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Adaptations to sea level change and transitions to agriculture at Khao Toh Chong rockshelter, Peninsular Thailand

Ben Marwick
University of Wollongong, bmarwick@uow.edu.au

Hannah G. Van Vlack
San Jose State University

Cyler Conrad
University of New Mexico

Rasmi Shoocongdej
Silpakorn University

Cholawit Thongcharoenchaikit
National Science Museum, Thailand

See next page for additional authors

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Authors

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Ben Marwick (University of Washington, University of Wollongong, bmarwick@uow.edu.au)

Hannah Van Vlack (San Jose State University)

Cyler Conrad (University of New Mexico)

Rasmi Shoocongdej (Silpakorn University)

Cholawit Thongcharoenchaikit (National Science Museum of Thailand)

Seungki Kwak (University of Washington)

2016-11-07

Abstract This study reports on an 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 deposits spanning the last 13,000 years. A suite of geoarchaeological methods suggest largely uninterrupted deposition, against a backdrop of geological data that show major changes in sea levels. Although there is a small assemblage of mostly undiagnostic ceramics and stone artefacts, there are some distinct changes in stone artefact technology and ceramic fabric. There is a substantial faunal assemblage, with changes in both the mammalian and shellfish taxa during the Pleistocene-Holocene transition, that correlate with local sea level fluctuation. This assemblage provides an opportunity to explore subsistence behaviours leading up to the transition to the Neolithic. We explore the implications for current debates on the prehistoric origins of agricultural subsistence in mainland Southeast Asia. The data highlight the importance of local contingencies in understanding the mechanisms of change from foragers to agriculturalists.

Introduction

An enduring dispute in Late Pleistocene and Holocene archaeology of mainland Southeast Asia (SEA) is the nature of the transition from forager economies to agricultural economies (Higham et al. 2011; White and Bouasisengpaseuth 2008). As a key milestone in complex human-environment interactions, this debate has many dimensions. One view in this 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 (Higham et al. 2011; Rispoli 2007). An alternative claim is that agriculture emerged from a locally contingent trajectory of changes in human-environment relationships (cf. Hunt and Rabett 2014; White 1989). While the cultivation of rice and the domestication of pigs and cattle took place in the Yangtze Valley earlier than elsewhere in mainland SEA (Chi and Hung 2010; Higham et al. 2011; Hutterer

1976), 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 (c. 50-10 k BP, all dates quoted here are uncalibrated unless otherwise noted) through to the middle Holocene (c. 6–3.5 k BP) -- is sparsely represented in the archaeological record. Southeast Asia has a rich and well-documented archaeological record for the later Holocene, when people were living more sedentary lifestyles, for example at Khok Phanom Di in Thailand and Man Bac in Vietnam (Higham and Bannanurang 1991; Oxenham et al. 2011). There are also many cave and rockshelter sites representing Pleistocene forager lifestyles, such as Tham Lod in Thailand and Xom Trai in Vietnam (Shoocongdej 2006; Moser 2001).

However, during the middle Holocene, the archaeological record in mainland SEA is particularly sparse. This 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 occurred during this time. Ceramics appeared in many parts of Southeast Asia; domesticated plants such as millet and rice appeared; stone artefact technologies transitioned from mostly flaked to mostly ground stone artefacts; and 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). But the sparse representation of this period in the archaeological record means that questions of the timing and character of these changes remain difficult to answer.

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 relatively detailed history of regional sea level change. This provides a unique opportunity to investigate locally contingent factors, such as the effect of sea level changes on human subsistence behaviours during the transition from forager to agricultural economies. We report on a geoarchaeological analysis of the site to provide a local environmental context of the human occupation. This analysis also aids our understanding of site formation processes and artefact taphonomy.

Background

During the Holocene, the primary loci of archaeological evidence in SEA changes from caves and rockshelters to open-air sites (cf. Conrad 2015; Higham 2014). This shift in settlement behaviours has been proposed to be a direct result of the transition to agriculture (White 1995), and is evident in surrounding regions. 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 6 k BP in Xianrendong and 5–4 k BP 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 (Chi and Hung 2012; Fu 2002). Occupation of these sites, characterized by the largest, Dingsishan, spans 10-5.5 k BP. The sites include pottery manufacturing workshops, cemeteries 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 cemeteries, and at a much later date an agricultural economy. The pottery and burial practices of the Dingsishan shell middens are 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 (Viet 2007). These sites were occupied by hunter-gatherer populations during 7.5–4 k BP (Viet 2007). Polished axes, pestles and mortars suggest cultivation, but clear evidence of food production only appears around 3.8-3.5 k BP at sites such as Man Bac with domesticated pig remains (Sawada et al., 2011).

While this gives a picture of continuity between hunter-gatherers and agriculturalists in southern China and parts of northern Vietnam, elsewhere in mainland Southeast Asia continuity is harder to see. Hang Boi cave in inland northern Vietnam has a thick shell midden that spans only 12.3-10.6 k BP (Rabett et al. 2011). At sites in Thailand, there is a gap between cave occupation and open site occupation. At Lang Rongrien rockshelter, in southern Thailand, the most recent dated occupation is about 8 k 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 8 k BP (Marwick and Gagan 2011; Shoocongdej 2006). At Laang Spean rockshelter in Cambodia, the most recent occupation in 5 k 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; Lloyd-Smith 2014). A key challenge here is that the human burials disturb the stratigraphy, making it difficult to assess continuity between forager occupation and later activity. There is also the possibility that open air sites were continuously occupied in the same way, but have been destroyed due to weather exposure and marine inundation. At extant open air sites, the record starts at around 4 k BP, for example at Khok Phanom Di (Higham and Thosarat 2004) and Nong Nor (Higham and Thosarat 1998), both near the Bang Pakong River, southeast of Bangkok, and at Ban Non Wat in northeast of Thailand (Higham and Kijngam 2011). Occupation at these sites is characterized by human 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 (Voris 2000; Sinsakul 1992). The most important sea level event for this region during this time is the mid-Holocene highstand. This highstand differs in timing and magnitude across the Indo-Pacific (Horton et al. 2005). Documented accounts of this highstand occur in the Straits of Malacca (Streif 1979; Geyh et al. 1979; Hesp et al. 1998), Phuket in southwest Thailand (Scoffin and Le Tissier 1998), and the Malay Peninsula (Tjia 1996; Kamaludin 2001). A combination of the geoidal eustacy and hydro- and glacio-isostacy activity in this region caused the sea level highstand, with magnitude up to +5 m in some locations. Sinsakul (1992) has summarised 56 radiocarbon dates of shell and peat from beach and tidal locations to estimate a Holocene sea level curve for peninsula Thailand that starts with a steady rise in sea level until about 6 k BP, reaching a height of +4 m amsl (above mean sea level). Sea levels then regressed until 4.7 k BP, then rising again to 2.5 m amsl at about 4 k BP. From 3.7 k to 2.7 k BP there was a regressive phase, with transgression starting again at 2.7 k BP to a maximum of 2 m amsl at 2.5 k BP. Regression continued from that time until the present sea levels were reached at 1.5 k BP.

The evidence for these sea level changes comes from direct dating of marine shells and peat deposits at geological sites in peninsular Thailand (Sinsakul 1992). Tjia (1996) collected over 130 radiocarbon ages from geological deposits of shell in abrasion platforms, sea-level notches and oyster beds and identified a +5 m highstand at ca. 5 k BP in the Thai-Malay Peninsula.

Scoffin and Le Tissier (1998) dated 11 intertidal reef-flat corals (microatolls) to identify a +1 m highstand at about 6 k BP in Phuket, southern Thailand. Caution is required when inferring a single sea level curve for this region because the altitudinal range of the indicators is not completely known, their degree of precision is not uniformly known, and the number of data points are small (Horton et al. 2005; Woodroffe and Horton 2005). However, Sathiamurthy and Voris (2006) summarise the evidence described above as indicating that between 6 and 4.2 k BP, the sea level rose from 0 m to +5 m along the Sunda Shelf, marking the regional mid-Holocene highstand. Following this highstand, the sea level fell gradually and reached the modern level at about 1 k BP. Therefore, the low landscape, such as in the Pang Nga region, makes the coastal karst of Krabi well-suited for assessing local environmental change on human groups during a time of major transitions in subsistence, from foragers to agriculturalists.

