived from the same population, indicating that the pattern of mobility and resource of exploitation at KTC was driven by the availability of these particular faunal resources.

Additionally, results suggest that the assemblage at KTC reflects a broadening diet breadth and a pattern of complex foraging throughout the Holocene. The broadening of diet breadth has been an interest of many ecological anthropologists, primarily interested in the onset of agriculture (Flannery 1965, 1969; Cleland 1966, 1976; Hardesty 1975; Dunnell 1967, 1972; Lyman 2008). Ecological anthropology often embraces theoretical notions of the broad spectrum revolution; however, it is a theory concerned with pre-agricultural societies (Zeder 2012). Thus far, the statistical results of the zooarchaeological assemblage indicate that KTC exemplifies the transition of exploitation of larger fauna to that of a wider array of smaller fauna, likely cause of environmental changes and human behavioral response to such density independent events (e.g., sea level rise, the onset of a warmer climate) occurring along the Thai-Malay Peninsula. Considering that KTC encompasses the chronology favored in broad spectrum revolution theory, evidence of the spread of agriculture throughout Thailand is yet to be determined.

Results from the Microbotanical Analyses

The results of the phytolith pilot study indicated that starches and silicate phytoliths were present, but identification and quantification was beyond the scope of this project.

The fossil pollen slides were analyzed using an Axioscop 2 light microscope and photographs of the fossil pollen slides were captured with the imaging software, Altra 20, which was attached to the light microscope (see Figure 4.4). All slides were viewed with 400x magnification.

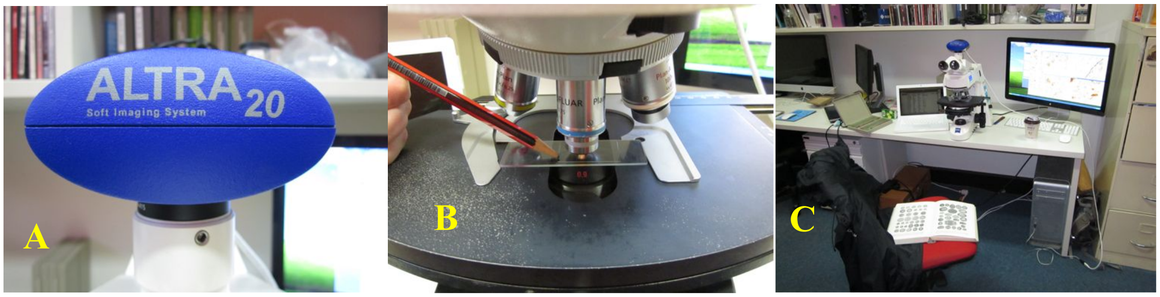


Figure 4.4 Altra 20 (A) is a soft imaging system that was used to image the fossil pollen slides from KTC. The Zeizz light microscope was used for the analysis of the microbotanicals (B) at 400x magnification, at the University of Sydney, Camperdown Geoscience Department. Images were displayed on a monitor (C) and identified using a pollen comparative collection and Huang (1972); data was recorded on an excel spreadsheet.

The results of the palynological analysis revealed a low pollen yield, suggesting evidence of poor preservation of fossil pollen at the rockshelter. Absolute pollen frequency diagrams could not be constructed on account of the unsubstantial amount of fossil pollen per slide. Pollen preserves best in anaerobic environments. KTC experienced periodic wetting and drying; this process expanded and contracted the clayey sediment which oxidized the fossil pollen. What was present in the fossil pollen slides were varied sizes of charcoal fragments, fungal spores, and other unidentifiable organogenics.

Summary of Results

The purpose of this chapter was to demonstrate trends in the cultural material deposited at KTC during the late-Pleistocene through Holocene. The results of the preliminary ceramic and lithic analysis suggest an incremental trend technology use during the mid-Holocene. The statistical analyses of the faunal assemblage deposited at

KTC indicated a complex pattern of foraging, where resource exploitation broadened during the mid-Holocene. Taphonomic processes and fragmentation of the faunal remains appear to affect each context similarly, allowing for unbiased quantifiable interpretation of faunal remains. The faunal assemblage is relatively nested; meaning that exploitation of fauna was strategic and generally came from the same population. Evidence of the changing biome due to density independent processes, such as the rise in sea level and climatic change, is evident in the faunal assemblage based on the appearance of open-grassland savanna fauna and then subsequent disappearance of it during the late-Pleistocene and early-Holocene. This chapter also presented the results of the fossil microbotanical study of KTC sediment. These studies presented preservation issues, and the need for further investigation of the phytolith assemblage. There was not enough fossil pollen to substantiate any claims regarding specific paleoenvironmental reconstruction, or the microclimate of KTC.

Chapter 5: Evaluation and Discussion of Findings

Introduction to the Discussion

The discussion in this chapter provides insights into the dynamic period of cultural change along the Thai-Malay Peninsula regarding complex foraging during the transitional period of agroecosystem development. The information presented in this chapter hypothesizes that foraging regimes utilized in southern Thailand contributed both to cultivation strategies and group survival. Artifacts in cultural deposits at KTC suggest both residential and logistical mobility patterns and site use. Environmental change is illustrated by the stable carbon isotope results, which suggests that sea level rise and stronger monsoonal conditions have been a driving factor of changing foraging strategies.

Evaluation of Findings

Determining the emergence of agriculture during the course of human history is not a new topic to archaeologists (Gorman 1971; Higham et al. 1981; Bailey et al. 1991; Maloney 1994; Watson 1995; White 1995; Flenley and Butler 2001; Hayden 2013). There are many implications that spawn from the term agriculture, the first being the selection and domestication of a particular species (Fuller 2006). The second implication of agriculture is the practice of ritualized labor. In the case of tropical rice cultivation, this is an important consideration to landscape management, caloric intake, and economic return rates (White 1995; Hayden 2013). The discussion provided in this chapter does not necessarily pertain to agriculture in Thailand, but rather the transition from hunter-gatherer and forager to that of an agroecosystem.

> "The conventional archaeological perspective is that agriculture was introduced to the region c. 5000-4000 B.P. by expanding agriculturalists from the central Yangtze region of China (Bellwood 1992, 1997; Higham 1995; Higham and Lu 1998). For the Malay Peninsula, archaeologists have also argued that there is a chronological and cultural gap between earlier late-Pleistocene-Holocene Hoabinhian hunter-gatherers and later Holocene agriculturalist… although, from the paucity of data, the extent to which the gap is in the data or in prehistoric occupations is unclear. Did hunter-gatherers leave the tropics as the humid forest developed (as Headland and Bailey might suggest)? Have we simply not identified mid-Holocene hunter-gatherer sites? Or, were there groups in the forest practicing a different set of food-production strategies?" (Kealhofer 2003:74)

The data from KTC begin to answer Kealhofer's questions. Available evidence suggests that hunter, gatherer, and forager groups did not leave the tropics. In fact, we know that foraging populations still exist on the Peninsular today. This evidence of foraging populations is recorded in ethnoarchaeological reports from the Mani tribe at Sakai Cave (Pookajorn 1991). There are several mid-Holocene archaeological sites on the Thai-Malay Peninsula: Sakai Cave, Lang Rongrien Rockshelter, Moh Khiew Cave, and Khao Toh Chong Rockshelter (Pookajorn 1991, 1996; Anderson 1990, 1997; Mudar and Anderson 2007; Hongo and Auetrakulvit 2011). Based on the analysis of KTC's zooarchaeological assemblage and data from geoarchaeological analyses, it is possible that hunter, gatherer, and foragers practiced mixed-swidden cultivation and foraging patterns that rely on riparian resources.

By using stable carbon isotope data archaeologists can interpret climate change and evaluate plant communities based on photosynthetic pathways of C_3 or C_4 ratios. There are three types of photosynthetic pathways that can be tested using geoarchaeological methodologies (refer to Appendix B for the KTC geoarchaeological reports). Plant photosynthetic pathways metabolize carbon fractionate in three different ways (CAM, C_3 and C_4). Each of the three types of photosynthetic pathways leave a specific isotopic pattern of $^{13}C/^{12}C$ (Van de Merwe 1982). C_3 plants thrive on sunlight (e.g., rice, wheat, vegetables, fruit), while C_4 plants (e.g., grasses, sugarcanes, millet) are light independent and thrive on CO_2 emissions (Van der Merwe 1982; DeNiro 1987; Simpson 2006). CAM pathways (Crassulacean acid metabolism) are C_4 plants that have adapted to arid conditions. CAM pathway plants function in high daytime temperatures with intense sunlight and low soil moisture.

In the tropics, there are usually less C_4 vegetation because of the amount of shade produced by the forest canopy, while, C_3 plants are found in this wetter and cooler environment. The geoarchaeological data suggest that the environment shifted from C_4 photosynthetic plants to C_3 photosynthetic plants at KTC, suggesting the climate became wetter and cooler throughout the Holocene in southern Thailand. Proxy data indicate that what was once an open grassland savannah environment became a denser vegetated rainforest environment with more shade throughout the mid-Holocene (Maloney 1992; Mudar and Anderson 2007; Marwick and Gagan 2011). The data also suggest that the site is relatively undisturbed, where some microbial activity may have aided in the decomposition of organic matter. This is likely a feature of the microclimate of the rockshelter and karstic system.

Figure 5.1 Tributary directly adjacent and north of KTC rockshelter.

The environment changed from open grassland savannah to a denser vegetated landscape as a result of regional climatic and environmental changes (Maxwell 2001; Songtham 2009; Sinsakul 1992; Tjia 1996; Horton et al. 2005). These changes are influenced by the increase in precipitation (e.g., monsoonal events and the rise in sea level). Accordingly, the increased precipitation of the estuary environment of the Krabi River Valley provided ideal conditions for the expansion of the mangrove forest habitats, tributaries, and the riparian species inhabiting the region (see Figure 5.1). The geoarchaeological testing provided the proxy data of increased precipitation and C_3 plant dominance throughout the Holocene at KTC (~10,000 years B.P. to Present). The faunal data also indicated this environmental shift, based on the lack of large mammalian fauna and appearance of riparian fauna in Holocene dated cultural deposits. As the climatic conditions became moister, seasonal changes in Thailand become less distinct. These environmental shifts provided an ideal location for wet rice cultivation techniques.

The appearance of clay sized mineral particles begin in mid-to-early-Holocene (refer to Table 3.1 and Figure 3.4). These results are suggestive of both the microclimate at the rockshelter site, as well as the increased precipitation throughout the Holocene in southern Thailand. These particles were brought into the site through colluvial and aeolian processes. During the wettest periods, water and sheetwash off the limestone face brought these clay particles into the site, burying the cultural artifacts left behind by foraging groups. Clay particles expand when wet and shrink when dry. The abundance of clay particles in sediment samples aided in the decomposition of vegetal remains, while the expansion and compression of the particles periodically oxidized the strata. Additionally, clay particles in the sediment provided ideal preservation for the calcified and silicate remains deposited in the sediment. The expansion clay particles allowed for microbial activity to take place within the sediment, and are perhaps one indication about the lack of nutrients in the soil.

The lack of soil nutrients indicates that success with dry land cultivation of rice would be less probable. Small scale wet rice cultivation (or pocket padis) can be constructed on the edges of estuary environments; this technique appears to be more reliable when the condition of soil lacks nutrients (Hayden 2013). Pocket padi cultivation is a simple swidden style of agriculture that is often constructed in estuary environments (Hayden 2013; Howell 2013). Paddy cultivation is a style of large-scale agriculture and involves a considerable amount of time, energy, and production capital. In paddy cultivation, irrigation is often routed into the paddy by way of dikes and canals, and fields are often ploughed using water buffaloes (Higham et al. 1981). Soil fertilizers and transplanting of seedlings is also necessary for rice paddy cultivation (White 1995). In contrast, pocket padi cultivation can be associated as a style of opportunistic horticulture. The process involves the clearing of a small area that is filled by a natural waterway, either by a stream or by heavy rainfall. There is no weeding or management. Pocket padi construction does not alter the landscape significantly, contrary to large-scale paddy cultivation. Small pocket padi horticulture runs the risk of drying out, pests eating the young chutes (e.g., small deer), or invasive grasses and bamboo taking over the area.

The model associated with cultivation in archaeological sites suggests several underlying features of the agroecosystem. Archaeobotanical evidence of rice is found in areas that have several characteristics: the exploitation of aquatic and riparian resources is prominent, along with a large and permanent level of sedentism. These sites often include permanent structures, some for specialized rituals and cemeteries. Among the artifacts associated with these sites are prestige items and grave goods (Hayden 2013: 83). Although this model is suited for cultivation sites in China, the comparison to Holocene dated southern Thailand archaeological sites is analogous because of the series of rockshelters and caves sites located along the Thai-Malay Peninsula (e.g., Sakai Cave, Moh Khiew Cave, Lang Rongrien Rockshelter and Khao Toh Chong Rockshelter).

Rockshelters and cave systems are often discussed as major landmarks for hunter-gather and foraging groups in southern Thailand, but more notably they are permanent structures, cemeteries, and centers for ritual (Pookajorn 1991; Anderson 2005). Additionally, KTC has one of the largest freshwater mollusk assemblages among these sites. All of the sites exhibit the use of turtle and tortoise species for subsistence, and the level of sedentism is representative of both residential and logistical models of hunter, gatherer, and forager mobility (Shoocongdej 2000). Ritual practice at these archaeological sites is exhibited in the ethnoarchaeological record of the Mani people, as they are known for their medicinal and ritual uses of botanicals at Sakai Cave (Hongo and Auetrakulvit 2011; Pookajorn 1991). Burials and grave goods are also associated with these sites, and present many anthropological issues involving the descendant communities regarding social and cosmological taboos of gravesites.

During the late-Pleistocene (~15,000 – 10,000 B.P.) hunter, gatherer, and forager groups at KTC focused on artiodactyl (Bovid, *Cervus unicolor, Muntiacus muntjak*) and freshwater or brackish water mollusk (*Neoradina prasongi*) exploitation. This is suggestive of aggregated sex differences in foraging activities, and foragers becoming closely associated and knowledgeable about estuary, mangrove, and riparian resources (Mudar and Anderson 2007). The KTC late-Pleistocene (~15,000 years B.P.) levels indicate that the faunal exploitation is relatively even, because hunter and gatherer populations were more efficient foragers utilizing prey with the highest post-encounter return rates. There is a transition away from the exploitation of single species (e.g., *Neoradina prasongi*), but there are still riparian resources being consumed (e.g., Testundines). In general, the trend of faunal resource exploitation at KTC illustrates that foraging groups broaden their scope of hunting, gathering, and foraging beginning in the early-Holcoene. This is an indication that more botanical resources are being exploited during the Holocene. Confirmation of this trend is represented in the nestedness results (NODF = 28), which indicate that the fauna is derived from the same population.

Figure 5.2 Stacked bivalves excavated from early Holocene cultural deposits.

