Adaptations to sea level change and the transition to agriculture in tropical monsoonal Peninsula Thailand

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This study reports on a geoarchaeological analysis of human adaptations to sea level changes in the tropical monsoonal environment of Peninsula Thailand. We excavated Khao Toh Chong rockshelter in Krabi and recorded archaeological depositsspanning the last 13,000 years. A suite of geoarchaeological methods suggest uninterrupted deposition and patterns of environmental change. These changes are possibly caused by increased precipitation, driving site formation processes which are suggestive of varying periods of aeolian and colluvial sedimentation. Although there is only a small assemblage of mostly undiagnostic ceramics and stone artefacts, there are some distinct changes in stone artefact technololgy and ceramic farbic. There is a rich and undisturbed faunal assemblage, with changes in the mammalian taxa during the Pleistocene-Holocene transtion, and changes in shellfish taxa that correlate with local sea level changes. These assemblage provides an opportunity to explore subsistence behaviours leading up to the transition to domestication. We explore the implications for current debates on the prehistoric origins of agricultural subsistence in Thailand.

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## Introduction

One of the hottest disputes in discussions of the Late Pleistocene and Holocene archaeology of mainland Southeast Asia is the nature of the transition from forager economies to agricultural economies. As a key milestone in complex human-environment interactions, the debate has many dimensions. At one extreme of the debate is the claim that agricultural technologies and cultures appeared in Southeast Asia as a result of influence from north Asia, via the lower Yangtze River and the Yellow River. At the other extreme is the claim is that agriculture emerged from a locally contingent trajectory of changes in human-environment relationships (cf. Hunt and Rabett 2014). While the cultivation of rice and the domestication of pigs and cattle took place in the Yangtze Valley earlier than elsewhere in mainland SEA (Higham et al. 2011; Chi and Hung 2010), the influence of local contingencies remains poorly understood. One of the enduring challenges is that a critical period of time for this transition -- the Late Pleistocene through to the middle Holocene -- is sparsely represented in the archaeological record. We have a rich and well-documented record for the later Holocene when people were living more sendentary lifestyles, for example at Khok Phanom Di in Thailand and Man Bac in Vietnam. And we have many cave and rockshelter sites representing Pleistocene forager lifestyles, such as Tham Lod in Thailand and Xom Trai in Vietnam.

However, middle Holocene (roughly uncal. 6000–3500 BP), the archaeological record in mainland SEA is particularly sparse. This major gap in archaeological evidence for the region has been called 'the missing millennia' (White and Bouasisengpaseuth 2008:39). It is an important period because major changes occured during this time. Ceramics appeared in many parts of Southeast Asia; domesticated plants such as millet and rice appeared; stone artefact technologies transitioning from mostly flaked to mostly ground stone artefacts; settlements expanded from primarily karstic upland and estuarine landscapes during the early Holocene to include inland alluvial lowland villages by the late Holocene (White 2011).

In this paper we present evidence of human activity from coastal Thailand that spans 'the missing millennia'. Khao Toh Chong rockshelter is significant because it has a rich faunal record spanning the middle Holocene, and is located in an area with a well-documented sea level curve. This provides a unique opportunity to investigate locally contingent factors such as sea level changes on human subsistence behaviours at a critical time in the period of the transition from forager economies to agricultural economies. We report on a geoarchaeological analysis of the site to provide a local environmental context to the human occupation, as well as helping to understand site formation processes and artefact taphonomy.

## Background

The Guangxi Province of southern China has extensive evidence of a forager economy with a semi-sedentary lifestyle during c. 7-4 k BP (Higham 2013). Cave occupation continues until 6000 BC in Xianrendong and 5000–4000 BC in Zengpiyan, and more than 30 open sites containing shell middens have been found on the terraces of the Zuojiang, Youjiang and Yongjiang rivers near Nanning, in southern Guangxi (Fu 2002; Chi and Hung 2012). Occupation of these sites, characterised by the largest, Dingsishan, spans 7000-3500 BC. The sites include pottery manufacturing workshops, cemetaries and large quantities of aquatic and terrestrial animal bones, indicating that fishing and hunting were important activities (no cultivars have been recovered). The archaeology of this region gives the impression of a continuous sequence of human occupation. We see gradual, overlapping adaptations resulting in changes in landscape use, the appearance of pottery and use of cemetaries, and at a much later date, an agricultural economy. The pottery and burial practices of the Dingsishan shell middens is identical to those found at the Da But sites of northern Vietnam, such as Da But, Con Co Ngua, Ban Ban Thuy, Lang Cong and Go Trung. These sites were occupied by complex hunter-gatherer populations during 5500–2000 BC (Viet 2007). Polished axes, pestles and mortars suggest cultivation, but clear evidence of food production only appears around 1500-1800 BC at sites such as Man Bac with domesticated pig remains (Sawada et al., 2011).