Previous research into archaeological correlates of these sea level changes in peninsular Thailand have been summarized by Anderson (2005). He describes faunal evidence from Lang Rongrien that has increases in marine shellfish abundances around 7.5 k BP and between 4.0 k and 2.5 k 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 peninsular Thailand. For example, Moh Khiew in Krabi with human remains at 25 k BP (Auetrakulvit et al. 2012; Chitkament 2007; Matsumara and Pookajorn 2005; Pookajorn 1994), Tham Khao Khi Chan in Surat Thani Province has occupation layers dating from 6.06 k BP to 4.25 k BP (Srisuchat and Srisuchat 1992). Buang Bap, also in Surat Thani, has faunal remains including marine shellfish dating between 6 k and 5 k BP (Srisuchat and Srisuchat 1992). Pak Om has a dense and diverse archaeological deposit, but its two dates of 9.35 k and 3.01 k 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 5.25 k and 4.75 k BP (Srisuchat and Srisuchat 1992). Finally, there is the Tham Sua shell midden in Krabi that is a deposit of marine shell greater than one meter deep and with a basal date of 6.44 k 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 at these sites provides neither a clear picture of stratigraphic integrity, nor their subsistence behaviour. The goal of our work at Khao Toh Chong was to build on this previous research by analysing an assemblage spanning the Holocene, and by conducting geoarchaeological analyses at the site to assess stratigraphic integrity and provide local environmental context of the human occupation.

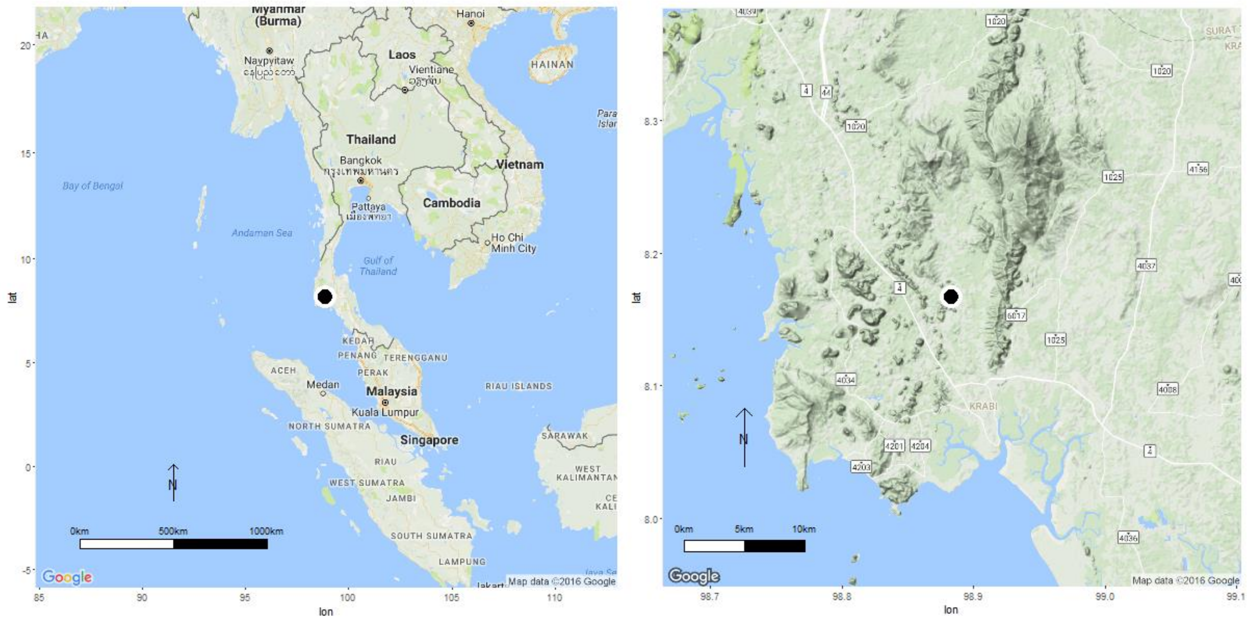

Figure 1: Maps of the region and local area of the Khao Toh Chong rockshelter. The majority of the landscape between the site and the coast is <30 m above the current sea level. Map data are from Google and DigitalGlobe, via ggmap (Kahle and Wickham 2013).

Methods

Excavation methods

In June-July 2011, we excavated two areas of 2x2 m to a depth of 1.6 m below the modern ground surface at Khao Toh Chong rockshelter (Figure 1). Our review of previous work in the region indicated that stratigraphic units often exceed 0.2 m, so we used semi-arbitrary excavated units of 0.05 m to subdivide the stratigraphic units and improve the spatial and chronological control of our finds. Our excavation units are semi-arbitrary because if we encountered a change in the deposit or the archaeology in the middle of an arbitrary excavation unit (i.e., before it was 0.05 m deep), then we stopped digging that unit immediately and began another unit to ensure that we captured the change in conditions as accurately as possible. After the excavation was complete, we grouped excavated units with similar depositional qualities for comparison and analysis of the archaeological and geoarchaeological data (this process is described in detail in Van Vlack 2014). Careful observations were made for traces of disturbance that might have mixed archaeological materials from different time periods. Excavated sediments were sieved using steel sheets with 5 mm and 10 mm diameter circular openings.

Khao Toh Chong rockshelter 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 some protection from the wind and rain. These boulders also trap 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 1.3 m below the surface. In trench B, excavations were obstructed by bedrock in the northwest and southwest quadrants. Subsequently, excavation depths in trench B extended to approximately 2.0 m in the northeast and southeast quadrants of the trench. Charcoal and shells were collected from hearths encountered during excavation for radiocarbon dating. Charcoal and shell samples were dated using AMS methods by the Direct AMS laboratory in Seattle, WA, USA. Radiocarbon ages were calibrated to 95% ranges using Bchron 4.1.1 with the IntCal13 curve (Haslett and Parnell 2008; Parnell et al. 2008; Reimer et al. 2011). Our archaeological and faunal analysis reported here is based on data from the southwest quadrant of trench A.

Geoarchaeological methods

To investigate changes in the environment of deposition that assist in interpreting the archaeological record, we analysed several physical and chemical attributes of the sediment in the archaeological deposit. Particle size distributions, pH, electrical conductivity (EC), soil organic material (SOM), calcium carbonate content, magnetic susceptibility, X-ray diffraction (XRD) and inductively coupled plasma-atomic emission spectrometry (ICP-AES) can be indicators of changes in the sources of sediments accumulating at the site and the mechanisms of accumulation. Carbon isotopes, fossil pollen and phytoliths are also indicators of vegetation change. In combination, these physical and chemical attributes can help to reveal change or stasis in environmental conditions during the time of human occupation at the site, which can help us understand the relationship between human behaviour and the mid-Holocene highstand event.

Bulk sediment samples were collected from a column taken from the south wall of excavation trench A. Sub-samples of sediment (1 g) from each context were individually dried at 60°C for 24 hours for particle size analysis. These sub-samples were sieved to remove the >2 mm particles, and the carbonates were removed by washing the sample in 20 mL of 1 M HCl. Samples were then centrifuged and treated with 30 mL of 30% H_2O_2 for an hour 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 a Horiba LA-950 at the University of Washington (UW) Materials Science Department. A quartz refraction index of 1.458 was used during analysis and the R package G2Sd v2.1.5 was used to compute summary statistics (Fournier et al. 2014).

We measured pH and EC using a portable Oakton Waterproof Dual Parameter PCSTestr 35 on sub-samples 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 (Gale and 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 Bartington MS2 Magnetic Susceptibility Meter with 10 cm^3 of sediment analyzed in sample pots at low and high frequency following Dearing (1999). Three replicates for each sample measurement of low and high frequency susceptibility were taken following Gale and Hoare (1991).