Forager efficiency at KTC suggests that hunter, gatherer, and forager groups utilized a variety of resources to maintain their subsistence base. While the statistical analyses of their exploits suggests a trend that is relatively narrow in the late-Pleistocene, broadening during the transition from Pleistocene to Holocene, and the forager diet continues to broaden until about the mid-Holocene. It is at this point in time that the analyses show some fluctuation from broad to relatively narrow. This small dip in the number of specimens exploited suggests that foragers are skilled and logistically utilizing these known resources around the rockshelter site. For example, turtle and tortoise remains are found in every context. While the turtles and tortoise are continuously exploited through time, it is not until the early and mid-Holocene that there is a dramatic increase in their abundance.

Perhaps during this time foraging groups became more dependent on riparian resources as an effect of aquaculture involved in pocket padi rice cultivation. It is around this time that evidence of rice cultivation appears in several archaeological sites in Thailand (Castillo 2011; Fuller 2006; Londo et al. 2006; Higham 2002). In addition, KTC mid-Holocene cultural deposits exhibit an increase in ceramic material, carbon isotopic rations towards C_3 plants, and the increase in dietary breadth- all coinciding around context 4 and 5 (2,967.0-6,370.5 cal. years B.P.); these data are consistent with the predictive fine-grained prey choice model and previous accounts of the adoption of cultivation practice throughout mainland SEA (Castillo 2011; Londo et al. 2006).

Foraging Strategies and Influence on Cultivation

At KTC the foraging pattern identified at the rockshelter was complex, utilizing both terrestrial and riparian species. Even today, mollusks are often incorporated into Thai dishes, but what is less documented is the use turtles in daily cooking (Sponsel 1998; see Figure 5.2). Turtle carapace is found at Lang Rongrien Rockshelter, Moh Khiew Cave, Sakai Cave, and KTC (Anderson 1991; Pookajorn 1996; Hongo and Auetrakulvit 2011). At KTC, Testundines are by and large to most abundant vertebrate group present, appearing in every context (see Figure 5.3; refer to Appendix C). Many archaeologists in the Asia-Pacific region, and more specifically within the archipelago, have noted the use of molluscan species in the diet (Bentley et al. 2007; Conrad et al. 2013; Higham 2002; King et al. 2014; Mudar and Anderson 2007; Rabett 2005; Shoocongdej 2006; White et al. 2004).

It is possible that the transition of mollusk exploitation mirrors the appearance of rice cultivation because rice may have substituted mollusk in the diet; while, the exploitation of Testundines is relatively the same because they are found in the same ecological niche but are more calorically efficient (cf. Bentley et al. 2007; Higham 1989, 2002:63; King et al. 2014; Mudar and Anderson 2007; Szabo and Amesbury 2011).

Turtle and tortoise species are relatively easy to catch when on dry land, and it has been presumed that their appearance in archaeological contexts is an example of sex and age differences in foraging strategies (Stiner et al. 2000; Cronk 2003; Mudar and Anderson 2007: 328). If age and sex differential foraging is occurring, then it is possible that the labor-intensive process of building pocket padis, transplanting chutes, among the other tasks involved in cultivation, would require a few extra hands that may take away from the skills and knowledge of collecting other food resources.

Figure 5.3 Testundines carapace with notable cut marks.

I hypothesize that the transition of intensive mollusk exploitation during the late-Pleistocene and early-Holocene represents a shift away from intensive wild resource exploitation to practicing cultivation throughout the mid-to-late-Holocene. This transition away from intensive mollusk exploitation was not instantaneous, rather the pattern is distinctive in multiple archaeofaunal collections in southern Thailand, and these represent the changing of foraging priorities. The nature of quantifying zooarchaeological assemblages is based on aggregated data over the course of hundreds or thousands of years; however, the data suggest this general pattern.

Faunal species commonly associated with rice paddies usually are considered pests, nutrient recyclers, pest predators, or vectors to humans and animals – with the exception of aquaculture techniques of cultivation where these species are embraced rather than removed. Aquaculture is akin to hunter, gatherer and forager techniques of opportunistic horticulture, where small plots are cultivated without intensive management. Molluscan species attracted to small wet rice cultivated plots include *Ampullariidae* species and *Pila* species, both of which are present in cultural deposits at KTC (Conrad et al. 2013; Roger 1996).

During the transition from intensive mollusk exploitation to cultivation practices (11,000-7,000 years B.P.), the people inhabiting KTC must have depended on shifting pocket padi cultivation, identified ethnographically as a current practice among the Chewong and Mani people of the Thai-Malay Peninsula (Hongo and Auetrakulvit 2011; Howell 2013; Pookajorn 1991). The main source of nutrition for hunter, gatherer and foragers at KTC likely came from the collection of fruits and other famine foods (e.g., yams, legumes, tubers, and nuts) along with hunting small game such as mollusks, small mammals, or turtle and tortoise species (Howell 2013: 97). The foragers at KTC were accustomed to estuary environments, often foraging for terrestrial aquatic fauna, which would made the transition to wet rice cultivation relatively easy because of their knowledge and experience with the ecological niche.

According to the distribution and abundance of Testundines, there are two spikes of exploitation at KTC (refer to Appendix C). The first spike appears approximately 7,866.5 cal. years B.P. and the second appears approximately 1,931.5 cal. years B.P.; it is possible that these abundances signify the initial introduction to rice cultivation during the early-Holocene, and then the full adoption an agroecosystems during the late-Holocene (cf. Castillo 2011, King et al 2014).

Fossil Microbotanical Assessment of KTC

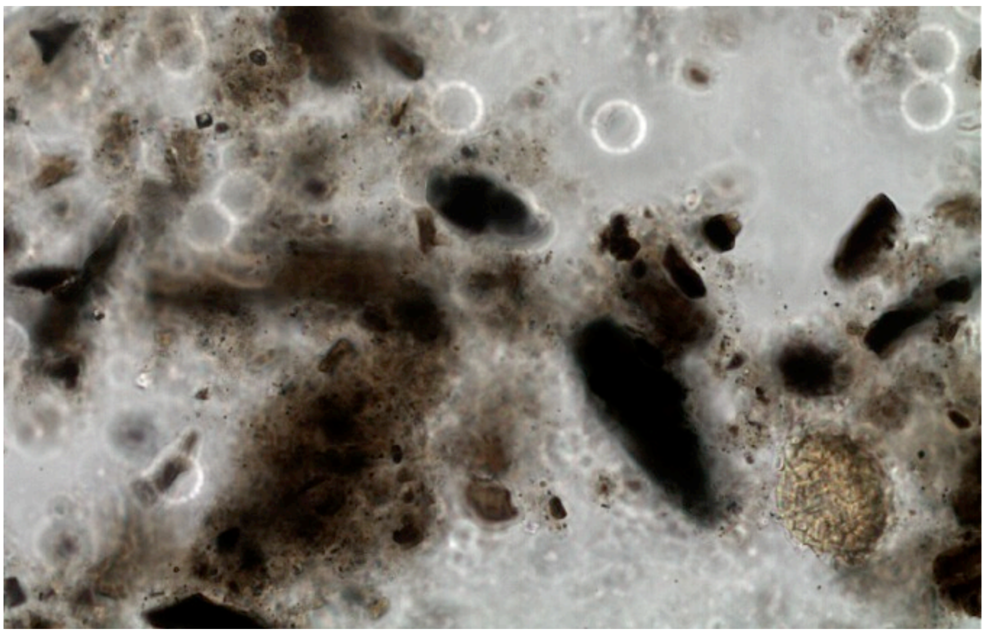


Figure 5.4 Charcoal and organogenics on a fossil pollen slide.

Given the zooarchaeological data and the environmental proxy data at KTC, paleobotanical proxies were included in the research design to investigate the utilization plants and any anthropogenic impacts on the landscape. There has been some evidence that pollen will preserve in karstic environments, as is the case at Sakai Cave located several kilometers south of KTC (Bhattacharya et al. 2010; Dimbleby 1985; Pookajorn

1996). The low pollen yield at KTC suggests that there are periods of drying and increasing precipitation (Dan Penny, personal communication 2013; Marwick and Gagan 2011; Maxwell 2001). The slides did exhibit charcoal and other organogenics (see Figure 5.4): an indication of poor soil quality for cultivation, changing climatic conditions consistent with the strengthening of the monsoon, and periodic oxidation of sediments. This may have be an influence to an adaptive style of wet rice cultivation given the constraints of the soil conditions (Maxwell 2001; White 1995). Pocket padi cultivation within riparian environments can provide rice panicles in the poorest soil (Montrakun 1964:33), often done through a series of wetting and drying, consistent with the geoarchaeological results at KTC.

Ethnoecological History

In the Thai-Malay Peninsula, palynological records have shown circumstantial evidence of landscape manipulation by way of charcoal and grass pollen abundances; this is an indication of landscape clearing practices by way of slash and burn, a method still practiced today to clear forest debris for sowing seeds (Maloney 1991). While there are several faunal species that are resilient to this style of cultivation, the first being reptiles; at KTC the most abundant exploitation of lizards (*Varanus sp.*) occurs in the mid-Holocene (Stott 1988: 344). Based on the complex foraging regime employed at KTC and overlapping chronology of the transition into an agroecosystem, it can be surmised that the abundance of this reptile species is exploited because if its availability on the landscape over other species whose habitat may have been destroyed on account of land clearing practices.

Naturally occurring fires are not a common factor in Southeast Asia, aside from rare instances of drought associated with El Niño (Maloney 1994:160; Stott 1988). Anthropogenic wielding of fire in Thailand has been used for many reasons, specifically in regards to rice cultivation. Carbonized botanicals are not often available at archaeological sites in SEA for two reasons. The first reason is that the region receives a long wet season, while the dry season is not substantially dryer. In the dry season, rainfall on the Thai-Malay Peninsula decreases only by several centimeters in comparison to the wet seaosn. In this environment, the slight differences between moisture in the wet and dry season would have aided in the decomposition of archaeobotanicals. The second reason for biases in the macrobotanical evidence in this region is that the accumulation of food is considered a social taboo among the hunter, gatherer, and forager groups (Hayden 2013; Howell 2013; Pookajorn 1991).

The presence of technology used at KTC shows a gradual abundance of ceramic and lithic flakes. The groups that occupied the rockshelter during the late-Pleistocene and throughout the Holocene provided cultural material that suggests a mix of residential and logistical models of mobility. Evidence in the late-Pleistocene suggest that groups stayed long-term at the site, utilizing and leaving behind larger style lithic technology, such as hammerstones and faunal remains of large mammals collected by skilled task forces (i.e., Bovid, and *Neoradina pragsongi*). Through time, it seems KTC was occupied by more of a logistical mobility pattern, illustrated by the appearance and rise in caches of ceramic sherds. It is possible that KTC was part of a greater mobility pattern in the region because of its proximity to both the coast (~12 km) and other rockshelter or cave sites (~4 km), which fits the median number of kilometers traveled in a single event by mobile hunter-gatherer groups (Brantingham 1991). Logistical mobility of foraging groups may have also increased the amount of use of the KTC. The shift in the residential model to that of a logistical model of mobility suggests that the region was utilized specifically for access to the shelter and the resources around it, in which case the population of foraging groups along the Peninsula may have been on the rise during the mid-Holocene. If rice cultivation, even at a small-scale, was practiced during the mid-Holocene on the Thai-Malay Peninsula then the predictive model of foraging strategy indicates that population growth would be a factor. With more resources available, both for a subsistence base and technologically to aid in the manufacturing of food products, population growth would be both possible to sustain and necessary for labor-intensive processes involved in the practice of cultivation.

Evidence of blowpipe technology, wooden traps, and spears are often sourced from bamboo and were recorded in the ethnoarchaeological work with the Mani tribe of Sakai Cave (Kuchikura 1988; Pookajorn 1996). At KTC, evidence of clay bullets were found deposited in cultural strata (see Figure 5.5). Indications about the lack of macrobotanical evidence of bamboo use extends beyond the scope of archaeological data collection; for example, ethnoarchaeological evidence of bamboo technology provides insights into the general archaeological record that is otherwise absent from deposits of cultural material. This is a preservation issue in southern Thailand because of the environmental conditions of the region; additionally, this issue inhibits multiple aspects to archaeological research, which should be a driving force for community involvement and ethnoarchaeological projects.

Bamboo technology has a wide array of uses, from cultivation and hunting to structural fortification. Clay bullets found at KTC may suggest the appearance of blowpipe technology in an area where there is little detail about this style of arboreal hunting. Cultural deposits, such as this one, are unique and can provide more insights into hunting practices during the Holocene.

Figure 5.5 Primate teeth (left) and a clay bullet (right) found at KTC during excavations in 2011.

Summary

Environmental archaeological research at Khao Toh Chong Rockshelter has provided evidence of the dietary transition of complex foraging to the possible adoption of cultivation practices along the estuary in the Krabi River Valley. Foraging strategies employed by groups occupying the site left deposits of faunal remains depicting exploitation of larger terrestrial fauna and mass collection of mollusks during the late-Pleistocene. A shift occurs during the early-to-mid-Holocene, where foraging groups exploited a broader variety of small terrestrial aquatic and mammalian populations. This shift suggests nuances of the forager diet, where hunter-gatherer and foragers transition into practicing cultivation in areas once primarily exploited for larger game. The sediment conditions at KTC suggest poor soil nutrients, an indication that small-scale wet-rice cultivation would have had stronger grain yields. Since groups were accustomed to foraging in estuary environments, the transition to this style of cultivation seems natural. The utilization of KTC began to change over time: the site was once an area for long-term residential occupation, and eventually became part of a systematic network of rockshelters and cave sites that were used for shelter, protection from monsoonal storms, and areas close to resources like water, fauna, and flora.

Chapter 6: Conclusions

Introduction

The primary aim of this thesis was to investigate behavioral changes of human exploitation patterns during prehistory in southern Thailand. Changing environmental conditions during the Pleistocene-Holocene transition provided an ideal environment for rice cultivation by the foragers who occupied rockshelters and cave sites. Given that rice cultivation emerged within this time frame in the Yangtze Valley of China and throughout the Indo-China region, the absence of evidence for introduction and cultivation practices in the Thai-Malay Peninsula does not represent complete absence of evidence. Rather, this thesis uses environmental archaeological approaches to apply predictive models that begin to answer these anthropological inquiries about the spread of cultivation practices throughout SEA. To get at the heart of this issue, it is important to first understand the general trends in the transition from hunter, gatherer, and forager to that of horticultural-based societies.

To understand human behavioral response of the environmental transition from Pleistocene to Holocene, this thesis utilized a multi-method approach to analyzing the archaeological assemblage from KTC. This research used data gathered during excavations of KTC in 2011 and 2012. The environmental archaeological case study of KTC provides insight into the transition of hunter, gatherers, and foragers to a mixed foraging-horticultural subsistence regime. This research considers whether cultivation was practiced within the forager diet, at what point this practice occurred in prehistory, and how proxy records used alongside theoretical models help archaeologists predict certain human behavioral responses which have aided the survival of our kind. Trends in the environmental proxies, the subsistence regime of foragers at KTC, and the technology deposited in cultural layers at KTC elucidate the emergence of an agroecosystem to have occurred sometime in the mid-Holocene along the Thai-Malay Peninsula.