While this gives a picture of continuity between complex hunter-gatherers and agriculturalists in southern China and northern Vietnam, elsewhere in mainland Southeast Asia continuity is harder to see. For example, there is a gap between cave occupation and open site occupation in Thailand. At Lang Rongrien rockshelter on peninsular Thailand, the most recent dated occupation is about 8000 BP, followed by undated and highly disturbed deposits containing burials and pottery (Anderson 1990:20). Similarly, in northern Thailand rockshelter occupation at Tham Lod and Ban Rai becomes discontinuous at around 8000 BP (Marwick and Gagan 2011; Schoocongdej, 2006). At Laang Spean rockshelter in Cambodia, the most recent occupation in 5000 BP, followed by later disturbance of the stratigraphy (Sophady et al. 2015; Forestier 2015). The general pattern seems to be that cave and rockshelter sites switch from being occasional habitation sites to burial sites in the middle Holocene (Anderson 1997). A key challenge here is that the burials disturb the stratigraphy, making it difficult to assess continuity between forager occupation and later activity. At open sites, the record starts at around 2000 BC (i.e. 4000 BP), for example at Khok Phanom Di, near the Bang Pakong River, southeast of Bangkok (Higham and Thosarat 2004) and at Ban Non Wat (Higham and Kijngam 2011). Occupation at these sites is characterised by burials, pottery, and in later phases, polished stone artefacts indicating crop cultivation.

To investigate the gap in the archaeological record between the shift from rockshelters to open sites during the middle Holocene, we chose to focus on coastal karstic valleys of Krabi province. This landscape has been exposed to major changes as sea levels rose and fell during the Late Pleistocene and Early Holocene (Figure 1). This makes it well-suited to assessing the effects of local environmental change on forager groups during a time of major transitions in subsistence. Sinsakul (1992) has documented a Holocene sea level curve for Thailand that starts with a steady rise in sea level until about 6000 BP, reaching a height of 4 m amsl (above mean sea level). Sea levels then regressed until 4700 BP, then rising again to 2.5 m amsl at about 4000 BP. From 3700 to 2700 BP there was a regressive phase, with transgression starting again at 2700 BP to a maximum of 2 m amsl at 2500 BP. Regression continued from that time until the present sea levels were reached at 1500 BP. The evidence for these sea level changes comes from direct dating of marine shells and peat deposits at geololgical sites in peninsular Thailand (Sinsakul 1992).

Previous research into archaeological correlates of these sea level changes in peninsula Thailand have been summarized by Douglas Anderson (2005). He describes faunal evidence from Lang Rongrien that has increases in marine shellfish around 7500 BP and between 4000 and 2500 BP. Anderson proposes that the increases in marine shellfish at the site are probably related to increases in sea levels. A small number of other sites have been previously investigated in several provinces of peninsula Thailand (Charoenwongsa et al. 1989). For example, Moh Khiew in in Krabi with its 25,000 year old human remains (Pookajorn 1994, Auetrakulvit, 1995, Matsumara and Pookajorn 2005, Chikament 2007), Tham Khao Khi Chan in Surat Thani Province has occupation layers dating from 6060 BP to 4250 BP (Srisuchat and Srisuchat 1992). Buang Bap, also in Surat Thani, has faunal remains including marine shellfish dating between 6000 and 5000 BP (Srisuchat and Srisuchat 1992). Pak Om has a dense and diverse archaeological deposit, but its two dates of 9350 and 3010 BP come from the same layer, so the chronology is uncertain (Srisuchat 1997). Khao Tau in Pang Nga is a site complex with deep stratification and abundant cultural materials dating to 4750 and 5250 BP (Srisuchat and Srisuchat 1992), Finally, there is the Tham Sua shell midden named in Krabi that is a deposit of marine shell greater than one meter deep and with a basal date of 6440 BP (Anderson 2005).