Organic carbon isotopes were analysed by sub-sampling 2 g of sediment which was dried at 60°C for 24 hours, then sieved to remove the >2 mm particle size fraction (Hartman 2011), and macro-organics were manually picked out and discarded. After sieving the samples were ground for 5 minutes using a mortar and pestle. Mineral carbonates were removed by placing the samples in 60 mL of 1 mol HCl for 24 hours, stirring every 10 hours of the 24 hour period

(Millwood and Boutton, 1998). The HCl was rinsed from the samples by adding 60 mL of deionized water into the samples for one minute and then drying at 60°C for 48 hours; this step was repeated three times. Isotope measurements were conducted using a Costech Elemental Analyzer, Conflo III, MAT253 at the UW Earth and Space Sciences IsoLab.

For XRD analysis, following McGrath et al. (2008), we sub-sampled 2 g of >2 mm sediment and ground it to a fine powder. Next 20 mL of 30% H_2O_2 was used to remove organic matter. After effervescence, sediment samples were dried for another 60°C for 24 hours. Samples were ground again, then scanned on a Bruker D8 Focus X-ray Diffractometer from 5° to 75° 2θ with a Cu radiation source at resolution 0.02° steps per second with 40 kV and 40 mA power output. MDI Jade 9 software was used to identify minerals.

For compositional analysis by ICP-AES a 1 g sub-sample of sediment was prepared with an acid digest extraction, following Misarti et al. (2011). The sample was added to 10 mL of HNO_3 and heated at 90°C for 15 minutes. Another 5 mL of HNO_3 was next added and heated at 90°C for 60 minutes. Next, deionized water, 30% H_2O_2 and 10 mL HCl were added and heated for 60 minutes. The samples were then diluted with deionized water and filtered before ICP-AES analysis. This acid digest provides a broad spectrum of elements in a known volumetric concentration, suitable for ICP-AES analysis (Balcerzak, 2002; Carter, 1993). The samples were analyzed in a Perkin Elmer Optima 8300DV in the UW Chemistry Department.

We were unable to extract quantifiable amounts of fossil pollen from the sediment samples (further details are reported in Van Vlack 2014). This is due to the frequent wetting and drying of the rockshelter deposits which created poor conditions for microfloral preservation. There was inorganic preservation of microflora, based on the presence of phytoliths, but these samples have not yet been analyzed (Van Vlack 2014).

Zooarchaeological methods

Methods for zooarchaeological analysis of the faunal remains from trench A-southwest quadrant of KTC are reported in Conrad et al. (2013) and Van Vlack (2014). To summarise, we conducted faunal identification using comparative collections at the Natural History Museum, National Science Museum of Thailand. Comparative and reference literature included Auetrakulvit (2004), Brandt (1974), and Lekagul and McNeely (1977). Quantification of the assemblage followed Lyman (2008) for taxonomic abundance (NISP and MNI). Analysis of Shannon's index was modeled after Magurran (2004), and Pielou's index was modeled after McCune et al. (2002).

Reproducibility and open source materials

To enable re-use of our materials and improve reproducibility and transparency according to the principles outlined in Marwick (2016), we include the entire R code used for all the analysis and visualizations contained in this paper in our SOM at https://dx.doi.org/10.6084/m9.figshare.2065602.v1. Also in this version-controlled compendium are the raw data for all the tests reported here, as well as a custom R package (Wickham 2015) containing the code written for this paper. All of the figures, tables and statistical test results presented here can be independently reproduced with the code and data in this repository. In our

SOM our code is released under the MIT licence, our data as CC-0, and our figures as CC-BY, to enable maximum re-use (for more details about these licences, see Marwick 2016).

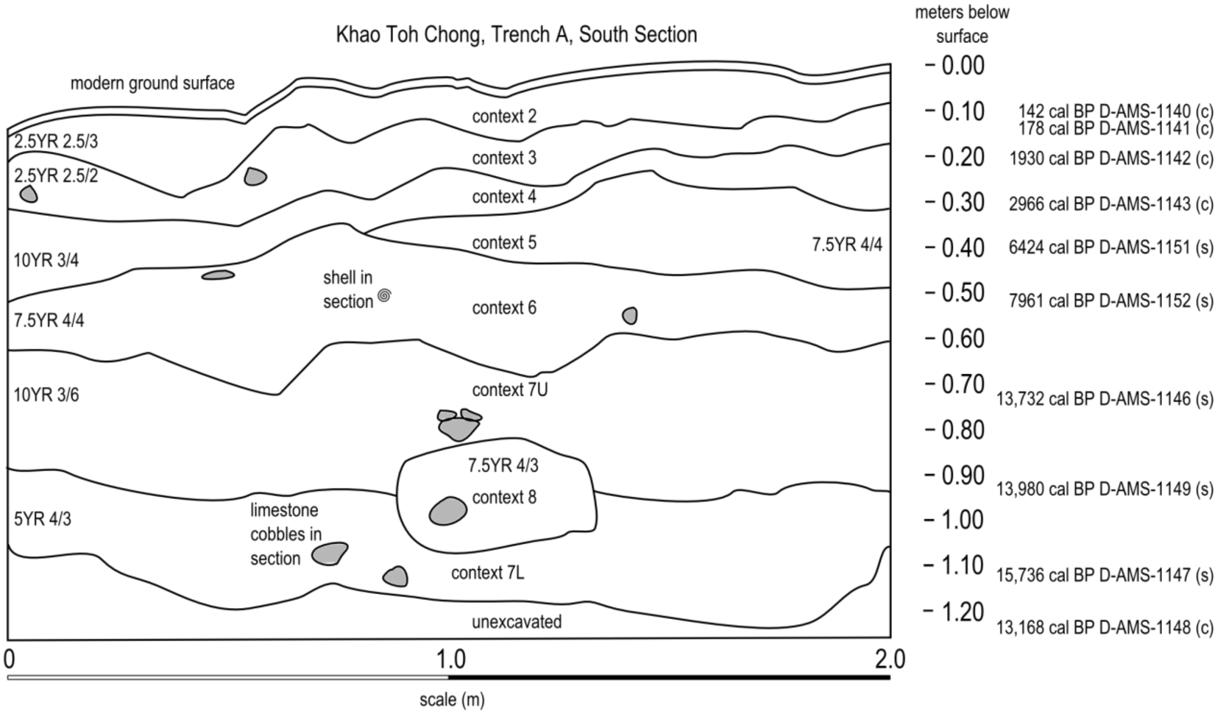

Figure 2: South section of Khao Toh Chong rockshelter trench A. The radiocarbon ages are the midpoints of the 95% calibrated age intervals. (c) indicates charcoal and (s) indicates shell as the material dated.