Summary of Findings

The Krabi River is southeast of the site by several kilometers, but a tributary of the river is found just north of KTC. Tributaries in the region provide an estuary environment of mangrove forests throughout the Krabi province. The Thai-Malay Peninsula is affected by two seasonal monsoons, wherein a brief dry period occurs for approximately three months. The environmental setting of KTC is a tropical rainforest setting, currently occupied by rubber tree plantation farmers.

The radiocarbon data sampled at KTC indicates that there is continual human occupation at the rockshelter, ranging from late-Pleistocene to present day. It may be likely that the site was occupied seasonally, suggested by the availability of resources that represent exploitation of wetter environments during the Holocene. Analysis of the artifact trends in the cultural deposits displayed preliminary results of mobility patterns of how the rockshelter was used. It is likely that during the late-Pleistocene, KTC was a residential site where heavier artifacts, flake stone debitage, and intensive-exploitation of large mammalian fauna and mollusk remains were deposited. During the Holocene, KTC was used more as a logistical site for gathering resources in close range to the shelter (e.g., fresh water, fauna, flora). Additionally, KTC falls within the median range of travel around several karstic caves and rockshelters where hunter-gatherer groups were likely seasonally mobile between sites.

The fossil microbotanical record sampled at KTC suggests periods of wetting and drying of clayey sediment at the rockshelter which caused oxidation of fossil pollen and decomposition therein. In fact, the face of the rockshelter is open westward and succumbs to the force of the southwest monsoon as it descends from China bringing with it moisture and warm air. The strength of the monsoons increased during the Holocene, and so it is possible that during this time the site was occupied more on a seasonal basis, and other rockshelter and cave sites in the area are utilized as part of a logistical mobility pattern within the karst region. Much of the agricultural activity today is reliant on rain-fed irrigation patterns, while hunter-gatherer and foraging groups still live remotely in the forests; for example, the Mlabri of the Nan province hills of northern Thailand (Pookajorn 1985, 1988, 1992).

Human behavioral ecology is a theoretical framework that suggests the evolution of human behavior as an adaptive method to environmental change. This theory embraces the fine-grained prey choice model, which provides insight into forager activity in terms of post-encounter return rates and efficiency. Zooarchaeological assemblages are among the most popular data sets used to analyze this theoretical model, while paleobotanical research is becoming more applied in terms of utilizing mixed approaches to understanding forager diets. Human behavioral ecology also includes the use of modern analogy to insight human behavioral response in the archaeological past (Cronk 2003).

At KTC, the late-Pleistocene forager diet consists of large prey, such as Bovid and artiodactyl game, which is consistent with the forager models analyzed from Pleistocene dated archaeological sites in the region (e.g., Lang Rongrien Rockshelter). The forager diet throughout the Holocene suggests a wider array of prey that is influenced by riparian species, such as turtles and the less intensive exploitation of mollusks. During the Holocene, primates are also found in cultural deposits which suggests the preference for larger prey when available. Because the utilization of riparian resources is so prominent in the archaeological sites in southern Thailand, it is likely that the transition into wet-rice cultivation was more natural and possibly adapted by knowledgeable foragers who utilized the estuary environment of the Krabi River Valley for food resources.

With the strengthening of the monsoon, poor soil nutrients, and estuary environments surrounding the rockshelter, it is likely that hunter-gatherers and foragers were practicing small swidden and pocket padi cultivation. During the Holocene, the climate became moister, providing more habitat potential for riparian resources. It is possible that early human populations were accustomed to constructing small pocket padis on the edges of estuary environments, those of which were not managed but cultivated and later revisited for harvest; this pattern of pocket padi cultivation is practiced by the Mani people who occupied Sakai Cave, as well as the Chewong of Peninsular Malaysia. Additionally, cosmological belief systems and social taboos prevent the idea and practice of accumulating food, as it is believed to increase chances of disease (Howell 2013; Roger 1996).

Geoarchaeological results suggest that the site was eventually buried through the process windblown sediment and sheetwash off the limestone face. The stable carbon isotope analyses at KTC provided information about the rise in C_3 levels recorded in sediments. Phytolithic remains, starches, and other organogenics were preserved and will need to be analyzed at a later date. The fossil pollen data suggest poor nutrients in sediments around the site, an indication about the incipient cultivation practices (cf. Castillo 2011; King et al. 2014; White 1995). However, the influx of C_3 indicates that fruiting trees and plants such as rice may have been more abundant in the mid-Holocene.

The zooarchaeological data shows environment trends that would have affect human populations, for example the appearance of large prey (e.g. Bovid, artiodactyl) in the late-Pleistocene deposits drop off during the transition into of Holocene dated deopists. The earth's transition from a glacial state into an interglacial state changed the flora in southern Thailand from an open grassland savanna to dense rainforest and mangrove environments. A greater abundance of smaller mammals, reptiles, and turtle species were exploited because they became more abundant in heavily vegetated estuary and riparian environments. The expansion of the Krabi River Valley estuary environment conditions during the Holcoene suggests that opportunistic horticultural was being practiced alongside the foraging of riparian resources in the Thai-Malay Peninsula. It is likely that these subsistence practice occurred simultaneously, in an aquaculture type of venture. The lack of soil nutrients indicates that if rice cultivation were to occur it would need to be grown in a padi style, while the increase of the monsoonal strength and seasonal storms provide ability to sustain rain-fed systems such as pocket padi cultivation.

The archaeological data presented in this thesis suggest several conclusions about KTC, primarily that the rockshelter was used was to provide shelter for mobile hunter, gatherer, and forager groups continuously throughout the late-Pleistocene and Holocene. Because sterile deposits were not reached during the 2011 excavation of KTC, it is likely that human occupation at the site extends beyond the scope of the research presented here. Based on the assemblage, the mobility style of foragers changed from residential to that of a logistical pattern of site use. The application of a mixed methods approach of these archaeological assemblages has provided further insights to the conditions required for cultivation, as well as the foraging strategy practice at KTC to efficiently sustain human populations through time. Archaeological records from around Thailand were considered to develop this research, including evidence from where foragers and agriculturalists were present.

Recommendations

Archaeological pursuits in the Thai-Malay Peninsula are recommended to include and prioritize fossil microbotanical science for two reasons. The first reason is that macrobotanicals face preservation biases that are not ideal for analyses, and their ability to deposit silicate, starches, and cellulose is more attainable given the preservation conditions. The second reason is that the multidisciplinary approach to archaeological science strengthens the credibility of findings and provides depth to human behavioral ecological traits such as foraging strategies.

On account of the lack of comparative collection, a detailed analysis of the phytolithic components deposited and extracted from KTC sediments should be considered by paleobotanists, geoscientists, or archaeologists. A triangulation of research would prove more useful in the analyses of fossil microbotanical research, especially samples procured from the mangrove and estuary environment of the Krabi River Valley. Another component of fossil microbotanical analyses should include the collection of pollen specimens, preferably by localized pollen traps.

This research provides in-depth analyses and description of archaeological material excavated from KTC in 2011. Artifacts deposited at the site illustrate the necessity for further investigation of cultural activity during the late-Pleistocene and throughout the Holocene in the tropical rainforest of the Thai-Malay Peninsula. This research illuminates the strengths of multidisciplinary analyses by providing thorough explanation of methods utilized, and analyses of how environmental processes interact with the full spectrum of biota. KTC was used as a case study example because of the availability of eco-artifacts for analysis as well as the continuous human occupation at the site, located in a region that has a rich cultural history but a gap in paleoenvironmental research.

Residue analysis of the ceramics deposited at KTC, edge-wear analysis of the flaked stone tools, and comprehensive analyses of zooarchaeological subsistence regimes in the region would provide insight into the transition of opportunistic foraging to an agroecosystem. These studies address archaeological inquiries about how humans adapted their horticultural practices to produce larger crop yields; what floral species were cultivated first, and why this may have occurred. Further analysis of cutmarks and taphonomic processes of faunal remains would provide insights into the butchery and cooking practices during prehistory, while strontium isotopic research of the human remains found at KTC may provide trophic levels of human dietary reliance during this transitional period. Biodiversity approaches to floral and faunal research can also greatly benefit environmental archaeological science by providing a comparative sample for archaeological deposits of fossil pollen, phytoliths, starches, and faunal remains.

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Appendix A:

Letter of permission from Dr. Ben Marwick and photographs of the southwest unit of trench A

Dr. Ben Marwick June 12, 2014
Department of Anthropology
University of Washington
M32, Box 353100
Seattle, WA 98195-3100
USA

Subject: Permission request for use of the aerial map of Khao Toh Chong Rockshelter, Marwick et al. 2013.

Dear Dr. Ben Marwick,

I am a graduate student with the Department of Applied Anthropology at San Jose State University, CA. I am in the process of preparing a Master's thesis for publication and am seeking permission to include the aerial map of Khao Toh Chong Rockshelter in my publication. The image of the map was published on page 33 of the *Hierarchies of engagement and understanding: Community engagement during archaeological excavations at Khao Toh Chong Rockshelter, Krabi Thailand* in Transcending the Culture-Nature Divide in Cultural Heritage: Views from the Asia- Pacific Region edited by Sue O'Conner in 2013 (Canberra, ANU E Press).

The work will be used to visually display orientation of the rockshelter site utilized in my research and analyses of the archaeological assemblage. The publication information is as follows: Van Vlack, Hannah G. 2014 Forager Subsistence Regimes in the Thai-Malay Peninsula: An Environmental Archaeological Case Study of Khao Toh Chong Rockshleter, Krabi. Unpublished Master's thesis, Department of Applied Anthropology, San Jose State University, California.

Please indicate your approval of this request by signing the letter where indicated below and returning it to me. Your signing of this letter will also confirm that you own the copyright to the above-described material.

Kind regards and many thanks,

Hannah Van Vlack

For copyright owner use:
PERMISSION GRANTED FOR THE USE REQUESTED ABOVE:

I, Ben Marwick, give permission to Hannah Van Vlack to use any images from the below-named work (of which I am the principle author) for the purposes described in the letter above.

By: Date: 24 June 2014

Title: Hierarchies of engagement and understanding: Community engagement during archaeological excavations at Khao Toh Chong Rockshelter, Krabi Thailand in Transcending the Culture-Nature Divide in Cultural Heritage: Views from the Asia- Pacific Region

Figure A:1 Khao Toh Chong Rockshelter (KTC) prior to excavation, looking north.

Figure A:2 KTC prior to excavation looking south.

Figure A:3 Trench A just after initial excavations. The Southwest unit square is located in the right foreground.

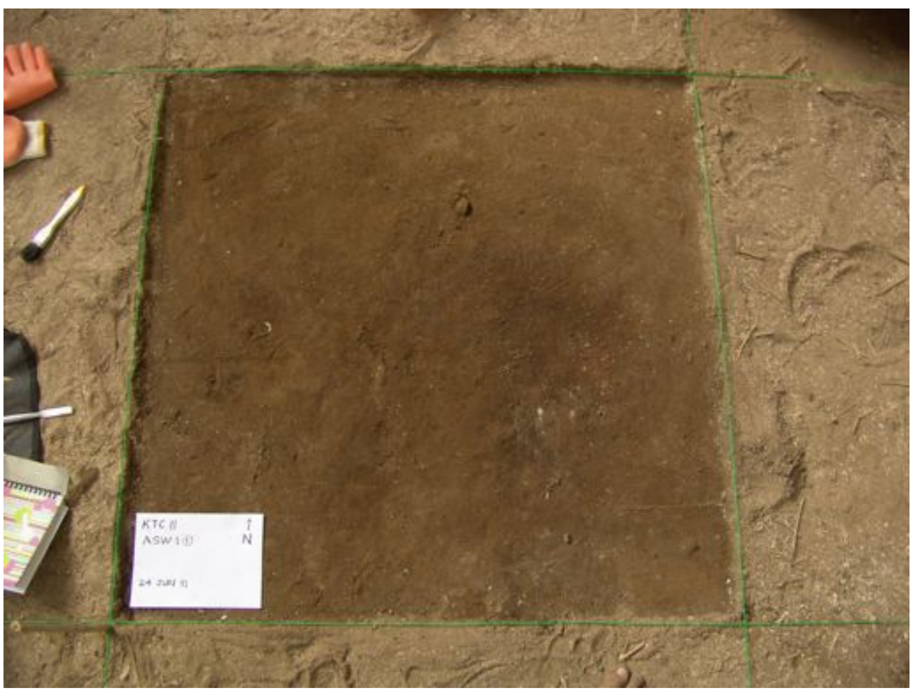

Figure A:4 KTC Trench ASW 1-1 Depth 0.03-0.1 MBS

Figure A:5 KTC Trench ASW 2-3 Depth 0.8 MBS

Figure A:6 KTC Trench ASW 3-5 Depth 0.15 MBS

Figure A:7 KTC Trench ASW 4-5 Depth 0.15 MBS

Figure A:8 KTC Trench ASW 4-6 Depth 0.19 MBS

Figure A:9 KTC Trench ASW 4-7 Depth 0.19 MBS

Figure A:10 KTC Trench ASW 6-12 Depth 0.45 MBS

Figure A:11 KTC Trench ASW 6-13 Depth 0.4 MBS

Figure A:12 KTC Trench ASW 7-14 Depth 0.53 MBS

Figure A:13 KTC Trench ASW 8-14 Depth 0.6 MBS

Figure A:14 KTC Trench ASW 8-15 Depth 0.6-0.65 MBS

Figure A:15 KTC Trench ASW 9-16 Depth 0.65 MBS

Figure A:16 KTC Trench ASW 10-16 Depth 0.7 MBS

Figure A:17 KTC Trench ASW 11-17 Depth 0.75 MBS

Figure A:18 KTC Trench ASW 12-19 Depth 0.8 MBS

Figure A:19 KTC Trench ASW 13-19 Depth 0.85 MBS

Figure A:20 KTC Trench ASW 14-19 Depth 0.9 MBS

Figure A:21 KTC Trench ASW 15-19 Depth 0.95 MBS

Figure A:22 KTC Trench ASW 16-21 Depth 1.0 MBS

Figure A:23 KTC Trench ASW 17-23 Depth 1.05 MBS

Figure A:24 KTC Trench ASW 18-25 Depth 1.1 MBS

Figure A:25 KTC Trench ASW 19-27 Depth 1.15 MBS

Figure A:26 KTC Trench ASW 20-27 Depth 1.25 mbs

Figure A:27 KTC Trench A basal deposits directly prior to backfilling. Depth 1.25 mbs.