These previous excavations demonstrate human occupation at several sites in peninsular Thailand during the critical time of sea level changes in the Holocene. However, the level of available detail does not give a clear picture of how human behavior relates to sea level changes, or the subsistence strategies. The goal of our work at Khao Toh Chong was to build on this previous work, not only by collecting an assemblage spanning the Holocene, but also by conducting geoarchaeolocal analyses at the site to assess stratigraphic integrity and provide local environmental context to the human occupation.

## Methods

### Excavation methods

In June-July 2011 we excavated two areas of 2x2 m in 5 cm units to a depth of 1.2 m below the surface at Khao Toh Chong rockshelter. The site is a limestone overhang at the base of a 300 m high karst tower in Thap Prik Village. The rockshelter is about 30 m long with an average of about 10 m from the rear wall to the dripline. The dripline is about 40 m above the ground and a series of large boulders (3-4 m high) at the dripline give protection from the wind and rain as well as trapping sediment in the shelter. The surface of the rockshelter is level fine sediment with no signs of disturbance and about 10 m above the surrounding ground, which is about 60 m above sea level. In Trench A, the southernmost trench, excavations reached a depth of 1.1 meters below the surface. In trench B, excavations were obstructed by bedrock in the northwest and southwest units. Subsequently, excavation depths in trench B extended to approximately 2.0 meters in the northeast and southeast units. Excavated sediments were sieved using 5 mm and 10 mm screens.

### Geoarchaeological methods

Bulk sediment samples collected from a column taken from the south wall of excavation trench A. Particle size was analyzed using laser-diffraction measured by a Horiba LA-950 in the University of Washington Materials Science Department. The samples were sieved to remove the >2 mm particlesand then pretreated with 1M HCl and 30% H2O2 to remove carbonates and organic material, then dried, then dispersed in deionized water using the surfactant Trixon X 10 and disaggregated using a sonic probe (c.f. Huckleberry, Stein, & Goldberg, 2003; Scott-Jackson & Walkington, 2005). All samples were assumed to have the index of refraction of quartz, 1.458.

Samples were prepared for compositional analysis by ICP-AES using two treatments of HNO3 followed by exposure to H2O2. The sample was then treated with HCl. This acid digest provides a broad spectrum of archaeologically-relevant soluble metals in a known volumetric concentration, as required for ICP-AES analysis (Balcerzak, 2002; Carter, 1993; Hunt, 2012). The samples were analyzed in a Perkin Elmer Optima 8300DV in the University of Washington Chemistry Department.

We measured pH and electrical conductivity (EC) using a portable Oakton Waterproof Dual Parameter PCSTestr 35 on subsamples with a 1:1 ratio of sediment to deionized water. Soil organic material (SOM) and calcium carbonate content were measured by the Loss on Ignition method (after Gale & Hoare, 1991), as the percent of mass lost after heating samples to 600ºC for 4 hours and 1000ºC for 2 hours. Magnetic susceptibility was measured using a Bartingon MS2 Magnetic Susceptibility Meter with three replicate measurements of high and low frequency susceptibility for each sample (after Gale & Hoare, 1991).

For XRD analysis, samples were scanned on a Bruker D8 Focus X-Ray Diffractometer with a Cu radiation source. The samples were prepared for XRD by treatment with 30% H2O2 to remove organic matter, then dried and ground finely. The samples were scanned from 5º to 75º at a resolution of 0.02 steps per second. We used MDI JADE 9 analyzing software to determine the mineral composition of the samples.

Two grams of sediment from each sample were prepared for phytholith analysis by deflocculation, removal of calcium carbonate, removal of humic acid, gravity separation and phytolith extraction (Coil et al. 2003; Piperno 2006). Samples for pollen analysis were prepared by removing coarse grain material (>100 um) from the sediment samples selected for testing, adding HCl for the removal of calcium carbonate, then adding to remove silica, after which the samples should only consist of organic matter which was then transferred to microscope slides (Van Vlack 2014).

Samples for carbon isotope analysis were finely ground, treated with 60 mL 1 M HCl, dried, rinsed with 60 mL deionized water, and dried again before final weighing and analysis using a Costech Elemental Analyzer, Conflo III, MAT253 at the UW Earth and Space Sciences IsoLab.