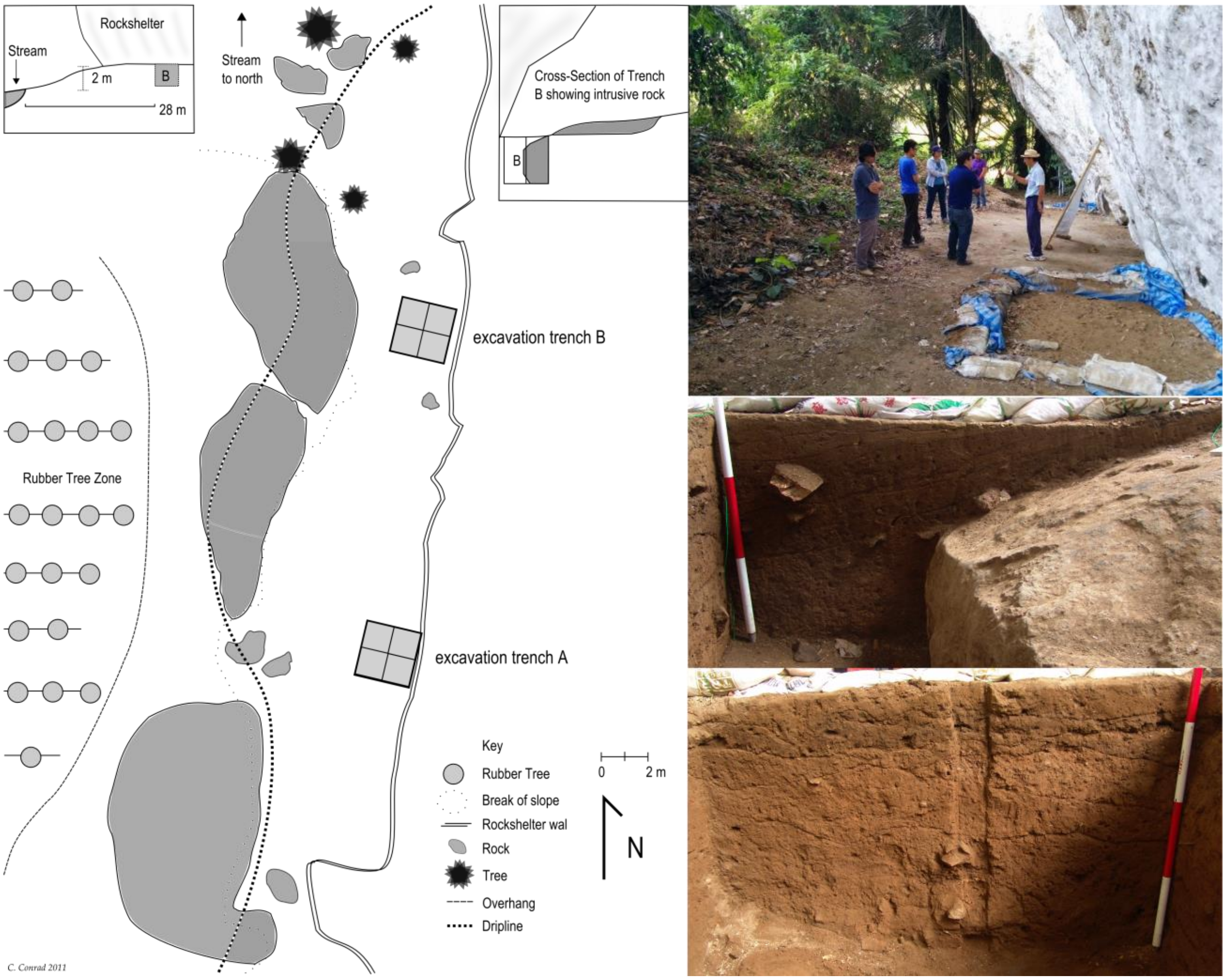

Figure 3: Plan of Khao Toh Chong rockshelter. The top image shows a view looking North, with trench A in the foreground. The middle image shows the South section of trench B. The bottom image shows the South section of trench A

Results

The key findings from our field observations during the exacavation were that the faunal assemblage was deposited with relatively few macroscopic traces of post-depositional disturbance (Figure 3). We did not encounter any human burials or animal burrows and there was very limited termite activity visible in the deposit. We did not reach bedrock, or sterile deposits, due to time constraints. All excavated materials are currently stored at the Silpakorn University Faculty of Archaeology's Phetchaburi campus.

Table 1: Summary of radiocarbon dates from Khao Toh Chong

Sample code	Age in years BP	1 sd error	Material dated	Excavation unit	Context	Depth below surface (m)	Calibrated upper 95%	Calibrated lower 95%
D-AMS	149	25	charcoal	1	1	0.10	10	275

1140								
D-AMS 1141	178	26	charcoal	2	2	0.10	0	291
D-AMS 1142	1973	27	charcoal	4	3	0.20	1876	1985
D-AMS 1143	2846	30	charcoal	5	4	0.30	2879	3054
D-AMS 1151	5592	29	shell	6	5	0.40	6313	6424
D-AMS 1152	7051	50	shell	8	6	0.53	7765	7961
D-AMS 1146	11813	42	shell	13	7U	0.72	13558	13732
D-AMS 1149	11990	50	shell	15	8	0.95	13746	13980
D-AMS 1147	13026	45	shell	19	7L	1.15	15411	15736
D-AMS 1148	11236	42	charcoal	20	7L	1.25	13049	13168

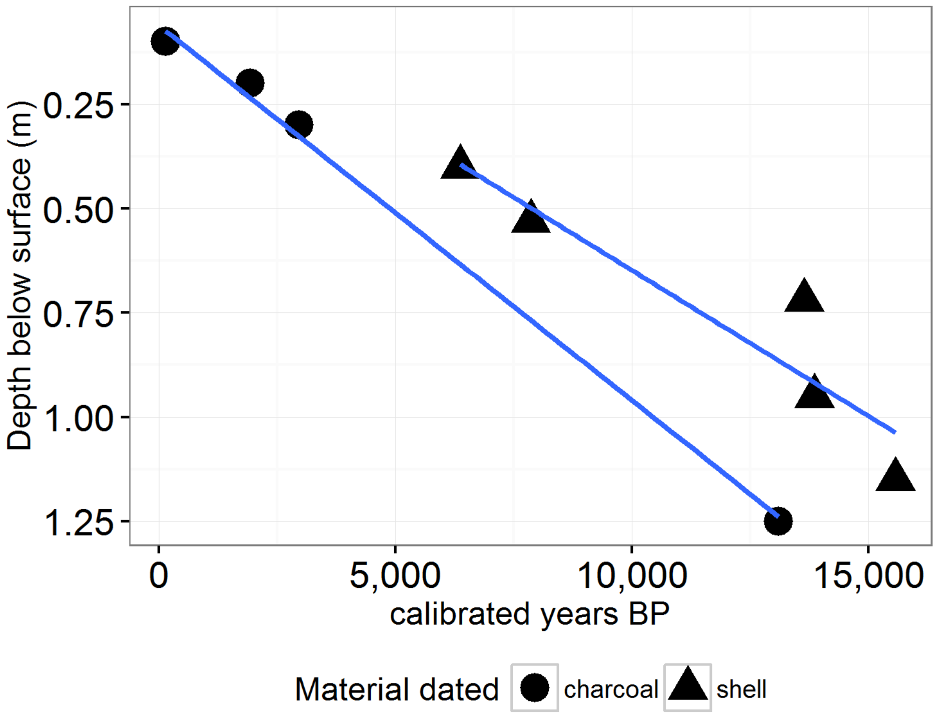

Figure 4: Depth-age plot of calibrated radiocarbon dates from archaeological excavations at Khao Toh Chong

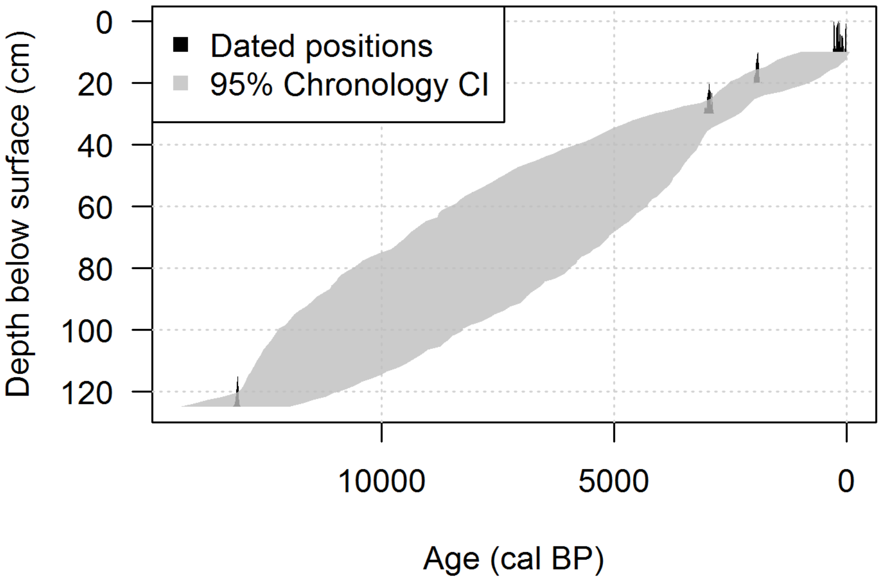

Figure 5: Depth-age model of calibrated radiocarbon dates on charcoal from Khao Toh Chong. The grey shaded area indicates the 95% confidence interval of the age at a given depth, computed by a non-parametric chronology model fitted to age/deoth data according to the Compound Poisson-Gamma model of Haslett and Parnell (2008). The black areas show the distribution of the calibrated ages.