Appendix B:

Radiocarbon Data for Khao Toh Chong Rockshelter from Direct AMS, Bothell, WA

DirectAMS | Radiocarbon Dating Services

Dr. Ugo Zoppi
Director, Accelerator Mass Spectrometry Lab

01 November 2012

Ben Marwick,
Assistant Professor,
University of Washington
Department of Anthropology
Denny Hall 117
Box 353100
Seattle, WA 98195-3100

Dear Ben,

Your samples submitted for radiocarbon dating have been processed and measured by AMS. Following results were obtained:

DirectAMS code	Submitter ID	$\delta(^{13}C)$	Fraction of modern		Radiocarbon age	
		per mil	pMC	1σ error	BP	1σ error
D-AMS 001140	Charcoal KTC11 ACE1	-16.6	98.16	0.30	149	25
D-AMS 001141	Charcoal KTC11 ASW2	-38.3	97.81	0.32	178	26
D-AMS 001142	Charcoal KTC11 ASW4	-25.0*	78.22	0.26	1973	27
D-AMS 001143	Charcoal KTC11 ASW5	-25.0*	70.17	0.26	2846	30
D-AMS 001146	Shell KTC11 ASW13	-13.4	22.98	0.12	11813	42
D-AMS 001147	Shell KTC11 ASE 17, 18, 19	-13.3	19.76	0.11	13026	45
D-AMS 001148	Charcoal KTC11 ASW20	-35.1	24.69	0.13	11236	42
D-AMS 001149	Shell KTC11 ASW15	2.8	22.48	0.14	11990	50
D-AMS 001150	Shell KTC11 ASW5	-3.2	22.46	0.14	11997	50
D-AMS 001151	Shell KTC11 ASW6	-9.7	49.85	0.18	5592	29
D-AMS 001152	Shell KTC11 ASW8	-8.2	41.57	0.26	7051	50

* estimated

A part for samples D-AMS 001142 and 001143, all results have been corrected for isotopic fractionation with $\delta^{13}C$ values measured on the prepared graphite using the AMS spectrometer. These can differ from $\delta^{13}C$ values of the original material, if fractionation occurred during sample graphitization or AMS measurement.

Best regards,

Ugo Zoppi

550 17th Avenue, Suite 550, Seattle WA 98122
Tel (206) 281-3915 – Fax (206) 281-5916 – www.directAMS.net

Appendix C:

Letter of permission from Cyler N. Conrad and Geoarchaeological Reports from 2012 on Khao Toh Chong Rockshelter Sediment

Mr. Cyler Conrad June 16, 2014
Department of Anthropology
MSC01-1040, Anthropology 1
University of New Mexico
Albuquerque, NM 87131
USA

Subject: Permission request for use of Krabi, Thailand regional maps and geoarchaeological reports of KTC

Dear Mr. Cyler Conrad,

I am a graduate student with the Department of Applied Anthropology at San Jose State University, CA. I am in the process of preparing a Master's thesis for publication and am seeking permission to include images you have produced of Khao Toh Chong Rockshelter (KTC) and the greater Krabi, Thailand region in my publication, as well as the written reports of the geoarchaeological analyses carried out in 2012 on the sediment collected during the 2011 excavation of KTC.

The images will be used to visually display orientation of the rockshelter site within the greater Krabi region. While, the geoarchaeological reports will be used to provide a research background of the rockshelter, in addition to providing supplemental data to the analyses I carried out in my own research. The publication information is as follows: Van Vlack, Hannah G. 2014 Forager Subsistence Regimes in the Thai-Malay Peninsula: An Environmental Archaeological Case Study of Khao Toh Chong Rockshelter, Krabi. Unpublished Master's thesis, Department of Applied Anthropology, San Jose State University, California.

Please indicate your approval of this request by signing the letter where indicated below and returning it to me. Your signing of this letter will also confirm that you own the copyright to the above-described material.

Kind regards and many thanks,

Hannah Grace Van Vlack

Hannah G. Van Vlack

PERMISSION GRANTED FOR THE USE REQUESTED ABOVE:

By: Cyler Conrad Date: June 19, 2014

Title: Cyler N. Conrad, Ph.D. Graduate Student, University of New Mexico

Geoarchaeological Analysis of Khao Toh Chong Rockshelter

by Cyler Conrad

Abstract

Sediments in rockshelter sites are important for determining aspects of site formation, human occupation and the environment of deposition. Geoarchaeological analysis of the Khao Toh Chong rockshelter in southwestern Thailand has provided detailed results through the use of sediment chemical analyses, magnetic susceptibility, x-ray diffraction, inductively coupled plasma –atomic emission spectrometry, and laser particle size analysis. The results of this study indicate that particle size is indicative of aeolian and colluvial site formation processes. Kaolinite clay mineralogy and elements of soil formation depict shifting patterns in the environment of deposition. Trace element data in conjunction with soil organic matter and magnetic susceptibility describe periods of increased human activity at the site. These results are interpreted as initial indications of site formation, environment and human occupation at the rockshelter.

1. Introduction

This geoarchaeological analysis aims to investigate changes in site formation processes, the environment of sedimentation and human activity at Khao Toh Chong rockshelter (KTC). Sediment samples have been analyzed by students in the University of Washington Geoarchaeology 482 winter course 2012. This work carries important implications for Thai, and Southeast Asia archaeology since most of the archaeological history in this region has come from rockshelter and cave sites (Anderson 2005).

Surprisingly, from peninsular Thailand little geoarchaeological analysis of sediments in rockshelter sites has occurred before. McGrath et al. have produced results on the formation processes responsible for the moated sites in the Mae Nam Mun river valley, Northeast Thailand, using comparable analyses to the ones described herein, yet this was an open site (2008). Rockshelter and cave geoarchaeological analyses within peninsular Thailand are relatively rare but in the immediate geographic region some important comparisons can be found. One example is the geoarchaeological analysis of Liang Bua cave in Flores, Indonesia (Westaway et al. 2009). Here particle size analysis of sediments was able to depict specific site formation processes. Importantly, peninsular Thailand does have many archaeologically rich rockshelter sites which offer valuable comparisons to this analysis. One of particular interest is Lang Rongrien rockshelter.

Lang Rongrien rockshleter was excavated by Douglas Anderson beginning in 1974 and has a rich archaeological record (Anderson 1990). This site has a record of human occupation extending back into the Pleistocene, which as Anderson describes, is rare in this region of the world (Anderson 2005). Lang Rongrien is located within a few kilometers of KTC which makes the results of this analysis important for comparison between sites. Few post-depositional processes have disturbed KTC which implies that this site could hold a well stratified record of human and environmental activity beyond the Holocene, making these interpretations of KTC sediments crucial for future research (Marwick et al. 2013). Although previous studies have used geoarchaeological analysis, few have used such broad analyses to answer questions about rockshelter environments in this region of Thailand. Here, an outline of the methods and results of pH, electrical conductivity, percentage of soil organic and carbonate matter, magnetic susceptibility, x-ray diffraction, inductively coupled plasma –atomic emission spectrometry, and laser particle size analysis will be discussed. In this study, investigation of site formation, human use, and environmental sedimentation processes using geoarchaeological techniques has described shifts in the rockshelter stability and weathering over time. This data indicates that changing periods of aeolian and colluvial processes and increased periods of precipitation are affecting the environment of sedimentation and influencing site formation. The identification of clay minerals and the analysis of trace elements have helped described periods of increased human occupation at the site.

2. Methods

This geoarchaeological analysis was conducted on sediments excavated from KTC rockshelter in Thap Prik Village outside of Krabi in southwestern Thailand (Marwick et al. 2013). KTC was excavated between June and July 2011 as part of an international archaeological field school with students from Thailand, Cambodia, Indonesia, Burma, Korea, Vietnam, the United States, and the Philippines. Each trench covered an area of 2x2 m and was excavated to slightly over 1 m depth in trench A and 2 m depth in trench B (Figure 1 replaced with Van Vlack 2014 Figure 3.2; Table 1). Samples were taken from the contexts of the trench A profile and one surface sample from trench B (Figure 2 replaced with Van Vlack 2014 Figure 3.4). The site is 60 m above sea level and found under a limestone overhang of a karst tower within the village. It is 30 m long and 10 m wide from the rockshelter wall to the dripline. Dating of KTC has not yet occurred but dates likely fall between the early Holocene, the lowest levels of the site, up through the late Holocene, the upper levels at the site (Marwick et al. 2013). The site lies in a region of monsoon rain forest which is characteristic of this tropical region of Thailand (Anderson 1990). Nine sediment samples ranging from A2 to A7 low, and B1 were used for this analysis.

Table 1. KTC Sample depth and color.

Sample ID	Depth (m)	Color-Dry	Color-Wet
KTC-B-1	0.02	10YR 4/4	10YR 3/6
KTC-A-2	0.09	2.5YR 3/2.5	5YR 4/3
KTC-A-3	0.22	2.5YR 2.5/2	7.5YR 3/2
KTC-A-4	0.3	10YR 3/4	10YR 3/4
KTC-A-5	0.4	7.5YR 4/4	7.5YR 4/4
KTC-A-6	0.53	7.5YR 4/4	7.5YR 4/4
KTC-A-7-High	0.72	10YR 3/6	10YR 3/6
KTC-A-8	0.92	7.5YR 4/3	7.5YR4/3
KTC-A-7-Low	1.1	5YR 4/3	7.5 YR 4/6

2.1 pH, electrical conductivity and color

Sediment pH and electrical conductivity were measured in a 1:1 sediment to deionized water ratio with a Oaklon PCSTestr 35. Huckleberry describes that humid climates or cultural deposits tend to have a more neutral or acidic pH because of the organic content in the sediments (2006). After stirring the samples they were set for 1 hour to stabilize as discussed by Huckleberry (2006). Buffer solution standards of pH4, 7 and 10 were used for calibration. A single 15000 µS EC solution standard was used. Three pH and EC measurements were taken for each sample. Three replicates were used for pH analysis to establish error terms. Sediment samples were tested between 4-5 seconds or until stabilization of the reading occurred. Color was measured dry, and wet, by adding drops of deionized water. Dry and wet samples were compared to a Munsell color chart under florescent light for identification.

2.2 Organic and carbonate matter content

Chemical analyses of total soil organic and calcium carbonate matter were next initiated. Loss-on-ignition analysis was used to determine sediment organic and carbonate concentrations (Heiri et al. 2001). This is important for it can be a reliable indication of human occupation since organic matter accumulates more frequently with human activity (Huckleberry 2006). Though, SOM can also reflect environmental processes, with the accumulation of naturally occurring organic matter during times of site stability. $CaCO_3$ content is important because it can accumulate from the dissolution of limestone over time. Since the rockshelter is composed of limestone, this could indicate a period of surface stability or increased weathering of the limestone due to environmental change (Goodman-Elgar 2008). Here, KTC samples were ground and dried for 24 hours at 105°C in a Thermo oven and weighed. Samples were then burned at 430°C for 4 hours in a 6000 Thermoline muffle furnace to determine organic matter concentration. For carbonate concentration, samples were burned at 1000°C for 2 hours and weighed.

2.3 Magnetic susceptibility

Magnetic susceptibility was measured using a Bartington MS2 Magnetic Susceptibility Meter. 10 cm^3 of sediment was analyzed in sample pots at both low and high frequency. Calibration of the meter occurred with a 3075 LF standard. Three replicates for each sample measurement of low and high frequency susceptibility were taken following Gale and Hoare (1991). Magnetic susceptibility values are known to be good indications of fire or buried stable land surfaces, which could provide evidence of weathering or human occupation at KTC (Crowther 2003).

2.4 X-ray diffraction

XRD samples were prepared following similar procedures of McGrath et al. (2008). Organic matter was sieved away, dried at 60°C for 24 hours, and ground into a fine powder. Next 20 ml of 30% H_2O_2 was used to remove extra organic matter. After effervescence it was removed and dried for another 60°C for 24 hours. After a final grinding, samples were loaded onto trays and scanned on a Bruker D8 Focus X-ray Diffractometer from 5° to 75°2θ with a Cu radiation source at resolution .02° steps per second with 40 kV and 40 mA power output. MDI Jade 9 software was used to identify minerals. XRD analysis may be useful in combination with particle size if clay minerals are identified within the samples. As Alam et al. describe the identification of kaolinite or illite within samples provides a good indication of clay formation and the environment of deposition (2008).

2.5 Inductively coupled plasma –atomic emission spectrometry

By analyzing the elements within samples possible human activities can be extrapolated, as well as some important characteristics of soil formation (Misarti et al. 2011). A Perkin Elmer Optima 8300DV was used for ICP-AES analysis in order to determine the elemental composition of samples. After samples were sieved and ground, 10ml of HNO_3 was added and heated at 90°C for 15 minutes (Misarti et al. 2011). Another 5ml of HNO_3 was next added and heated at 90°C for 60 minutes to drive the reaction. Next, deionized water and 30% H_2O_2 were added for increased oxidization and 10ml HCl was added and heated for chloride formation. The samples were diluted with deionized water and filtered before being measured and placed into Falcon tubes for ICP-AES analysis. Elemental standards were used for calibration. In order to compare underlying patterns in the ICP results, principal component analysis was used to quantify elemental variation (VanPool and Leonard 2011).

2.6 Laser particle size analysis

Huckleberry describes that particle size analysis is important for determining formation processes and the origin of deposition for site sediments (2006). As such this data will provide important aspects of environmental and site occupation processes. Sediment samples were dried at 60°C for 24 hours. Mass was record and 20 ml of 1 M HCl was used to remove carbonates. Samples were then centrifuged and treated with 30 ml of 30% H_2O_2 for over an hour in order to remove organics (Scott-Jackson and Walkington 2005). Additional drying occurred for 30 hours in a 60°C oven. Each sample was added to a mixture of deionized water and surfactant Triton X 10 and agitated before being run in the Horiba LA-950. A quartz refraction index of 1.458 was used during analysis.

3. Results

KTC sediment samples depict a pattern of environmental change, possibly caused by increased precipitation, driving site formation processes which are suggestive of varying periods of aeolian and colluvial sedimentation. Human occupation data suggests that periods of activity occurred when the rockshelter surface stabilized and weathering of the sediments increased.

3.1 Chemical analyses and magnetic susceptibility

The results of the basic chemical, magnetic susceptibility and particle size analyses are depicted in figure 3 and table 2. Some of these variables suggest important relationships, but only two are highly correlated. For instance, pH values at KTC are generally alkaline though and important shift occurs from pH9.1 to pH7.6 between contexts A-5 and A-6. Results of EC suggest only a decreasing trend through the samples. Although not correlated with other variables, calcium carbonate content also displays important shifts. $CaCO_3$ content begins at 8.3% and then increases until A-6 where once again a shift is seen. In A-5 $CaCO_3$ content measures 12.5% and drops in A-6 to 10.4%. This increases until a drop is again seen at A-7-Low to 8.5%. These variables are important, yet the strongest relationship between variables is found with SOM and X.fd which is highly correlated between samples (Table 3). A biplot and correlation analysis between SOM and X.fd shows them to be highly correlated (r=-.96, p=0, Figure 4). Percentage of soil organic matter is 7.9 at the surface, and then decreases throughout the lower contexts. There is a slight increase in SOM from A-5 at 3% to A-6 at 3.5% which remains relatively stable until a drop in organic content at A-7-Low. A relative pattern of decreasing SOM over time at KTC is depicted in the results. General changes in magnetic susceptibility values do occur throughout the site with increasing values through A-5 and decreasing values through A-8. A-7-Low sees a slight increase in magnetic susceptibility, reversing the decreasing trend.