## Results

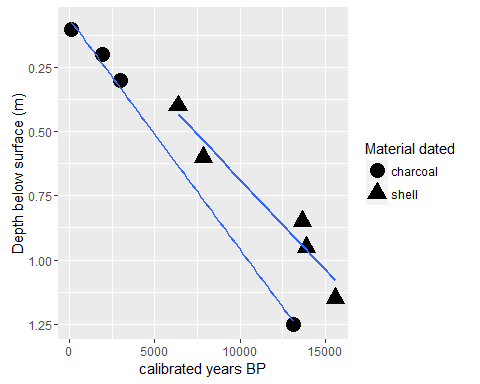
They key findings of our excavations were a faunal assemblage in a deposit with relatively few traces of post-depositional disturbance. We did not encounter any burials or animal burrows and there is very limited termite activity in the deposit. We did not reach bedrock due to time constraints.

All excavated materials are currently stored at the Silpakorn University Faculty of Archaeology's Phetchaburi campus. The raw data and code used to generate the results presented here are online at ***DOI***.

### Chronology

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Sample code | Age in years BP | 1 sd error | Material dated | Excavation unit | Depth below surface (m) | Calibrated upper 95% | Calibrated lower 95% |
| 1 | D-AMS 1140 | 149 | 25 | charcoal | 1 | 0.10 | 10.000 | 275.00 |
| 2 | D-AMS 1141 | 178 | 26 | charcoal | 2 | 0.10 | 0.000 | 291.00 |
| 21 | D-AMS 1142 | 1973 | 27 | charcoal | 4 | 0.20 | 1876.000 | 1985.00 |
| 3 | D-AMS 1143 | 2846 | 30 | charcoal | 5 | 0.30 | 2878.975 | 3054.00 |
| 4 | D-AMS 1151 | 5592 | 29 | shell | 6 | 0.40 | 6313.000 | 6424.00 |
| 5 | D-AMS 1152 | 7051 | 50 | shell | 8 | 0.60 | 7765.000 | 7961.00 |
| 6 | D-AMS 1146 | 11813 | 42 | shell | 13 | 0.85 | 13558.000 | 13732.00 |
| 7 | D-AMS 1149 | 11990 | 50 | shell | 15 | 0.95 | 13745.975 | 13980.00 |
| 8 | D-AMS 1147 | 13026 | 45 | shell | 19 | 1.15 | 15410.975 | 15736.02 |
| 9 | D-AMS 1148 | 11236 | 42 | charcoal | 20 | 1.25 | 13048.975 | 13168.00 |

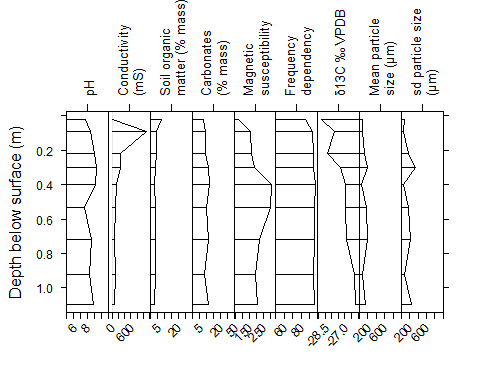
Table 1: Summary of radiocarbon dates from Khao Toh Chong

  
 Figure 1: Depth-age plot of calibrated radiocarbon dates from Khao Toh Chong

Charcoal and shell samples were dated using AMS methods by Direct AMS. Radiocarbon ages were calibrated to 95% ranges using Bchron 4.1.1 with the IntCal 09 curve (Bronk Ramsey 2009). Five charcoal samples and five shell samples returned radiocarbon age determinations. The shell's ages are offset from the charcoal ages by an average of 3015 years, indicating a substantial reservoir effect. Considering only the charcoal dates, the excavated deposit spans about 13,500 cal. BP through to about 150 cal. BP.

The depth-age relationship for the dated samples is strongly linear, suggesting a constant rate of sediment accumulation. Although there is nearly a meter between the lowest and second lowest charcoal samples, the linear tendency of the shell samples that span this gap suggest that the accumulation of sediment at the site has been constant through the Holocene.

### Geoarchaeology

  
 Figure 2: Summary of bulk sediment analysis of samples from Khao Toh Chong

Analysis of sediments collected from the 2011 Khao Toh Chong excavations show a relatively constant depositional environment. The deposit is mostly sandy silt with occassional additions of coarser sands and gravels (for example in context A-4, 0.3 m below surface). Slight fluctuations in particle size distribution and carbonate percentage suggest minor variations in contributions from alluvial and colluvial inputs (including limestone eroding from the karst tower). Overall the picture is of relatively constant and uninterrupted deposition.