Chronology

Five charcoal samples and five shell samples returned radiocarbon age determinations (Table 1). The ages of these shells are offset from the ages of the charcoal by an average of 2945 years, indicating a substantial reservoir effect. Considering only the charcoal dates, the excavated deposit spans from before 13.5 k cal. BP through to about 0.15 k cal. BP (Figure 5).

The depth-age relationship for the dated samples is strongly linear, suggesting a constant rate of sediment accumulation (Figure 4). 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. Using the ages of the charcoal samples, we computed a non-parametric chronology model to estimate the approximate ages of undated excavation units. Using this model, we estimate the date of the lowest excavation level to be approximately 16.8 k cal. BP.

Table 2: Correlations of geoarchaeological variables at KTC. Cell values are Pearson's product-moment correlation coefficient and values in parentheses are p-values. Strong significant correlations are in bold. EC = electrical conductivity, SOM = Sediment organic matter, fd = frequency dependency, mean size = mean sediment particle size, sd size = standard deviation of sediment particle size.

	EC	SOM	$CaCO_3$	X_{lf}	fd	$d^{13}C$	mean size	sd size
pH	0.09 (0.81)	-0.52 (0.15)	0.61 (0.08)	0.17 (0.66)	0.17 (0.67)	0.16 (0.69)	0.07 (0.85)	0.4 (0.29)
EC		-0.09 (0.83)	-0.15 (0.7)	-0.17 (0.65)	0.41 (0.28)	-0.26 (0.5)	-0.28 (0.46)	-0.23 (0.54)
SOM			-0.69 (0.04)	**-0.76 (0.02)**	-0.26 (0.49)	**-0.81 (0.01)**	-0.35 (0.35)	-0.39 (0.3)
$CaCO_3$				0.66 (0.05)	-0.33 (0.38)	0.47 (0.2)	0.38 (0.31)	0.47 (0.2)
X_{lf}					-0.28 (0.47)	0.64 (0.06)	0.22 (0.58)	0.07 (0.86)
fd						0.18 (0.64)	0.03 (0.94)	0.14 (0.71)
$d^{13}C$							0.27 (0.48)	0.26 (0.5)
mean size								**0.9 (0)**

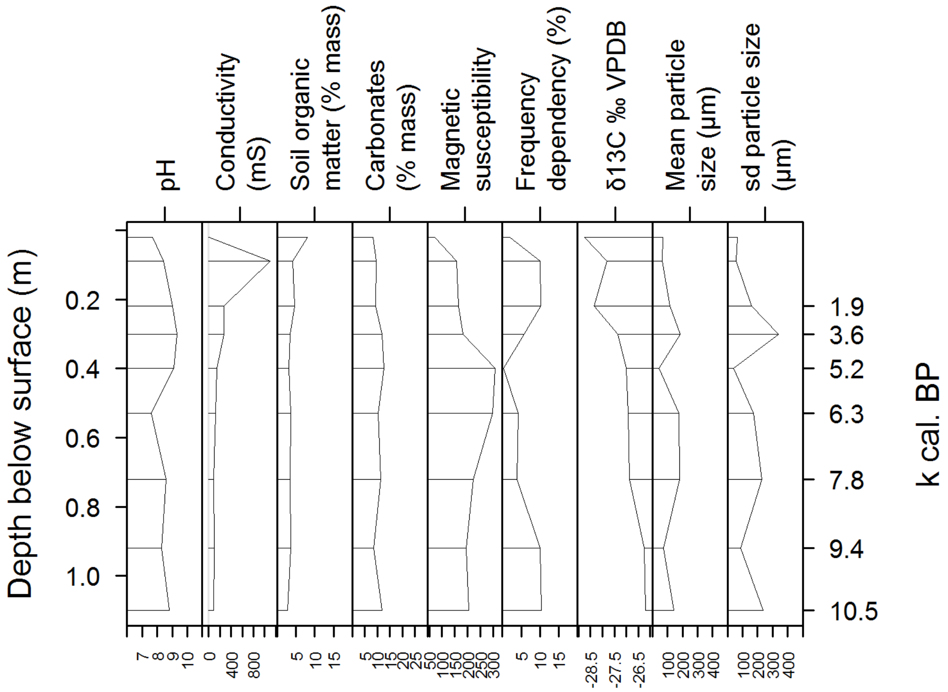

Figure 6: Summary of bulk sediment analysis of samples from Khao Toh Chong. Magnetic susceptibility is reported as low frequency mass specific units 10^{8} m^{3} kg^{-1}. Right side axis shows modelled ages at sample location depths

Geoarchaeology

Analysis of sediments collected from the 2011 Khao Toh Chong excavations show a relatively constant depositional environment. The deposit is mostly sandy silt with occasional additions of coarser sands and gravels (for example in context 4 of trench A, 0.3 m below surface). Slight fluctuations in particle size distribution and carbonate percentage likely reflect minor variations in contributions from alluvial, fluvial and colluvial inputs -- including limestone eroding from the karst tower (Gale and Hoare 1991). Overall, the picture is of relatively constant and uninterrupted deposition.

Chemical analyses and magnetic susceptibility

The results of the chemical, magnetic susceptibility and particle size analyses are depicted in Figure 6. The pH values at KTC are strongly alkaline throughout, with a shift occurring from pH 9.1 to 7.6 between contexts 5 and 6 of trench A (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, reflecting a continuous contribution from the limestone rock of the shelter. Low frequency magnetic susceptibility peaks in context 5 of trench A (0.40 m below surface), indicates an enrichment of magnetic minerals in the deposit. Context 5 has the highest proportion of carbonates (12%), which would reduce magnetic susceptibility; the change in this context is not a simple dilution of magnetic minerals by diamagnetic minerals.

Carbon isotope analysis

The δ^{13}C values at KTC range between -28.75‰ and -26.2‰, with values becoming increasingly depleted in more recent times (Figure 6). The tissues of C_3 plants have δ^{13}C values ranging from −32‰ to −20‰, while those of C_4 plants range from −17‰ to −9‰ (Deines 1980). This indicates an overall dominance of C_3 plants, suggestive of forested-grassland vegetation, including evergreen trees and shrubs, surrounding the site (DeNiro 1987; Yoneyama et al. 2010).

Table 3: Summary of X-ray diffraction data from Khao Toh Chong. Units are percent mass.

Context	Quartz	Calcite	Kaolinite	Periclase
B1	79.6	12.6	0.0	7.9
A2	66.1	11.1	19.9	2.9
A3	64.3	12.2	19.6	4.0
A4	89.5	7.8	0.0	2.7
A5	92.3	7.7	0.0	0.0
A6	68.9	9.5	19.0	2.6
A7U	80.5	19.5	0.0	0.0
A8	81.4	12.9	0.0	5.7
A7L	87.2	10.3	0.0	2.5

X-ray Diffraction

The XRD analysis showed quartz and calcite present in all samples, indicating a similar source of sediments throughout the depositional history of the site. Kaolinite was identified in samples from contexts 2, 3, and 6, suggesting a greater contribution of more intensely weathered sediment during the formation of those deposits (Alam et al. 2008). 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 variation throughout the sequence. Small amounts of periclase were observed, indicating metamorphosis of the local limestone.

Table 4: Elemental concentration by ICP-AES, all measurements are in ppm

	Ca	Fe	K	Mg	Mn	Na	Sr	Ti	Zn
B1	5.68	5.19	4.29	5.01	4.24	4.45	2.30	2.89	2.94
A2	5.25	4.94	3.88	4.80	3.90	3.94	1.98	2.82	2.61
A3	5.17	4.85	3.80	4.70	3.81	3.71	1.94	2.71	2.49
A4	5.64	5.18	4.17	5.00	4.14	3.91	2.40	3.14	2.85
A5	5.48	5.04	3.90	4.86	3.95	3.61	2.21	2.87	2.68
A6	5.46	5.10	3.88	4.91	4.01	3.49	2.19	2.77	2.77
A7U	5.61	5.26	4.23	5.09	4.15	3.56	2.47	3.18	2.93
A8	5.44	5.15	3.99	4.77	4.05	3.27	2.27	2.96	2.68
A7L	5.57	5.23	4.14	4.86	4.13	3.35	2.49	3.07	2.82

Table 5: Correlation matrix of elements analysed by ICP-AES. Cell values are Pearson's product-moment correlation coefficient and p-value are in parentheses. Strong significant correlations are in bold.