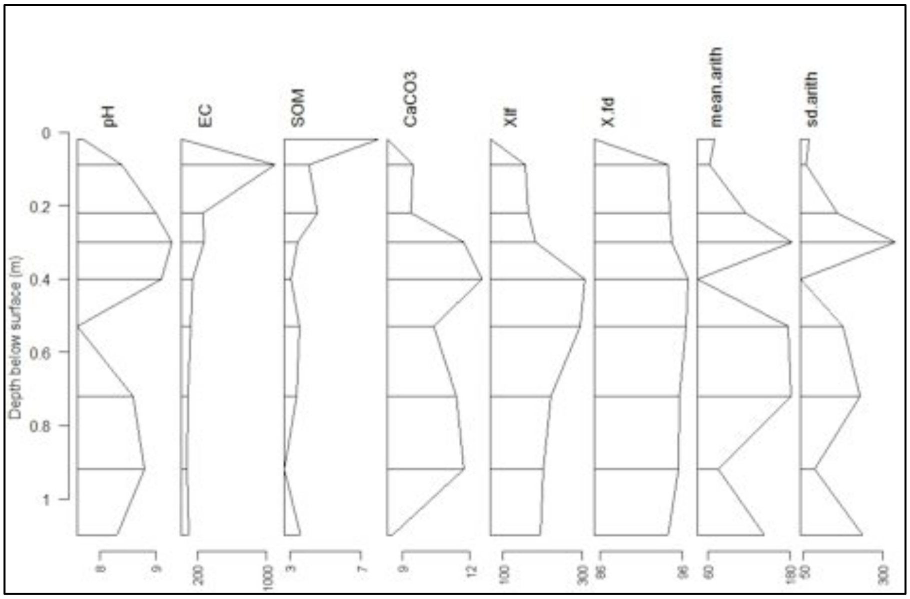

Figure 3. Relationship between chemical, magnetic susceptibility and particle size analyses. Mean.arith and sd.arith relate to the mean and standard deviation of the particle size at KTC.

Table 2. Results of chemical properties and magnetic susceptibility.

Sample ID	Depth (m)	pH	EC	SOM	CaCO3	Xlf	%fd
KTC-B-1	0.02	7.7	12	7.9	8.3	70	85.3
KTC-A-2	0.09	8.4	1100	4	9.4	157.4	94.3
KTC-A-3	0.22	9	268	4.5	9.3	164.2	94.5
KTC-A-4	0.3	9.3	272	3.4	11.7	182.6	94.8
KTC-A-5	0.4	9.1	144	3	12.5	308.7	96.8
KTC-A-6	0.53	7.6	122	3.5	10.4	296.7	96.5
KTC-A-7-High	0.72	8.6	89	3.4	11.4	221.6	95.7
KTC-A-8	0.92	8.3	84	3.6	11.7	195.4	94.4
KTC-A-7-Low	1.1	8.8	98	2.6	8.5	203.9	95.6

Table 3. Correlations between variables at KTC, * indicates correlation where $p<0.001$.

	pH	EC	SOM	CaCO3	Xlf	X.fd
pH	1NA	0.1	-0.52	0.61	0.17	0.47
EC	0.1	1NA	-0.09	-0.15	-0.18	0.12
SOM	-0.52	-0.09	1NA	-0.69	-0.76	(-.96*)
CaCO3	0.61	-0.15	-0.69	1NA	0.67	0.65
Xlf	0.17	-0.018	-0.76	0.67	1NA	0.83
X.fd	0.47	0.12	(-.96*)	0.65	0.83	1NA

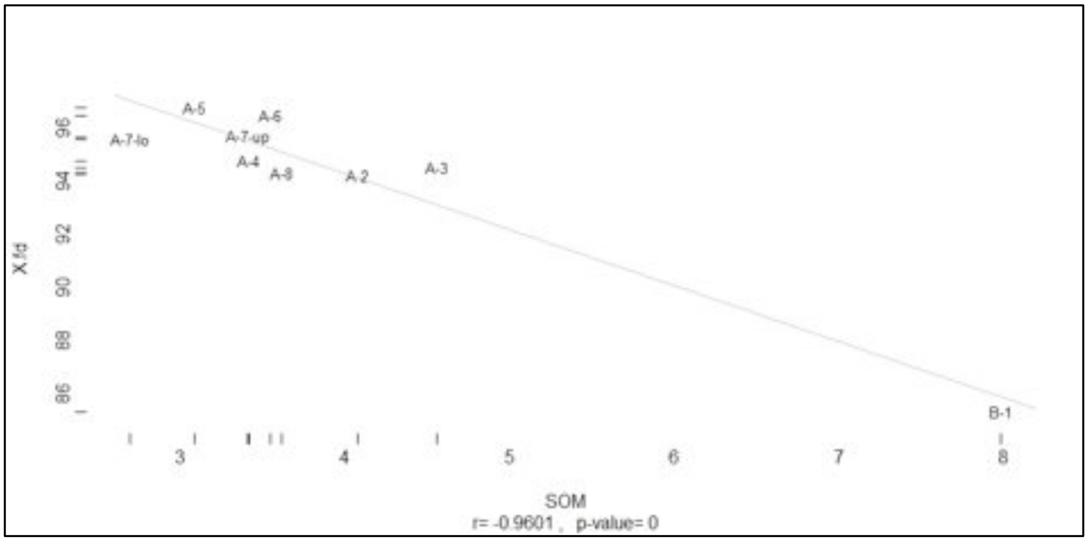

Figure 4. Correlation analysis between SOM and X.fd.

3.2 X-ray Diffraction

XRD analysis to determine the mineralogy of site samples produced limited results. As table 4 describes, quartz was found within every KTC sample. After some exploratory analysis with MDI Jade 9, quartz also appears take up >90% of the sample. Importantly this table is in rank order, depicting decreasing identified mineral abundance moving away from quartz to the right. Jade was unable to output a complete quantitative analysis of mineral abundances within samples, so XRD data mainly serves as a references of comparison between contexts. Though, the identification of kaolinite in samples in A-3, A-5, A-6, and A-7-Low provides important information for clay accumulation. Interestingly in samples A-7-High and A-8 there were no other minerals identified other than quartz, but this quickly reverses in A-7-Low.

Table 4. XRD Mineral composition.

Sample ID	Minerals				
KTC-B-1	Quartz				
KTC-A-2	Quartz	Calcite			
KTC-A-3	Quartz	Calcite	Kaolinite	Goethite	
KTC-A-4	Quartz				
KTC-A-5	Quartz	Calcite	Mimetite	Magnesium Calcite	Kaolinite
KTC-A-6	Quartz	Kaolinite			
KTC-A-7-High	Quartz				
KTC-A-8	Quartz				
KTC-A-7-Low	Quartz	Calcite	Mimetite	Kaolinite	Andalusite

3.3 Inductively coupled plasma-atomic emission spectrometry

Principle component analysis was used to determine the number of variables accounting for the variance in KTC samples. Here principal components which were used for analysis accounted for 80% of the variation (Figure 5). This is important because figure 6 represents a plot of K and Mn content at KTC which is highly correlated (p=.95).

A biplot of this data also displays this strong relationship (Figure 7). Another important relationship if found between Ba, Co, Cu, Sr, and V (Figure 8). There is a high correlation between Ba and each of these elements (p=.97, .93, .94, .94). Finally, an important correlation between Ni and Cr is seen (p=.94, Figure 9). A biplot of this relationship displays the correlation well (Figure 10). Overall the precise measurement for the samples is 3.516 ppb.

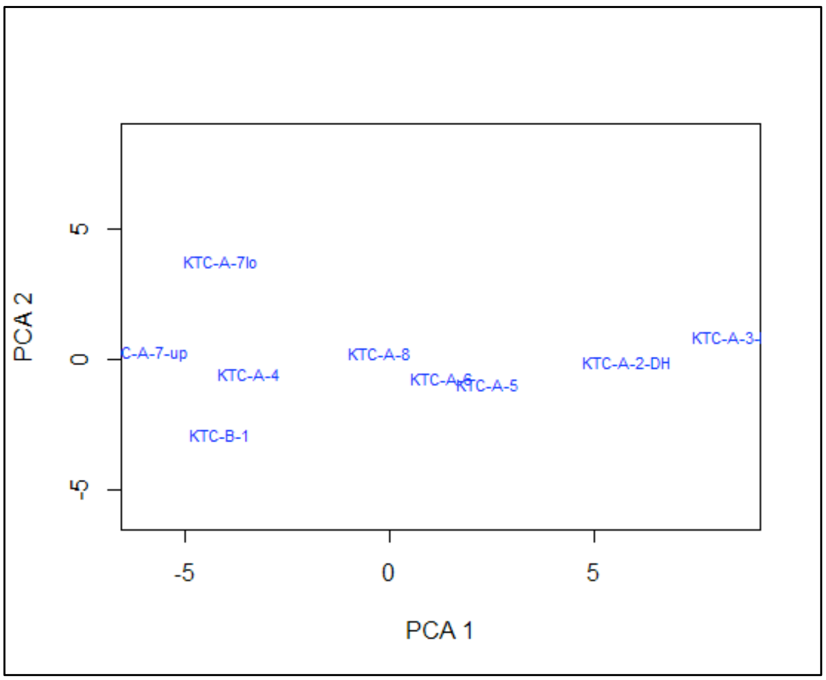

Figure 5. Principle component analysis of variation between contexts.

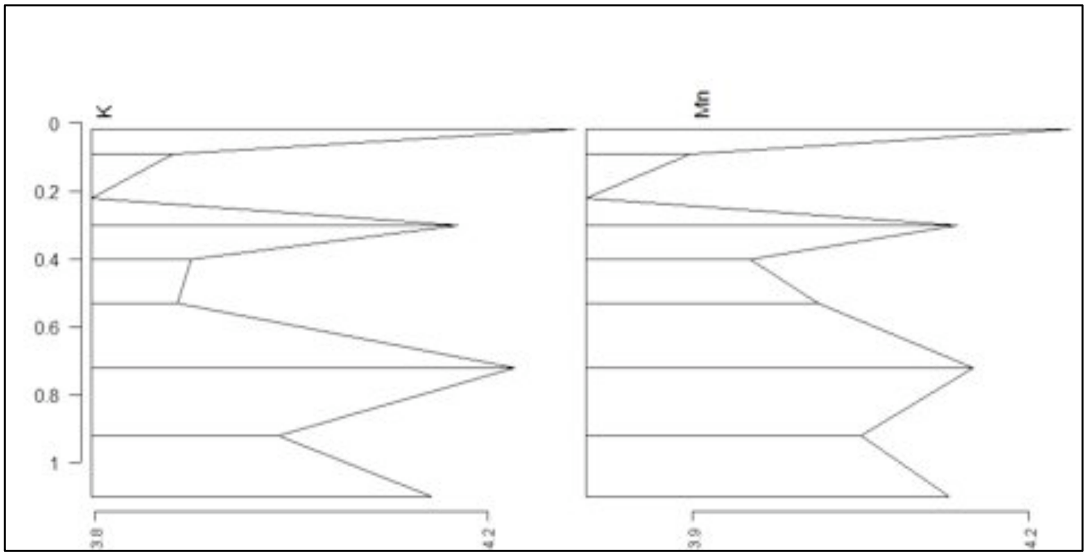

Figure 6. Stratigraphic plot of changes in K and Mn content.

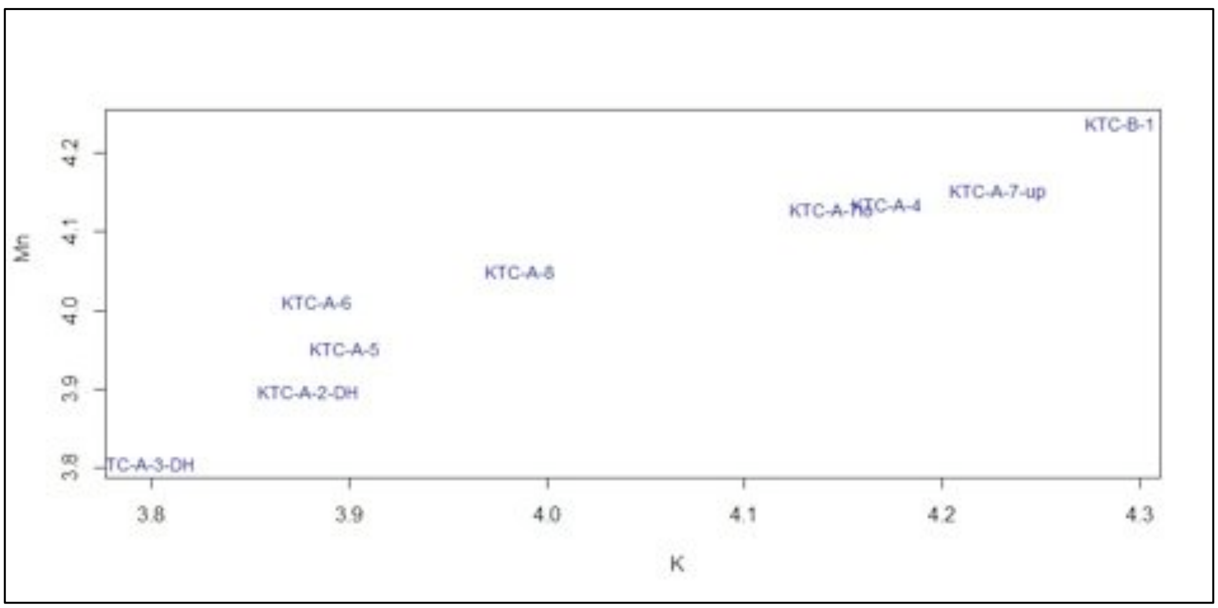

Figure 7. Biplot of K and Mn relationship between contexts.