#### Chemical analyses and magnetic susceptibility

The results of the basic chemical, magnetic susceptibility and particle size analyses are depicted in Figure 2. pH values at KTC are strongly alkaline throughout, with a shift occurring from pH 9.1 to 7.6 between contexts A-5 and A-6 (0.4-0.53 m below surface). Electrical conductivity (as a proxy for soluble minerals) and soil organic matter decline sharply below the surface, probably due to natural decay of organics. Soil carbonates are steady between 8% and 12% throughout. Low frequency magnetic susceptibility peaks at 308 in context A-5 (0.40 m below surface), indicating an enrichment of magnetic minerals in the deposit. This context also has the highest proportion of carbonates (12%), which would reduce magnetic susceptibility, so the change in A-5 is not a simple dilution of magnetic minerals by diagmatic minerals. Frequency dependency varys little, suggesting little change in the size of magnetic particles.

#### X-ray Diffraction

Table 2: Summary of X-ray diffraction data from Khao Toh Chong

The XRD analysis showed quartz and calcite present in all samples. Kaolinite was identified in samples in A-2, A-3, and A-6, suggesting a greater contribution of more intensely weathered sediment during the formation of those deposits. An alternative possibility is that the Kaolinite derives from ceramics found in those contexts. The proportions of Calcite in each sample support the loss on ignition results for carbonates, showing low varition throughout the sequence. Small amounts of Periclase were observed, indicating metamorphosis of the local limestone.

#### 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 83% of the variation. PCA also indicates that contexts A-7-High and Low, A-4, and B-1 are grouped together, indicating that their elemental groupings are similar. Context A-8, A-6 and A-5 are also grouped, and finally A-2 and A-3 complete the last grouping. This is important because figure 6 represents a plot of K and Mn content at KTC which are highly correlated (r=0.95). Another important relationship is found between Ba, Co, Cu, Sr, and V. There is a high correlation between Ba and each of these elements (r=0.97, 0.93, 0.94, 0.94). Finally, an important correlation between Ni and Cr is seen (r=0.94). The precision of measurement for the samples is 3.516 ppb

#### Pollen and phytolith analysis

We were unable to extract quantifiable amounts of pollen or phytoliths from the sediment samples. This is likely due to the frequent wetting and drying of the rockshelter deposit which creates poor conditions for microflora preservation.

#### Carbon isotope analysis

The δ13C values show a dominance of C3 plants, with a decreasing contribution of C4 plants in more recent times (Figure 12). This increasing contribution of C3 plants suggests and increasingly dense vegetation and wetter paleoclimates in more recent levels.

### Archaeology

The archaeological materials consist mostly of small broken pieces of earthenware and flaked stone artefacts (Figure 11). Overall, the assemblage is small and undiagnostic, however, it does demonstrate continuous occupation of the site from the earliest levels of our excavation. The isolated pieces of ceramic found in the lower levels are likely the result of post-depositional intrusions from treeroots and faunal activity.

There are several distinct changes in the sequence in each of the major categories of evidence we recovered at KTC. The stone artefact technology changed from polished adze flakes made from fine-grained sedimentary rock accompanied by ceramics in the upper levels to large flaked cores and flakes made from coarse-grain metamorphic rock in the lower levels. The ceramic assemblage also changes from black sherds in the upper levels to thicker, red sherds with frequent incised decorations in the lower levels and then ceramics disappear altogether when flaked cores and artiodactyl remains appear in the lowest levels. We interpret the lower levels, with their artiodactyl remains, flaked stone artefacts and absence of ceramics and polished stone artefacts, as likely to have been deposited during the late Pleistocene or early Holocene

### Faunal assemblage

Mammalian abundance and distribution at the rockshelter throughout the late-Pleistocene and Holocene describes a diverse array of taxa in the deposits (Tables 7 and 8). Although the majority of identified mammalian taxa represent a small sample size, there are several important patterns in the KTC assemblage. For example, the identification of large sized artiodactyl taxa, including the Sambar deer (Cervus unicolor) and Muntjak deer (Muntiacus muntjak) at the late-Pleistocene and early Holocene period suggests that a more open and drier forest habitat surrounded the rockshelter during that time (Francis, 2008).