	Fe	K	Mg	Mn	Na	Sr	Ti	Zn
Ca	**0.92 (0)**	**0.89 (0)**	**0.86 (0)**	**0.95 (0)**	0.2 (0.61)	**0.89 (0)**	**0.71 (0.03)**	**0.95 (0)**
Fe		**0.86 (0)**	**0.76 (0.02)**	**0.94 (0)**	-0.09 (0.81)	**0.97 (0)**	**0.82 (0.01)**	**0.91 (0)**
K			**0.82 (0.01)**	**0.95 (0)**	0.35 (0.36)	**0.82 (0.01)**	**0.76 (0.02)**	**0.92 (0)**
Mg				**0.81 (0.01)**	0.34 (0.37)	**0.71 (0.03)**	0.66 (0.05)	**0.93 (0)**
Mn					0.24 (0.54)	**0.86 (0)**	**0.71 (0.03)**	**0.96 (0)**
Na						-0.19 (0.62)	-0.16 (0.67)	0.25 (0.51)
Sr							**0.88 (0)**	**0.85 (0)**
Ti								0.7 (0.04)

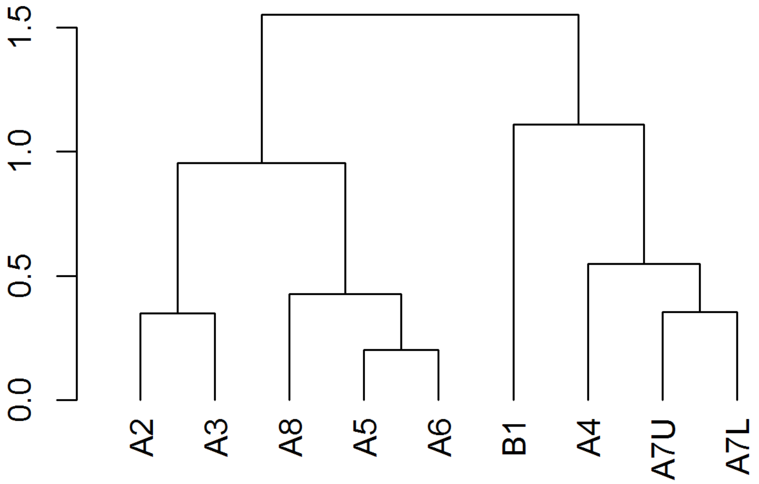

Figure 7: Dendrogram of depositional contexts from Khao Toh Chong, showing a hierarchical cluster analysis of ICP-AES results of sediment samples

Inductively coupled plasma-atomic emission spectrometry

Results from ICP-AES analyses are presented in Table 4, with the concentrations of elements of interest to geogenic and anthropogenic sources including Si, Ca, Sr, Mn, Fe, Zn, Na, K, Mg, and Ti (Araujo et al. 2008; Arroyo-Kalin et al. 2009; Cook 1965; Costa and Kern 1999; Eidt 1985; Knudson et al. 2004; Middleton 2004; Middleton and Price 1996; Woods 1984; Woods and Glaser 2004). The majority of these elements are strongly positively correlated (Table 5), and there are no significant negative correlations.

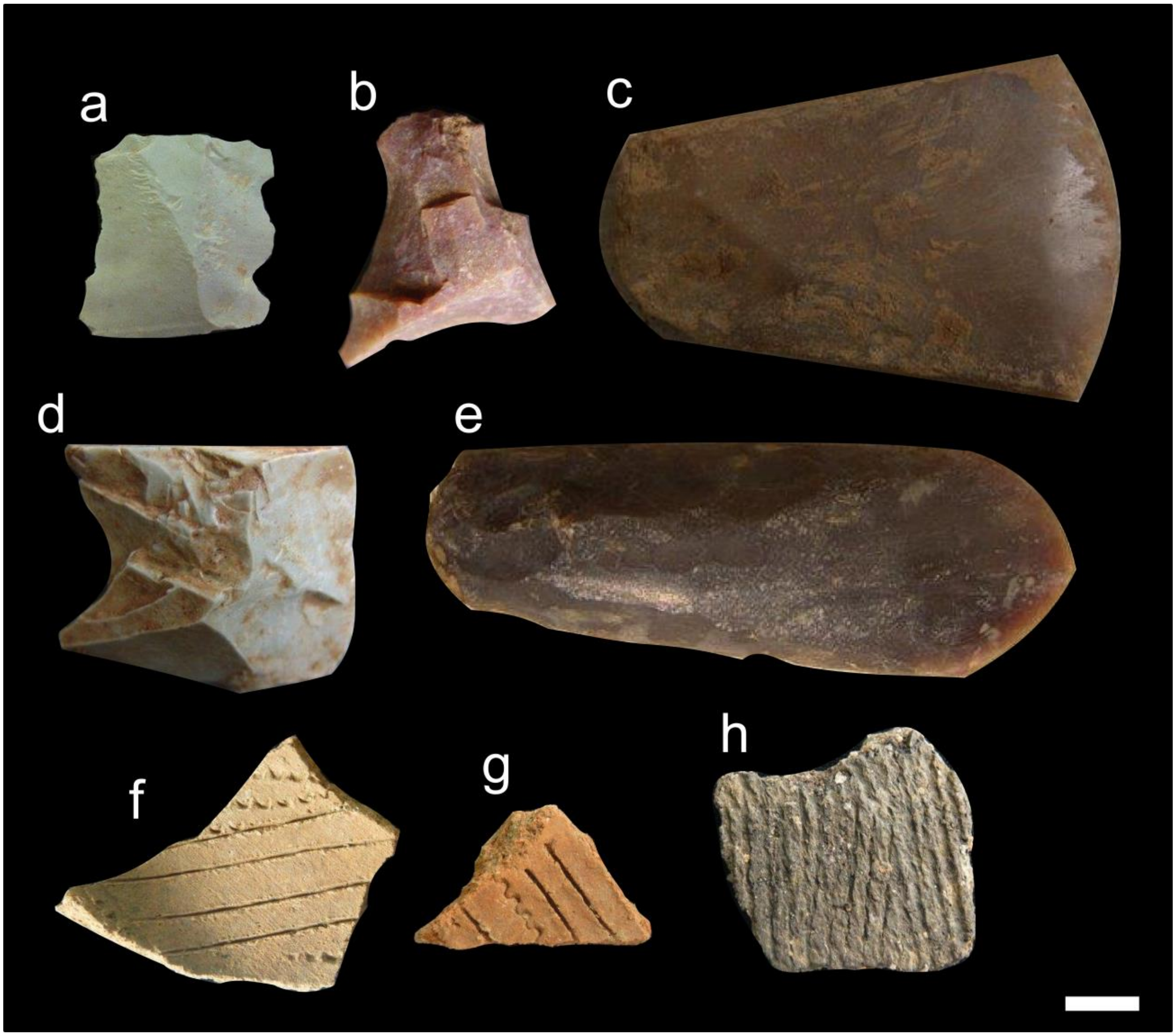

Figure 8: Examples of ceramics, ground and flaked stone artefacts from Khao Toh Chong. a) chert flake (EU19), b) quartzite flake (EU18), c) quartzite polished adze (EU5), d) chert flake (EU18), e) quartzite polished adze (EU5), f & g) ceramic sherd with incised and infilled decoration (EU3), h) cord-marked ceramic (EU4)

Table 6: Summary of ceramics and stone artefacts recovered from Khao Toh Chong.