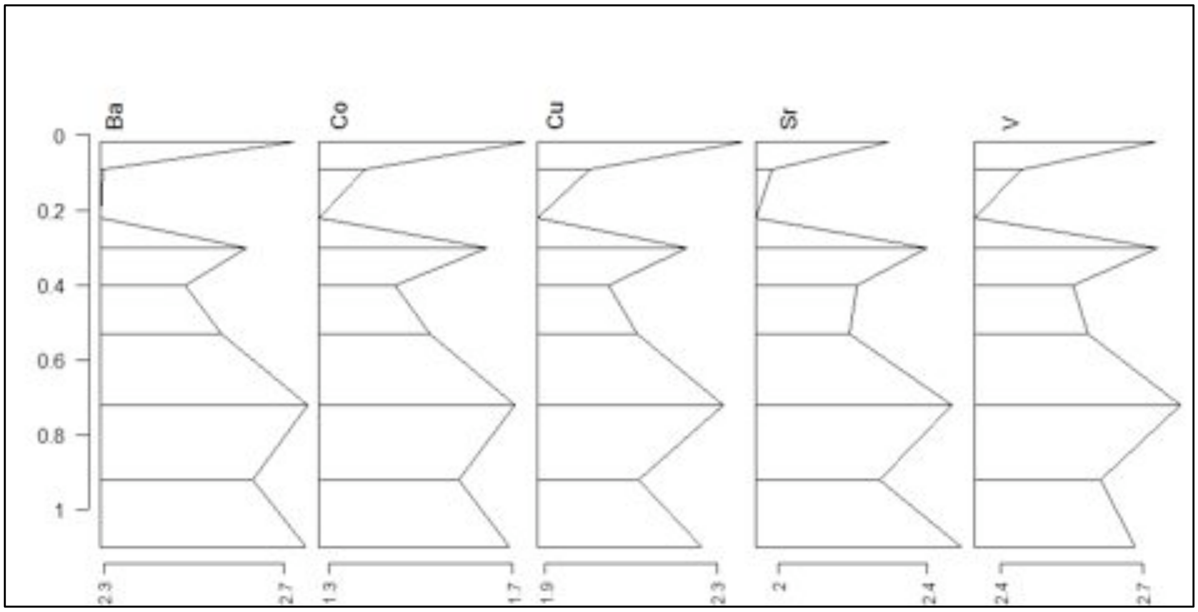

Figure 8. Stratigraphic plot of changes in Ba, Co, Cu, Sr, and V content.

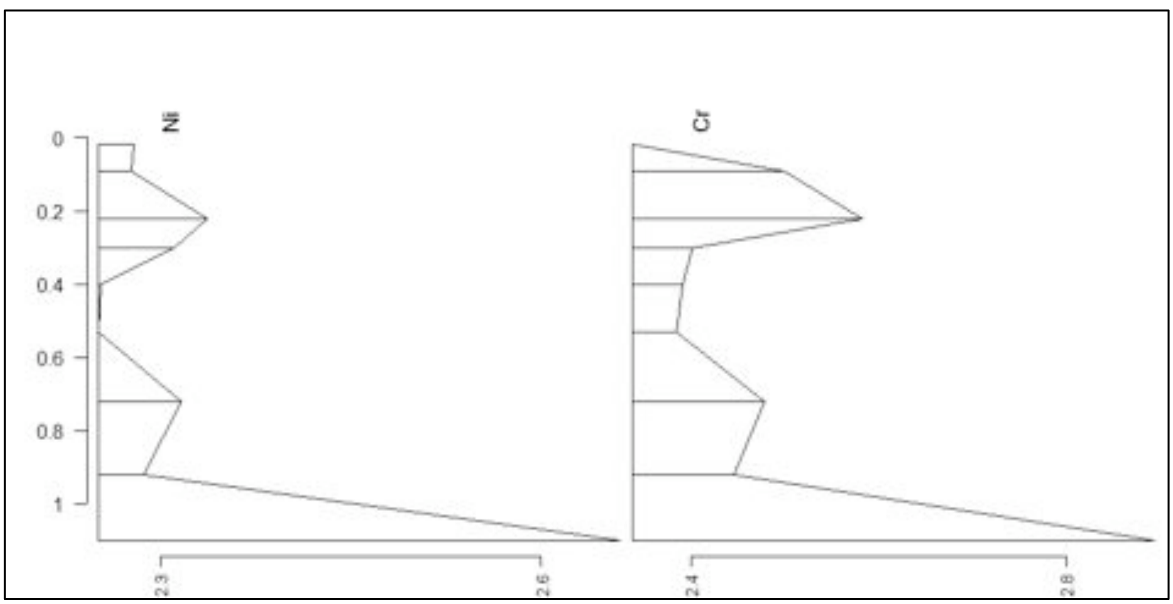

Figure 9. Stratigraphic plot of changes in Ni and Cr content.

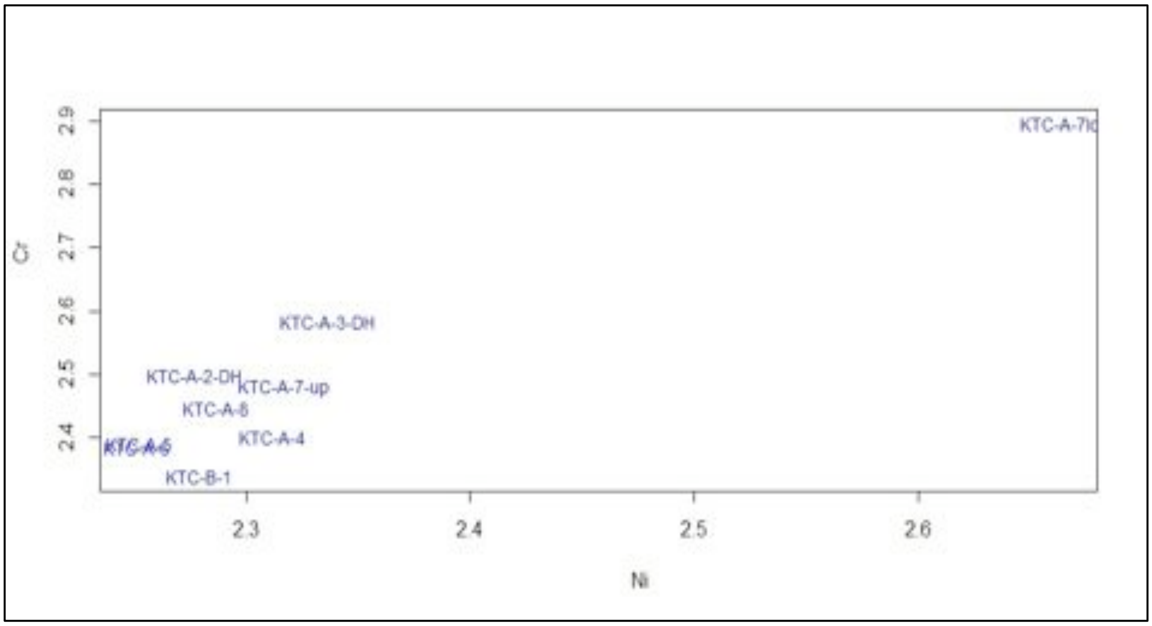

Figure 10. Biplot of Ni and Cr relationship between contexts.

3.4 Laser particle size analysis

Particle size analysis provided important information for site formation processes at KTC. As table 5 describes, mean particle size increased and reached a high point at A-4 and A-7 High. These two contexts also had the largest grain size mode. Quantification of silt sized particles is particularly significant, because these include clay sized clasts. Although identification of clay sized clasts is not readily available, silt particles can be used as a proxy for the overall abundance within samples. Importantly the highest percentage of silt sized particles occurs at A-5 and A-8, opposite the contexts with large particle mean sizes.

Table 5. Particle size analysis with the percentage of silt size particles throughout contexts.

Sample ID	Lithology	Mean (μm)	Modes (μm)	Median (μm)	%Silt
KTC-B-1	Sandy Mud	70.38	.76 - 3.90 - 67.52	50.68	40.02
KTC-A-2	Sandy Mud	62.59	.76 - 3.41 - 67.52	47.31	42.39
KTC-A-3	Slightly Gravelly Muddy Sand	114.67	.76 - 3.90 - 88.58	76.28	26.85
KTC-A-4	Slightly Gravelly Muddy Sand	182.54	.76 - 3.41 - 77.34 - 1337.48	70.54	31.29
KTC-A-5	Sandy Mud	44.99	.67 - 26.11 - 67.52	31.01	58.19
KTC-A-6	Muddy Sand	177.25	.51 - 29.91 - 229.08	134.76	29.19
KTC-A-7-High	Muddy Sand	181.01	.58 - 6.72 - 67.52 - 678.50	67.76	37.03
KTC-A-8	Sandy Mud	74.95	3.41 - 26.11 - 200	33	53.38
KTC-A-7-Low	Slightly Gravelly Muddy Sand	142.86	2.98 - 77.34	72.47	28.02

4. Discussion

Results of the geoarchaeological analysis of KTC sediments allow for an informative understanding of site formation processes, the environment of sedimentation, and human activity. The goal of this analysis was to investigate these processes at KTC which was successfully accomplished. These results also tend to qualify with previous geoarchaeological findings in limestone rockshelters and caves throughout Southeast Asia (Westaway et al. 2009). As Anderson discusses, KTC results match patterns of rockshelter formation and occupation in this region (2005). Aeolian and colluvial sedimentation, human activity, and weathering of site deposits provide the basis of this determination. This investigation has been able to successfully describe these aspects through use of physical and chemical properties of sediment samples. The major limitation of this analysis is that KTC archaeological material evidence is unavailable to compare with these interpretations. Also statistical analysis has confirmed that some of these variables lack strong correlation to support hypotheses. XRD analysis was not able to quantify minerals, and ICP analysis was unable to calculate P content. Still, the geoarchaeological work accomplished thus far provides an important backdrop for future site and comparative analysis in Southeast Asia.

Understanding particle size data has provided important implications for site formation processes. Mean particle size for samples is relatively consistent throughout the site. Very fine sand, and fine sand characterize the majority of these samples, yet there are important variations taking place (Goldberg and Macphail 2006). For instance, although fine sands are representative of aeolian sedimentation, important colluvial processes are at work here as well (Huckleberry and Fadem 2007, Waters 1992). Aeolian windblown sediments are supported by the small particle size of the sediments found in most samples. Where large modes do occur at A-4 and A-7-High this is indicative of colluvial processes depositing larger sized particles into the rockshelter. In limestone rockshelters this process is very common for the limestone is continually eroding in the process of weathering (Farrand 2001). This conclusion is supported by Westaway et al. who describe the site formation processes occurring at Liang Bua cave in Flores, Indonesia. Here mean particle sizes, comparable with KTC sediments, are argued to have been deposited by low energy environments (2009). This site was inundated with fluvial sediments which provide the basis of their interpretation, yet the underlying processes are comparable here. The low energy fluvial environment which deposited small sized particles into the site is equivalent to the aeolian deposition taking place at KTC.

Particle size analysis also suggests important environmental changes in sedimentation taking place in the site. Where mean particle size is low and silt content is high at A-5, the clay mineral kaolinite is found. XRD analysis was unable to provided quantitative values for minerals, and can only be used in a comparative fashion, yet this is an important implication of environmental stability. As Alam et al. argue a stable surface is needed in order for weathering to affect sediments which form soils that clay minerals accumulate in (2008). Kaolinite itself is also indicative of intensive chemical weathering, usually in lower altitudes in the humid tropics, and suggests deposits in which water movement is high (Alam et al. 2008). Alkalies are usually removed by this process which matches the noticeable drop in pH between A-5 and A-6. As the mineralogical data suggests, the environment may have stabilized and become wetter at A-5 where a mean particle size of 44.99 μm is found. This would have allowed soil formation to begin and clay minerals to accumulate. Kaolinite is also found in A-6 which could be indicative of a transformation of minerals in the soil profile (Waters 1992). This explanation matches particle size data since soil formation and clay mineral accumulation occur in stable environments. At A-4 and A-7-High particle size analysis suggests that intensive weathering must have also been occurring at those contexts but through different processes since clay's and clay sized particles are less abundant.

In addition to XRD analysis, ICP data describes periods of relative environmental stability and change at KTC. Comparison of elements found in tropical soils, Ba, Co, Cu, Sr, and V provide evidence that soil formation is occurring at peaks in B-1, A-4, A-7-High, and A-7-Low (Kabata-Pendias and Pendias 1984, Haslam et al. 2011). Ni and Cr which are also important indicators of soil formation have a high statistical correlation in KTC samples and support this conclusion. Interpretation of this data indicates that weathering occurred differently throughout the Holocene at KTC. During A-4 and A-7-High soil formation is undoubtedly occurring on a stable surface in which aeolian and colluvial sedimentation is taking place. At A-5 and A-6 clay formation suggests a weathering pattern of increased precipitation at the site. These results suggest that differing periods of environmental change are driving site formation processes of sedimentation. Although further analysis is needed to qualify these results, previous research suggests that precipitation did increased during the Holocene in Southeast Asia (Marwick and Gagan 2011). Importantly, principal component analysis results express that context A-4 and A-7-High are related as well as A-5 and A-6. This provides support to these claims.

Although particle size and XRD results have provided important implications for site formation process and the environment of sedimentation, an important aspect of human occupation is also seen at KTC. ICP analysis along with SOM content and magnetic susceptibility values provide evidence that human activity and occupation did occur. By measuring K and Mn elemental values it is possible to extrapolate human activity. Previous research has established that elements K and Mn are found in correlation with waste, hearths, and some food processing areas (Misarti et al. 2011). KTC samples indicate that during periods of stability and soil formation, these elements are most abundant. This is important for two reasons. First, it describes that human occupation at the rockshelter occurred during periods when the rockshelter surface stabilized. Second, if human activity is not the cause of these element abundances then it is possible that soil formation processes are instead responsible for these correlated values. If these results do in fact predict soil formation processes then they only serve to support site formation processes and environmental dynamics instead. Yet when combined with the high correlation between SOM and X.fd data, this interpretation suggests that these values are evidence of human activity. As Marwick discusses, magnetic susceptibility values are indicative of decaying organic matter and fire (2005). Since SOM and X.fd values are relatively high during periods of increased K and Mn element abundances this suggests that the site was stabilized and cultural activity caused an increase in organic matter and fire evidence in the rockshelter. These results describe the Holocene as an active period of site formation processes, human occupation, and environmental sedimentation occurring at the rockshelter.

5. Conclusion

KTC data represent shifting periods of aeolian and colluvial site formation processes. Environmental stability during these periods accelerated soil and clay formation. Clay formation occurred during periods of increased water activity at the site and possibly overall precipitation in the region. Human occupation likely occurred relatively continuously throughout the Holocene yet it appears most frequently during periods of stability at the site when soil formation occurs. Anthropologically and cultural-historically these results have important implications for the archaeological history of Southeast Asia groups. In the tropics, where site preservation is generally poor due to the high acidity of sediments, rockshelter sites and caves are crucial in their ability to preserve archaeological material. Thus important aspects of cultural processes can be derived from studying the geoarchaeology and artifact remains from this site. Understanding the environment of deposition and environmental change during this period will also influence knowledge of site formation processes which may influence where to survey for future archaeological sites. This type of geoarchaeological analysis has occurred in few sites throughout Southeast Asia so these results are important as a basis for scientific critique and replication throughout the region. Further XRD and ICP-AES analysis may be possible to determine human occupation zones at a higher degree of clarity than accomplished here. Once material data is available for analysis, these results should also be incorporated into the geoarchaeological interpretation of the site. Finally, micromorphological studies may be useful in determining microstratigraphic sequences of deposition. Although this study has limitations it has provided important descriptions of human activity, site formation, and the environment of deposition at the Khao Toh Chong Rockshelter.