The values for species richness per context, of the mammalian, reptilian, and piscean taxa appears to be driven primarily by the presence or absence of carapace elements belonging to the Order Testudines, likely representing species of the turtle Family Trionychidae and Emydidae, based upon comparable faunal analyses at Lang Rongrien Rockshelter (Mudar and Anderson, 2007). Identification of abundant Varanus sp., and a moderate representation of Macaca sp., occurred in abundance with Testundines elements. Overall the presence of vertebrate remains, in comparison with invertebrate remains, was low at the rockshelter. Artiodactyl remains are notably restricted to the terminal Pleistocene and early Holocene deposits.

Of the identified mollusk remains (Figure 10), nine taxa were identified to the species level while an additional fourteen were identified to a broader degree of taxonomy. Mollusk species richness varies between 0-11 species throughout the unit with a mean of 4.21 per context. Neoradina prasongi shells are of the most abundant species in the assemblage, specifically during the late-Pleistocene and early Holocene (Figure 11). When combined with shells from the Family Amblemidae and Cyclophoridae, these three taxa account for 97% of the identified mollusk taxa at KTC.

## Discussion

### Geoarchaeology

As Anderson (2005) discusses at Lang Rongrien, KTC results match patterns of rockshelter formation and occupation in this region. Aeolian and colluvial sedimentation, human activity, and weathering of site deposits provide the basis of this determination. 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 in modes taking place (Goldberg and Macphail 2006). Also, 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). Yet where a small particle size mode is seen in A-8 this is indicative of clay formation. Clay formation indicates that this must have been a period of low energy water movement or stability in the rockshelter. This conclusion is supported by Westaway et al. (2009) who describe the sites 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, and these comparisons are seen 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. (2008) 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). Alkalis 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). Interestingly in A-8 where the greatest amount of clay sized particles is seen, there is no indication of kaolinite. This suggests that there may be alternative clay minerals which the XRD analysis failed to identify. 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 clays 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 and the source of sedimentation was shifting through contexts. During A-4 and A-7-High soil formation is probably occurring on a stable surface in which aeolian and colluvial sedimentation is taking place. At A-5, A-6, and A-8 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, A-6, and A-8. This provides support to these claims.

Although particle size and XRD results provide initial implications for site formation process and the environment of sedimentation, an important aspect of human occupation is also seen at KTC. 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. These results describe the Holocene as an active period of site formation processes, human occupation, and environmental sedimentation occurring at the rockshelter.

### Faunal assemblage

KTC rockshelter has a remarkably undisturbed record of mammalian, reptilian, piscean, and molluscan assemblages present in situ deposits. The invertebrate record at the rockshelter provides a unique and detailed description of molluscan taxa and subsistence patterns during periods of occupation. Neoradina prasongi molluscs were abundant during the late-Pleistocene, but much less frequent during the mid and late Holocene.

As Brandt (1974) describes, Neoradina prasongi mollucs live in fresh-water stream habitats. At KTC, N. prasongi shells constitute the bulk of molluscan food waste in the archaeological assemblage. The period of peak discard rates for N. prasongi is approximately 9 ky cal B.P., suggesting that the most intensive use of the rockshelter occurred during this time. Utilization of this mollusk also indicates that freshwater stream habitats occurred in proximity to the rockshelter during the late-Pleistocene and early Holocene. Mudar and Anderson (2007) have suggested that during the late-Pleistocene a drier and more open environment occurred in the Krabi region, this period was also characterized by increased monsoon seasonality. During the peak mollusk discard period of the late-Pleistocene, a drier and more open environment would have allowed hunter-gatherer groups to utilize large artiodactyls in the grassland-savannah habitat, alongside N. prasongi in seasonally abundant fresh-water stream resources. Occurrence of abundant turtle or tortoise remains at KTC also suggests that fresh-water stream habitats were found in proximity to the site throughout the late-Pleistocene and early-Holocene.