Context	Lithic count (n)	Lithic mass (g)	Ceramic count (n)	Ceramic mass (g)
1	2	18.7	99	176.2
2	0	0.0	1	0.9
3	0	0.0	194	417.9
4	20	73.6	162	383.7
5	11	19.4	42	67.0
6	2	2.7	34	111.3
7U	2	6.3	24	38.1
8	3	3.5	0	0.0

7L 8 57.8 2 42.2

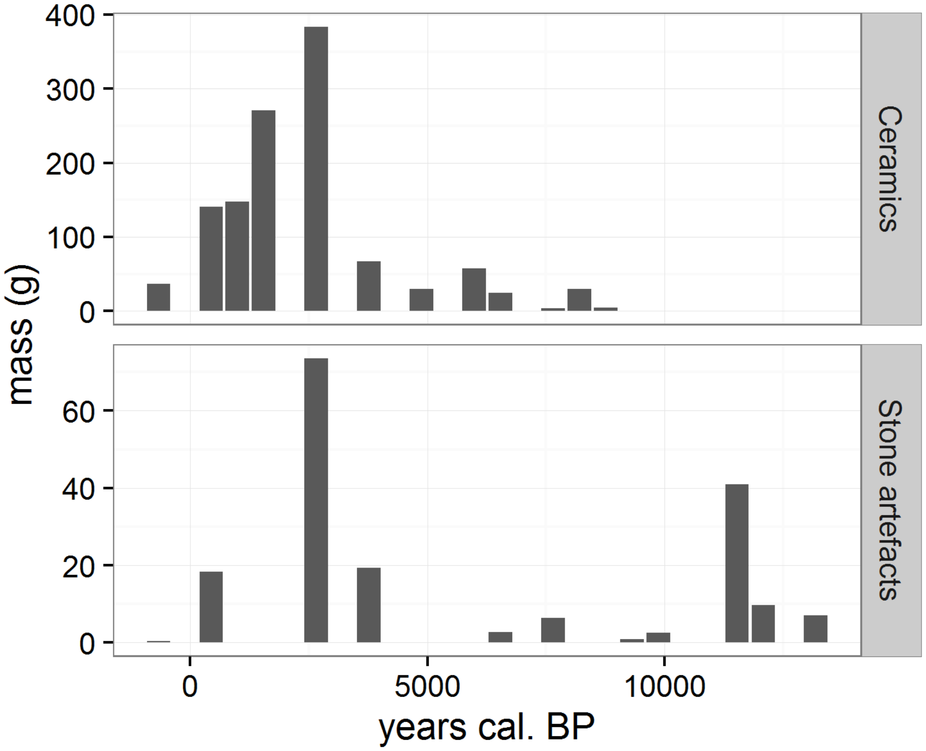

Figure 9: Distribution of ceramics and stone artefacts in each excavation unit over time at Khao Toh Chong. Ages older than 13,000 cal BP have been extrapolated using the age-depth model described above.

Material culture

The archaeological materials consist mostly of small broken pieces of ceramic and flaked stone artefacts (Table 6, Figure 8, Figure 9). The stone flakes are relatively small, unretouched and typically have little to no dorsal cortex. There are no unambiguous signs of Hoabinhian technology, such as unifacially flaked flat ovoid cobbles, or flakes that might have been removed from these cobbles. Two complete polished adzes were found in the upper layers, and several flakes with traces of abrasion on the platforms were also recovered, indicating on-site adze manufacturing. Ceramic decorations at KTC are typical for the region, including cord-marked and parallel incised and infilled lines (Rispoli 2007; Anderson 1990; Pookajorn 1994). There are no significant correlations between the artefact counts and masses and any of the geoarchaeological variables. Artefacts were found in every excavation unit, but we suspect that ceramics in the lower part of the deposit may be post-depositional vertical displacement due to trampling and frequent wetting and drying of the deposits. Frequent episodes of wetting and drying are indicated by the extensive decomposition of fossil pollen and macrbotanical remains. However, disturbance is not a significant factor at KTC as supported by the mineralogical and sediment particle size data. Similar depositional processes occurred at Spirit Cave in northern Thailand (Gorman 1970). For example, radiocarbon dating of residues on ceramics from Spirit Cave obtained much younger dates (c. 3 k BP) than the stratigraphically associated charcoal samples (c. 7.6 k BP; Lampert et al. 2003). This shows that there is probably some mixing in the stratigraphic layers at Spirit Cave. Comparatively, the KTC ceramics may have also shifted vertically over time due to the episodes of regional increases in precipitation from either the water table or seasonal monsoonal storms.

The archaeological sequence at KTC shows signs of change over time, similar to the geoarchaeological sequence described above, indicating that disturbance has not been so extensive as to completely erase time-ordering of artefacts in the deposits. The stone artefact technology changes from to large flaked cores and flakes made from coarse-grained metamorphic rock in the lower levels to polished adze flakes made from finer-grained rock in the upper levels. The ceramic assemblage also changes from thick, red sherds with frequent incised decorations in the lower levels to predominantly black sherds in the upper levels. However, the small number of artefacts in the deposit overall limits the degree to which we can distinguish these changes as part of a major regional trend or idiosyncratic use of this site.

Table 7: NISP of mammal, reptile and fish remains recovered from Khao Toh Chong (MNI values in parentheses, columns are depositional contexts formed by grouping consecutive spits with similar qualities).

Taxon	1	2	3	4	5	6	7U	8	7L	Total
Osteichthyes	5 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	7 (2)
Testudines	21 (1)	1 (1)	43 (1)	17 (1)	11 (1)	43 (2)	32 (1)	4 (1)	43 (1)	215 (10)
Varanus sp.	1 (1)	0 (0)	3 (1)	7 (1)	6 (1)	14 (1)	2 (1)	2 (1)	4 (1)	39 (8)
Pythonidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	1 (1)
Primates	2 (1)	0 (0)	1 (1)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	2 (1)	6 (4)
Macaca sp.	0 (0)	0 (0)	6 (1)	0 (0)	0 (0)	0 (0)	8 (1)	1 (1)	2 (1)	17 (4)
Trachypithecus obscurus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	2 (1)
Rodentia	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	3 (1)	0 (0)	0 (0)	4 (2)
Rattus remotus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (1)
Cannomys badius	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1)	2 (1)
Atherurus macrourus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (1)
Carnivora	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	1 (1)
Tragulidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	1 (1)
Cervus unicolor	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	1 (1)
Muntiacus muntjak	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1)	3 (1)	5 (2)

Bovinae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	1 (1)
Total	29 (4)	1 (1)	54 (5)	24 (2)	17 (2)	60 (6)	52 (9)	9 (4)	58 (8)	304 (41)

Table 8: NISP of mollusk remains recovered from Khao Toh Chong (MNI values in parentheses).

Taxon	1	2	3	4	5	6	7U	8	7L	Total
Neritidae	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)
Nerita balteata	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (2)	0 (0)	0 (0)	0 (0)	2 (2)
Cyclophorus sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	7 (7)	0 (0)	0 (0)	7 (7)
Cyclophorus cf. saturnus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	1 (1)
Cyclophorus malayanus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	9 (9)	1 (1)	1 (0)	0 (1)	11 (11)
Cyclophoridae	0 (0)	0 (0)	2 (2)	3 (3)	2 (2)	12 (1)	20 (28)	5 (5)	27 (30)	71 (71)
Rhiostoma jalorensis	0 (0)	0 (0)	0 (0)	2 (2)	5 (2)	11 (10)	5 (9)	2 (2)	2 (2)	27 (27)
Rhiostoma sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	9 (6)	0 (3)	2 (2)	11 (11)
Filopaludina sp.	0 (0)	0 (0)	0 (0)	2 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (2)
Viviparidae	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)
Pila sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (2)	0 (4)	0 (0)	6 (6)
Ampullariidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	2 (3)	0 (0)	3 (3)	6 (6)
Neoradina prasongi	0 (0)	0 (0)	8 (8)	134 (134)	71 (52)	115 (82)	3390 (1584)	545 (2215)	583 (771)	4846 (4846)
Telescopium telescopium	0 (0)	0 (0)	0 (0)	3 (3)	3 (2)	3 (3)	5 (4)	0 (2)	0 (0)	14 (14)
Muricidae	0 (0)	0 (0)	1 (1)	4 (4)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	6 (6)
Plectopylis degerbolae	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	1 (1)	5 (2)	3 (3)	3 (5)	13 (12)
Amphidromus atricallosus	0 (0)	0 (0)	0 (0)	1 (1)	1 (0)	0 (1)	1 (1)	0 (0)	0 (0)	3 (3)
Anadara sp.	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)
Arcidae	0 (0)	0 (0)	0 (0)	3 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	4 (0)
Pseudodon sp.	0 (0)	0 (0)	0 (0)	1 (0)	9 (0)	0 (0)	0 (0)	0 (0)	0 (0)	10 (0)