Stable Carbon Isotope Analysis of Khao Toh Chong Rockshelter

by. Cyler N. Conrad

Abstract

Sediments in rockshelter sites are important for determining aspects of site formation, human occupation and the environment of deposition. Previous geoarchaeological analysis of the Khao Toh Chong (KTC) rockshelter in southwestern Thailand has provided detailed results describing natural and cultural processes influencing site formation and occupation. Here, additional stable carbon isotope analysis of soil organic matter provides evidence of C_3 and C_4 vegetation community dynamics. The results of this study indicate that C_3 plants dominate the ancient vegetation profile at KTC. Enrichment of $\delta^{13}C$ values over time is indicative of microbial activity in the decomposing organic matter, fully consistent with a discovered correlation between soil organic matter and $\delta^{13}C$ values. Results are interpreted as initial indications of site vegetation history and palaeoenvironmental conditions at the rockshelter.

1. Introduction

This stable carbon isotope analysis aims to investigate changes in vegetation communities and palaeoclimate at Khao Toh Chong rockshelter (KTC). This work carries important implications for Thai, and Southeast Asia archaeology since most of the archaeological history in this region has come from rockshelter and cave sites (Anderson 2005). Few stable carbon isotope records from peninsula Thailand that analyze palaeoclimate and vegetation communities from archaeological sites exist and as such this analysis provides valuable information for future geoarchaeological research. Isotopic analyses in Southeast Asia have instead focused on diet reconstruction and geographic distribution of humans and animals (Bentley et al. 2007 and Pushkina et al. 2010). Isotopic studies from Thailand and the greater region have also focused on modern biogeography of vegetation communities which provides an important comparison between modern and ancient plant communities (Kuramoto and Minagawa 2000 and Yoneyama et al. 2010). Still, some regional archaeological comparisons do exist. One example comes from a southern Indian Middle Palaeolithic site which also analyzed $\delta^{13}C$ ratios in order to determine landscape vegetation and climate change during the late Pleistocene (Haslam et al. 2012). Although $\delta^{13}C$ records from peninsular Thailand are lacking, Thailand and Southeast Asia have an archaeologically rich record of rockshelter sites that offer valuable comparisons to further analyses. Here, sediment samples have been analyzed in the University of Washington Geoarchaeology Lab during spring quarter 2012.

Isotopic analysis of soil organic matter is important as a proxy for understanding climate change and vegetation communities. When plants photosynthesize and metabolize carbon they do so in three different ways which fractionize $^{13}C/^{12}C$ isotopes in specific patterns (Van der Merwe 1982). Measured in parts per thousand, or per mil (‰) and designated by δ (^{13}C content), the three forms of photosynthesis are the C_3, C_4, and CAM pathways. The Chicago PDB marine carbonate standard is used as a control to measure $\delta^{13}C$ values. Originally a Cretaceous marine fossil *Belemnitella americana*, the

PDB is now reproduced in a variety of materials and set at zero with all ratios measured against it (Van der Merwe 1982). Plants which have $\delta^{13}C$ values between -33 and -22‰ and a mean of -27‰ are known as C_3 plants because after fixation of carbon dioxide a compound is left with three carbon atoms (DeNiro 1987). Plants which form a four carbon atom compound after fixation of CO_2 during photosynthesis are known as C_4 plants and range between -16 to -9‰ with a mean of -12.5‰. Crassulacean acid metabolism, or CAM, plants use a different compound to fixate CO_2 and under differential environments can resemble both C_3 and C_4 plant $\delta^{13}C$ ratios. Without an accurate pollen record a detailed analysis of CAM plants is uninformative because of the variability inherent in the unknown vegetation taxa. In addition to specific $\delta^{13}C$ values, C_3 and C_4 plants represent specific climatic and environmental conditions which are routinely used to interpret palaeoclimate. Grasses in subtropical, savannah and arid environments fixate CO_2 through the C_4 pathway. All shrubs and trees from tropical forests and temperate environments fixate CO_2 through the C_3 pathway (Van der Merwe 1982). Interestingly, C_4 vegetation tends to be found in hot climates, yet tropical forests which are extremely hot tend to have little C_4 vegetation because the forest canopy provides shade and C_4 vegetation is adapted to direct radiation from the sun. Additionally, C_4 vegetation suggests environments with less water because of the plants' ability to quickly and efficiently fixate CO_2 in hot, dry environments. Contrary to this, typical C_3 vegetation suggests cooler and wetter environments where water is more abundant and temperatures cooler in order for the slower fixation of CO_2 to occur.

In this study, investigation of palaeoclimate and vegetation change using stable carbon isotope analysis of soil organic matter has described the dominate vegetation community represented in the rockshelter and explanations for shifts in $\delta^{13}C$ values over time. This data indicates that C_3 vegetation is proportionally high at the site. Depleted C_3 ratios near the surface suggest that microbial activity is differentially affecting $\delta^{13}C$ values through time at the site. Overall $\delta^{13}C$ ratios depict a palaeoclimate which was cool and wet, consistent with tropical forest-grassland environments.

2. Methods

Stable carbon isotope analysis was conducted on sediments excavated from KTC rockshelter in Thap Prik Village outside of Krabi in southwestern Thailand (Marwick et al. 2013). KTC was excavated between June and July 2011 as part of an international archaeological field school with students from Thailand, Cambodia, Indonesia, Burma, Korea, Vietnam, the United States, and the Philippines. Each trench covered an area of 2x2 m and was excavated to slightly over 1 m depth in trench A and 2 m depth in trench B (Figure 1 replaced with Van Vlack 2014 Figure 3.2). Samples were taken from the contexts of the trench A profile and one surface sample from trench B (Figure 2 replaced with Van Vlack 2014 Figure 3.4). The site is 60 m above sea level and found under a limestone overhang of a karst tower within the village. It is 30 m long and 10 m wide from the rockshelter wall to the dripline. Dating of KTC has not yet occurred but dates likely fall between the early Holocene, the lowest levels of the site, up through the late Holocene, the upper levels at the site (Marwick et al. 2013). The site lies in a region of monsoon rain forest which is characteristic of this tropical region of Thailand (Anderson 1990). Nine sediment samples ranging from A2 to A7 low, and B1 were used for this analysis.

In order to quantify the variation within and between samples, three replicate samples were prepared for each stratigraphic context. Preparation began by decontaminating glassware and weighing 2.0±.01 g of sediment per sample. After an initial dry at 60°C for 24 hours samples were poured over a 2mm sieve to remove the >2mm particle size fraction (Hartman 2011). Organics were picked out and discarded before samples were ground for 5 minutes using a mortar and pestle. In order to eliminate carbonates in the sample 60 mL of 1 M HCl was stirred into the samples and left to sit for 24 hours while stirring every 10 hours (Millwood and Boutton 1998). To rinse the samples of HCl, 60 mL of deionized water was stirred into the samples for 1 minute before setting to dry at 60°C for 48 hours. Two more rinse cycles occurred where 60 mL DI water was stirred into the samples for one minute before setting to dry at 60°C for 24 hours each. Completing the rinse cycle ensured that trace amounts of HCl were removed from the samples before final weight and analysis by the mass spectrometer (Fry et al. 1992).

All samples were transferred into labeled polypropylene microvials or sediment bags and taken to the UW Earth and Space Sciences IsoLab for $\delta^{13}C$ analysis. Results were obtained using a Costech Elemental Analyzer, Conflo III, MAT253 with continuous flow and He carrier gas. IsoDat software was used to quantify $\delta^{13}C$ ratios.

3. Results

KTC sediment samples depict a pattern of vegetation consistent with a cool and wet climate, and microbial activity at the rockshelter. Results indicate that $\delta^{13}C$ values depict vegetation communities which are C_3 plant dominant ranging from -28.79‰ to -26.01‰ with a mean value of -27.28‰ (Table 6). A depletion of $\delta^{13}C$ values occurs while moving from context A7Low towards the B1 surface. This depletion is important because there is more variation between samples than within which suggests that these results are not hampered by equipment error or contamination and are replicable (Figure 12). A significant correlation is also seen between $\delta^{13}C$ values and soil organic matter (Figure 11 and Table 7). Microbial activity is suggestive as causation for this correlation over time.

Table 6. Raw isotope data by sample and depth.

Sample	Depth (m)	$\delta^{13}C$ (‰)
B1a		-28.75
B1b	0.02	-28.72
B1c		-28.79
A2a		-27.85
A2b	0.09	-27.85
A2c		-27.73
A3a		-28.36
A3b	0.22	-28.22

Sample	Depth (m)	$\delta^{13}C$ (‰)
A3c		-28.44
A4a		-27.24
A4b	0.3	-27.48
A4c		-27.38
A5a		-27.00
A5b	0.4	-26.94
A5c		-27.04
A6a		-26.80
A6b	0.53	-27.04
A6c		-26.97
A7Ha		-26.83
A7Hb	0.72	-26.85
A7Hc		-26.90
A8a		-26.16
A8b	0.92	-26.37
A8c		-26.21
A7La		-26.01
A7Lb	1.1	-26.21
A7Lc		-26.38

Table 7. Correlations between variables at KTC, * indicates correlation where $p<0.001$.

	pH	EC (mS)	SOM (% mass)	CaCO3 (% mass)	Xlf	X.fd	Mean (um)	st. dev. (um)	d13C ‰ VPDB
pH	1NA	0.10	-0.52	0.61	0.17	0.47	-0.06	0.24	0.15
EC (mS)	0.10	1NA	-0.09	-0.15	-0.18	0.12	-0.28	-0.23	-0.26
SOM (% mass)	-0.52	-0.09	1NA	-0.69	-0.76	-0.96	-0.26	-0.28	-0.803*
CaCO3 (% mass)	0.61	-0.15	-0.69	1NA	0.67	0.65	0.06	0.08	0.46
Xlf	0.17	-0.18	-0.76	0.67	1NA	0.83	0.20	0.05	0.64
X.fd	0.47	0.12	-0.96	0.65	0.83	1NA	0.29	0.24	0.67
Mean (um)	-0.06	-0.28	-0.26	0.06	0.20	0.29	1NA	0.90	0.27
st. dev. (um)	0.24	-0.23	-0.28	0.08	0.05	0.24	0.90	1NA	0.26
d13C ‰ VPDB	0.15	-0.26	-0.803*	0.46	0.64	0.67	0.27	0.26	1NA

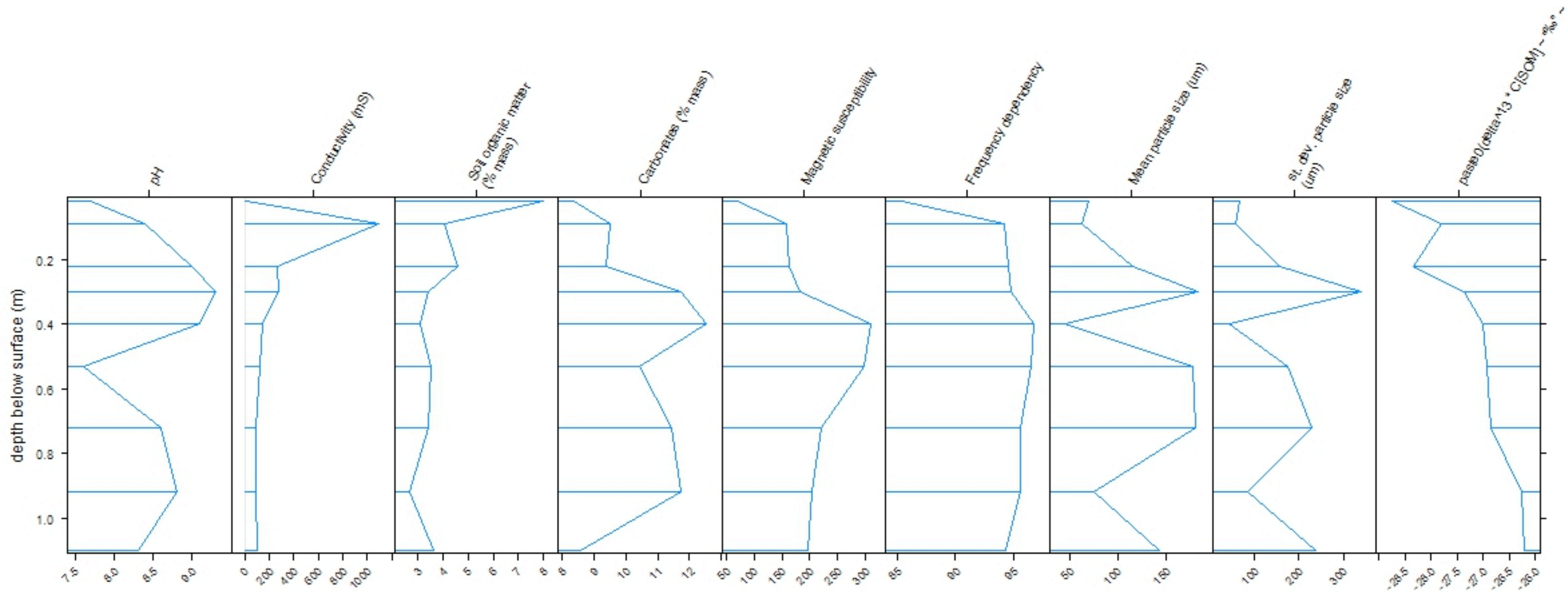

Figure 11. Carbon isotope data in context with other geoarchaeological data. L-R: pH, electrical conductivity, soil organic matter percentage, carbonate percentage, magnetic susceptibility and frequency dependency, particle size mean and standard deviation, and $\delta^{13}C$ values.