At Lang Rongrien the abundant Testudines elements through time provided evidence that a previously unidentified record of Southeast Asian turtle and tortoise exploitation occurred at the rockshelter (Mudar and Anderson, 2007). This record also appears at KTC with the presence of abundant Testudines specimens throughout the late-Pleistocene and Holocene deposits. Although, at archaeological sites located near KTC and Lang Rongrien, this record was not identified. Moh Khiew Cave and Sakai Cave in southern peninsular Thailand both had very low abundances of Testudines remains during the late-Pleistocene and Holocene (Pookajorn, 1996). Generally, Testudines elements were only identified by presence or absence at these sites. Since Lang Rongrien and KTC both provide evidence of turtle and tortoise exploitation, this represents a unique fresh-water stream foraging pattern. It also suggests that fresh-water stream habitats were abundant during the late-Pleistocene and early Holocene, in the Krabi region. Furthermore, previously identified shifts in monsoon seasonality, and intensity, during this time suggests that precipitation may have increased during the early Holocene in Peninsular Thailand, matching the faunal record at KTC (Marwick and Gagan, 2011).

The declining exploitation of freshwater N. prasongi molluscs into the Holocene, reaching a minimum at 6 ky cal BP may reflect the shift from freshwater to mangrove swamp habitats in this region or a shift in the foraging dynamics of prehistoric groups (Shoocongdej, 2000 and 2010). The timing of the lowest amount of shells in the deposit coincides with the peak sea levels observed by Sinsakul (1992).Rising sea-levels throughout the Holocene would have shifted mangrove environments closer to the rockshelter overtime, which may have influenced the abundance and distribution of locally available resources and freshwater stream environments (Anderson, 1990; Horten et al., 2005; Tjia, 1996, and Sinsakul, 1992). As Barker et al. (2005) describes, archaeologists in Southeast Asia have recently tried to identify how effectively late-Pleistocene hunter-gatherers utilized tropical rainforest environments. Initial faunal data from KTC describes a pattern of hunter-gather groups utilizing a diverse range of locally available taxa in the tropical rainforest environment, suggesting that hunter-gatherers at KTC were able to effectively adapt to shifts in local environmental conditions. Additionally, radiocarbon dates suggest that once intensive harvesting of N. prasongi ends during the middle-Holocene, the emergence of rice agriculture and farming in mainland Southeast appears (Barker et al., 2005; Castillo, 2011 and White et al., 2004). Thus, declines in mollusk utilization may reflect a pattern of rising sea-levels, shifting environmental conditions, and occurrence of agriculture during the mid and late-Holocene in peninsular Thailand. Shell exploitation picks up again at KTC at 3000 cal BP, coincident with the regressive phase at 3700 to 2700 BP described by Sinsakul (1992).

Our data from KTC not only suggests that a subsistence change occurred at the Pleistocene-Holocene transition, but that foragers utilizing the rockshelter displayed a unique pattern of faunal exploitation not previously seen at archaeological sites in Thailand. As Bulbeck (2003) describes, large abundances of shellfish in rockshelter sites tend to date to the middle-Holocene when a transition towards a broad-spectrum diet occurs, not during the terminal Pleistocene. The earlier peak in the molluscan assemblage at KTC suggests that a different pattern of shellfish exploitation occurred here, one that we link to local environmental conditions. This suggests that the diversity of past human subsistence behaviours in this region may have been underestimated and broader diets may have appeared earlier than previously observed. Khao Toh Chong is a valuable archaeological and palaeoecological resource aiding the understanding of hunter-gatherer subsistence behaviours in Southeast Asia during the late-Pleistocene and Holocene.

## Conclusion

Excavations revealed continuous human occupation at KTC from recent times back to 11,000 years ago. The faunal assemblage proved the most abundant and interesting aspect of the excavated materials, and broadly confirms some of the patterns previously observed at Lang Rongrien. The most striking find is the correlation between the abundance of shellfish and the sea level, with low sea levels at the Pleistocene-Holocene transition corresponding to a peak in shellfish discard, followed by a decline in shellfish and lithic discard at 6 k BP at the same time as the peak Holocene sea levels, and then another small peak in shellfish at 3 k BP during a regressive phase. Although the changes in artefact technology were subtle during the time represented by the excavated deposit, the subsistence behaviors suggest that the intensity of site use was tied to sea levels. Ancient human occupants appeared to have found the site favorable for habitation during conditions of low sea levels. Presumably during higher sea levels they sought shelter further inland. In any case, we have shown that adaptation to sea level changes did not require major technological reorganization for the occupants at KTC, but instead was managed by adjusting settlement and land-use patterns to maintain access to resources such as shellfish.

## Acknowledgements

## References

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