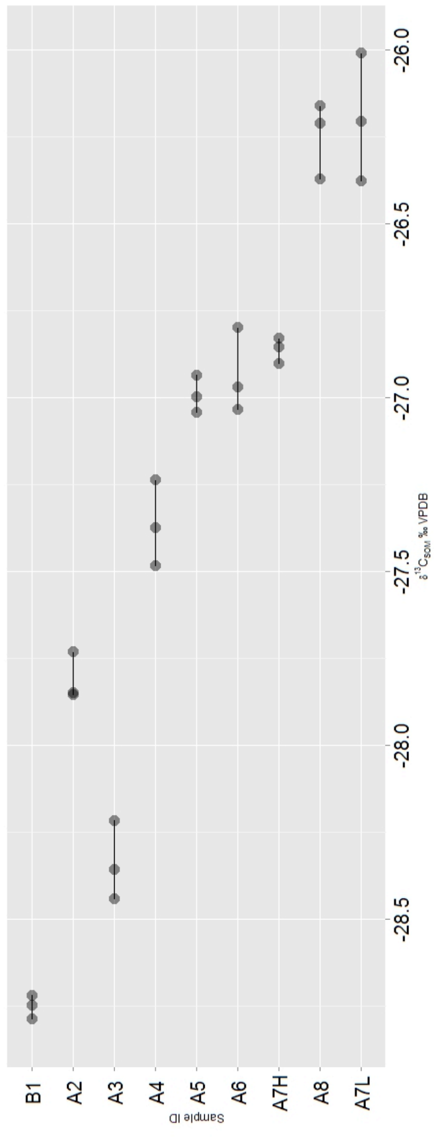

Figure 12. Variation within and between $\delta^{13}C$ sample

4. Discussion

Results of the stable carbon isotope analysis of KTC sediments allow for an informative understanding of ancient vegetation communities and palaeoclimate conditions, yet these results also indicate that soil microbial activity is driving the $\delta^{13}C$ values. The goal of this analysis was to investigate these processes at KTC which was successfully accomplished. Results also tend to qualify with previous isotopic analyses of archaeological sites in tropical regions around the globe (Haslam et al. 2012, Krishnamurthy and DeNiro 1982, Pessenda et al. 1996). Anderson (2005) describes rockshelter sites throughout Southeast Asia, and the KTC geoarchaeological results match patterns of rockshelter formation and occupation in this region. As such these results further indicate that this analysis will substantially aid in the understanding of palaeoenvironmental conditions throughout Southeast Asia. The major limitation of this analysis is that KTC sediment samples have yet to undergo a rigorous palynological analysis which could provide a detailed description of flora taxa which are providing the isotopic signature in the decomposing organic matter. Without palynological analysis, these results only reflect large scale vegetation dynamics instead of individual plant species dynamics or edible plant species brought into the rockshelter by human populations. Still, the stable carbon isotope research accomplished thus far provides an important backdrop for future site and comparative analyses.

The significant correlation between soil organic matter and $\delta^{13}C$ values is important because it provides evidence that the KTC results are representative of the vegetation in the region and the processes of microbial decomposition in the rockshelter. As Tieszen (1991) writes, isotopic values should match soil organic matter if vegetation is the driving factor behind the decomposition of organic material. If vegetation is consistent through time, and correlated with organic matter, then it is the decomposing organic vegetation providing the $\delta^{13}C$ values. Yet, if $\delta^{13}C$ values are enriched through time by only 2-6‰ preferential microbial activity instead of vegetation change is likely driving the results. Microbial activity differentially depletes biochemical markers which can enrich $\delta^{13}C$ values in soil organic matter over time (Tieszen 1991 and Lerch et al. 2011). Lerch et al. (2011) write that microbial biomass can derive murein, chitin, lipid, and melanin compounds in soil organic matter. When microbial activity decomposes organic matter these compounds make up a significant aspect of dissolved organic matter and influence $\delta^{13}C$ ratios. Thus the $\delta^{13}C$ values in soil organic matter can express ratios of molecular contribution by microbial activity which enriches isotopic values over time. Importantly, this process of fractionation during microbial activity and processing of organic material during decomposition is known to drive the $\delta^{13}C$ values in soil organic matter by enrichment over time (Lerch et al. 2011). When analyzing $\delta^{13}C$ changes it is difficult to determine whether these shifts are correlated with vegetation change or microbial activity. Microbial biomass is known to enrich $\delta^{13}C$ values by as little as 2-6‰, since KTC results indicate an enrichment between 2-3‰ over time this provides strong evidence of microbial enrichment not vegetation shift (Wynn 2007, Tieszen 1991 and Schweizer et al. 1999). Only additional biological analyses of microbial biomass in these sediments will clarify the ultimate effect of microbial fractionation. Since a significant correlation is found between soil organic matter and $\delta^{13}C$ values, this is indicative of microbial activity driving the enrichment of $\delta^{13}C$ over time. Still, the dominate C_3 vegetation community described provides additional insight into paleoclimatic conditions at the rockshelter.

In a modern analogue Yoneyama et al. (2010) discovered that C_3 plants collected in Thailand have $\delta^{13}C$values ranging between -34.4‰ to -26.1‰, and C_4 plants between -15.7‰ and -12.0‰. These results indicate that vegetation in this region has a quantifiable difference between C_3 and C_4 plants, making determinations of palaeoclimate possible. Additionally Ambrose and Sikes (1991) discuss that C_3 plants thrive in cool, moist, and shaded areas of forested grassland. This includes tropical environments in which forest-grassland plants fully comprise C_3 ratios. KTC results have a mean $\delta^{13}C$ value of -27.28‰ suggesting dominate C_3 vegetation throughout the site, indicative of tropical forest-grassland vegetation and cooler, moister climates throughout the Holocene. A cool and moist climate throughout the Holocene which is characterized by C_3 vegetation matches patterns of $\delta^{13}C$ depletion in archaeological sites across the globe (Huckleberry and Fadem 2006, Haslam et al. 2012 and Bowman et al. 2007). The consistent C_3 plant ratios are suggestive of forested-grassland vegetation found in tropical settings inundating the rockshelter with vegetation material throughout the Holocene. Interestingly, isotopic analysis from the bivalve *Margaritanopsis laosensis* in Tham Lod and Ban Rai rockshelters in northwest Thailand also depicts increased precipitation and wetness throughout the Holocene, matching the results of the KTC isotopic record (Marwick and Gagan 2011). Enrichment of $\delta^{13}C$ values over time can be described by isotopic fractionation and microbial activity which does not suggest significant vegetation change throughout this period.

5. Conclusion

KTC isotopic data provide a depiction of palaeoclimate conditions and vegetation dynamics at the rockshelter. Vegetation is dominated by C_3 ratios and enrichment over time occurs because of microbial activity in the decomposing organic matter. Completed geoarchaeological analyses combined with stable carbon isotope results suggest that KTC is an archaeologically rich rockshelter site that has remained relatively undisturbed through the Holocene. Anthropologically, this site provides an important record of cultural activity in Southeast Asia, and further artifact analysis will begin to uncover this record. Understanding the palaeoclimate record provides the opportunity to interpret vegetation communities and environmental conditions. Further palynological analysis may help identify flora taxa which will only strengthen the isotopic record. Although this study has limitations it has provided important descriptions of paleoclimate, vegetation communities, and microbial activity at the Khao Toh Chong Rockshelter.

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Appendix D:

Minimum Number of Individuals (MNI) and Number of Identified Specimens (NISP): Zooarchaeological Quantification Collected During 2012 Post-Excavation Analyses of Khao Toh Chong Rockshelter, Krabi

Table D.1 Record of the invertebrate minimum number of individuals from KTC, Trench A southwest unit. Data recovered in 2011, and recorded in 2012.

KTC Invertebrate MNI									
Context No.	**1**	**2**	**3**	**4**	**5**	**6**	**7H**	**8**	**7L**
Gastropoda									
Neritidae gen. indet.	-	-	1	-	-	-	-	-	-
Nerita balteata	-	-	-	-	2	-	-	-	-
Cyclophorus sp.	-	-	-	-	-	7	-	-	-
Cyclophorus cf. *saturnus*	-	-	-	-	-	-	-	1	-
Cyclophorus malayanus	-	-	-	-	9	1	-	1	-
Cyclophoridae gen. indet.	-	2	3	2	1	28	5	30	-
Rhiostoma jalorensis	-	-	2	2	10	9	2	2	-
Rhiostoma sp.	-	-	-	-	-	6	3	2	-
Filopaludina sp.	-	-	2	-	-	-	-	-	-
Viviparidae gen. indet.	-	1	-	-	-	-	-	-	-
Pila sp.	-	-	-	-	-	2	4	-	-
Ampullariidae gen. indet.	-	-	-	-	-	3	-	3	-
Neoradina prasongi	-	8	134	52	82	1584	2215	771	-
Telescopium telescopium	-	-	3	2	3	4	2	-	-
Muricidae gen. indet.	-	1	4	-	1	-	-	-	-
Plectopylis degerbolae	-	-	1	-	1	2	3	5	-
Amphidromus atricallosus	-	-	1	-	1	1	-	-	-
Bivalvia									
Anadara sp.	-	-	-	-	-	-	-	-	-
Arcidae gen. indet.	-	-	-	-	-	-	-	-	-
Pseudodon sp.	-	-	-	-	-	-	-	-	-
Amblemidae gen. indet.	-	-	-	-	-	-	-	-	-
Corbiculidae gen. indet.	-	-	-	-	-	-	-	-	-
MNI	**0**	**12**	**151**	**58**	**110**	**1647**	**2234**	**815**	**0**

Table D.2 Record of vertebrate minimum number of individuals from KTC, Trench A southwest unit. Data recovered in 2011, and recorded in 2012.

	KTC Vertebrate MNI								
Context No.	**1**	**2**	**3**	**4**	**5**	**6**	**7H**	**8**	**7L**
Osteichthyes subclass indet.	1	-	-	-	-	-	1	-	-
Testudines fam. indet.	1	1	1	1	1	2	1	1	1
Varanus sp.	1	-	1	1	1	1	1	1	1
Pythonidae gen. indet.	-	-	-	-	-	-	-	-	1
Primates fam. indet.	1	-	1	-	-	1	-	-	1
Macaca sp.	-	-	1	-	-	-	1	1	1
Trachypithecus obscurus	-	-	-	-	-	-	1	-	-
Rodentia fam. indet.	-	-	1	-	-	-	1	-	-
Rattus remotus	-	-	-	-	-	1	-	-	-
Cannomys badius	-	-	-	-	-	-	-	-	1
Atherurus macrourus	-	-	-	-	-	1	-	-	-
Carnivora fam. indet.	-	-	-	-	-	-	1	-	-
Tragulidae gen. indet.	-	-	-	-	-	-	1	-	-
Cervus unicolor	-	-	-	-	-	-	1	-	-
Muntiacus muntjak	-	-	-	-	-	-	-	1	1
Bovidae gen. indet.	-	-	-	-	-	-	-	-	1
MNI	**3**	**13**	**156**	**60**	**112**	**1653**	**2242**	**819**	**8**

Table D.3 Record of invertebrate number of identified specimen from KTC, Trench A southwest unit. Data recovered in 2011, and recorded in 2012.

KTC Invertebrate NISP									
Context	**1**	**2**	**3**	**4**	**5**	**6**	**7H**	**8**	**7L**
Gastropoda									
Neritidae gen. indet.	-	-	-	1	-	-	-	-	-
Nerita balteata	-	-	-	-	1	1	-	-	-
Cyclophorus sp.	-	-	-	-	-	-	7	-	-
Cyclophorus cf. *saturnus*	-	-	-	-	-	-	-	-	1
Cyclophorus malayanus	-	-	-	-	-	9	1	1	-
Cyclophoridae gen. indet.	-	-	2	3	2	12	20	5	27
Rhiostoma jalorensis	-	-	-	2	5	11	5	2	2
Rhiostoma sp.	-	-	-	-	-	-	9	-	2
Filopaludina sp.	-	-	-	2	-	-	-	-	-
Viviparidae gen. indet.	-	-	1	-	-	-	-	-	-
Pila sp.	-	-	-	-	-	-	6	-	-
Ampullariidae gen. indet.	-	-	-	-	-	1	2	-	3
Neoradina prasongi	-	-	8	134	71	115	3390	545	583
Telescopium telescopium	-	-	-	3	3	3	5	-	-
Muricidae gen. indet.	-	-	1	4	-	1	-	-	-
Plectopylis degerbolae	-	-	-	1	-	1	5	3	3
Amphidromus atricallosus	-	-	-	1	1	-	1	-	-
NISP	**0**	**0**	**12**	**151**	**83**	**154**	**3451**	**556**	**621**
Unidentified Gastropod	-	-	8	75	143	266	1176	255	834
Bivalvia									
Anadara sp.	-	-	1	-	-	-	-	-	-
Arcidae gen. indet.	-	-	-	3	-	1	-	-	-
Pseudodon sp.	-	-	-	1	9	-	-	-	-
Amblemidae gen. indet.	-	-	-	-	1	66	191	18	367
Corbiculidae gen. indet.	-	-	-	-	-	-	1	-	-
NISP	**0**	**0**	**1**	**4**	**10**	**67**	**192**	**18**	**367**
Unidentified Bivalve	1	-	16	150	76	424	781	176	1103
Invertebrate NTAXA	0	0	5	11	8	11	13	6	8

Table D.4 Record of vertebrate number of identified speciment from KTC, Trench A southwest unit. Data recovered in 2011, and recorded in 2012.

KTC Vertebrate NISP									
Context	**1**	**2**	**3**	**4**	**5**	**6**	**7H**	**8**	**7L**
Osteichthyes subclass indet.	5	-	-	-	-	-	2	-	-
Testudines fam. indet.	21	1	43	17	11	43	32	4	43
Varanus sp.	1	-	3	7	6	14	2	2	4
Pythonidae gen. indet.	-	-	-	-	-	-	-	-	1
Primates fam. indet.	2	-	1	-	-	1	-	-	2
Macaca sp.	-	-	6	-	-	-	8	1	2
Trachypithecus obscurus	-	-	-	-	-	-	2	-	-
Rodentia fam. indet.	-	-	1	-	-	-	3	-	-
Rattus remotus	-	-	-	-	-	1	-	-	-
Cannomys badius	-	-	-	-	-	-	-	-	2
Atherurus macrourus	-	-	-	-	-	1	-	-	-
Carnivora fam. indet.	-	-	-	-	-	-	1	-	-
Tragulidae gen. indet.	-	-	-	-	-	-	1	-	-
Cervus unicolor	-	-	-	-	-	-	1	-	-
Muntiacus muntjak	-	-	-	-	-	-	-	2	3
Bovidae gen. indet.	-	-	-	-	-	-	-	-	1
NISP	**29**	**1**	**54**	**24**	**17**	**60**	**52**	**9**	**58**
Unidentified Fragments	499	8	230	139	54	316	105	44	160
Vertebrate NTAXA	3 *	1	5	2	2	5	8 *	4	8

* Taxon Osteichthyes subclass indet. excluded from NTAXA due to the broad degree of identification.

Appendix E:

Fossil Pollen Analysis of Khao Toh Chong Rockshelter, Krabi

Table E. 1 Fossil pollen record from archaeological sediments collected at KTC during excavation in 2011.

Slide Label / Slide Number	A	B	C
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	-	-	-
7	-	-	-
8	-	-	-
9	-	-	-
10	-	-	-
11	-	-	-
12	-	-	-
13	-	-	-
14	-	-	-
15	-	-	-
16	-	-	-
17	-	-	-
18	1*	-	-

*The preservation of fossil pollen at KTC was extremely poor, the only grain present was from 7L, an invasive species (*Macaranga* sp.) that is not considered an accurate representation of the floral chronology of KTC.