Amblemidae	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	66 (0)	191 (0)	18 (0)	367 (0)	643 (0)
Corbiculidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	1 (0)
Total	0 (0)	0 (0)	13 (12)	155 (151)	93 (58)	221 (110)	3643 (1647)	574 (2234)	988 (815)	5687 (5027)

Table 9: Ecological indices of diversity and evenness for the faunal assemblage recovered from Khao Toh Chong. Pielou's index is also known as the Shannon index of evenness

Context	NTAXA	Simpson	Pielou
1	4	0.750	1.000
2	1	0.000	0.000
3	9	0.740	0.807
4	11	0.231	0.268
5	6	0.245	0.335
6	14	0.485	0.461
7U	20	0.085	0.092
8	11	0.020	0.033
7L	16	0.121	0.124

Zooarchaeology

Mammalian abundance and distribution at the rockshelter throughout the Late Pleistocene and Holocene describes a diverse array of taxa in the deposits (Table 7). 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 dietary evenness per context, of the mammalian, reptilian, and fish taxa appear to be driven primarily by the presence or absence of carapace elements (Van Vlack 2014). Carapace recovered at KTC likely belong to the Order Testudines and represents species of the turtle Family Trionychidae and Geoemyidae. This identification is 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 Testudines elements. Overall, the presence of vertebrate remains was relatively low when compared to the abundance of invertebrate remains at the rockshelter. Artiodactyls are notably restricted to the Late Pleistocene and Early Holocene deposits.

Of the identified invertebrates, nine taxa were identified to the species level while an additional fourteen were identified to a broader degree of taxonomy (Table 8). Mollusk species richness varies between 0-11 throughout the trench 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. When combined with shells from the Family Amblemidae and Cyclophoridae, these three taxa account for 97% of the identified mollusks at KTC (Conrad et al. 2013).

For all identified fauna, MNI and logNISP values for each context are strongly correlated (r = 0.647, df = 7, p = 0.06), indicating that the rate of fragmentation is constant (Lyman 2008). Ecological indices of taxonomic diversity and evenness vary over time, suggesting complexities in forager behaviour (Table 9). Generally, these indices have low values, indicating both low diversity and the dominance of a small number of taxa in the assemblage. This is largely controlled by the abundance of *Neoradina prasongi*, which dominate the assemblage in the lower levels despite a greater number of other taxa also present. In the upper levels where *Neoradina prasongi* is absent, the diversity and evenness indices increase but overall counts are low suggesting the site was less frequently used for subsistence activities.

Discussion

Geoarchaeology

The general picture of the geoarchaeological data is one of subtle, mostly uncoordinated changes in the variables we measured. That said, there are some important correlations that aid the interpretation of the palaeoenvironmental context of the site. We interpret this as indicative of relatively constant conditions of deposition, without homogenising processes that would have erased the trends we see in the geoarchaeological variables. The sediment texture suggests a mixture of aeolian, colluvial and fluvial inputs, typical of cave and rockshelter deposits in the tropics (cf. Westaway et al. 2009). Sediment composition varies little over time, as indicated by the measurements of organic matter, carbonates and pH in the bulk samples, and the ICP-AES data.

Visual inspection of the stratigraphic plot of the KTC data (Figure 6) suggests that the magnetic susceptibility frequency dependency values of track mean particle size more closely than they track low frequency magnetic susceptibility. This indicates that soil formation and weathering processes control magnetic susceptibility more than burning processes, such as cooking, at the site (Dearing et al. 1996). Magnetic susceptibility values can be altered by fires, pedogenesis, and chemical weathering (Dalan and Banerjee 1998; Fassbinder et al. 1990; Le Borgne 1960; Linford et al. 2005; Maher and Taylor 1988). Magnetic susceptibility is negatively correlated with soil organic matter in the KTC deposits (Table 2). A negative correlation can be explained by a negligible contribution from *in situ* pedogenesis toward enriching magnetic susceptibility. This suggests that the enhancement of susceptibility may have occured off-site, rather than through *in situ* processes in the deposit. If the magnetic susceptibility signal is not coupled to anthropogenic burning at the site, as suggested by the the relationship between mean particle size and frequency dependency, the high susceptibility values at 0.40 m below surface (c. 4-5 k cal. BP) may indicate warmer/wetter conditions. One possible mechanism linking higher sediment magnetic susceptibility values to warmer/wetter conditions has been suggested by Ellwood et al. (1997). They propose that higher magnetic susceptibility values might result from increased production of maghemite due to higher pedogenetic rates on the landscape, with enriched sediments washing into and forming site deposits. At KTC see signals of increased site use through artefact discard rates, peaking in contexts 4 and 5. If the mechanism of Ellwood et al. (1997) is plausible, this increase in site use may reflect people seeking shelter during warmer/wetter conditions. Further analyses with remanence (e.g. HIRM, SIRM) measurements will improve our understanding of these relationships.

Carbon isotope values indicate a consistent dominance of C_3 plants in the local environment over time, similar to the present-day environment. The small monotonic depletion in carbon isotope values throughout the Holocene suggests that the deposit has some stratigraphic integrity, despite the anomalously deep finds of ceramics. The depletion in carbon isotope values may be due to several factors, including changes in the ratio of C_3 and C_4 plants on the landscape, changes in the growing conditions of plants (such as canopy structure, and water or nutrient stress), changes in the ratios of isotopically distinct organic fractions in the sediment organic matter, and changes in organic inputs from microorganisms in soils (Tieszen 1991). At KTC, carbon isotope values are strongly negatively correlated with sediment organic matter. As SOM values increase, the carbon isotope values become increasingly depleted. This is the opposite of what is usually expected when SOM is the primary mechanism controlling carbon isotope values in shallow deposits such as KTC, because SOM often enriches $\delta^{13}C$ values with increasing depth (Ehleringer et al. 2000) even as the absolute SOM content decreases with depth (Jobbágy and Jackson 2000). Since SOM is probably not the primary driver of $\delta^{13}C$ values at KTC, then we may be observing a decrease in the relative ratios of C_4/C_3 plants on the landscape, indicating increasingly dry conditions in more recent periods.

Aridity and temperature are important factors in controlling this ratio, but their exact relationships vary from region to region (Pagani et al. 1999; Huang et al. 2001; Schefuβ et al. 2003; Zhang et al. 2003). C_4 photosynthesis is often associated with warm-season precipitation, dry/hot environments, and high light intensities because C_4 plants are more efficient than C_3 species in their use of water, light, and nitrogen (Sage 1999; Pagani et al. 1999). This means that C_3 plants are favored over C_4 plants at times of lower temperature and winter precipitation or during periods of decreased East Asian summer monsoon strength. In the upper 0.2 m, around 3-2 k cal BP, at KTC we see increasingly depleted $\delta^{13}C$ values, suggesting a reduction in C_4 plants as a result of cooler and dryer conditions relative to the Early Holocene. This is consistent with cooler/dryer conditions indicated by a decrease in magnetic susceptibility occurring at KTC at the same time. However, the trend in $\delta^{13}C$ values at KTC is relatively low magnitude, and isotopic fractionation and microbial activity cannot be fully dismissed as contributing factors (Lerch et al. 2011; Schweizer et al. 1999; Tieszen 1991; Wynn 2007). Carbon isotope values of leaf wax n-alkanes may help to overcome these ambiguities because these are more diagnostic than those from bulk sediments, which contain materials of both terrestrial and aquatic origin.

The magnetic susceptibility and carbon isotope data indicate a transition from warmer/wetter conditions at 5-4 k cal. BP to dryer conditions around 3-2 k cal. BP. There are very few nearby comparable records spanning this period, but our interpretations are consisitent with a strong Asian summer monsoon in the Early Holocene, and weakening into the Middle and Late Holocene (Cook and Jones 2012). Lake sediment sequences from northeast Thailand indicate peak Holocene wetness slightly earlier than KTC, at around 7 k and 6.6 k cal. BP, followed by dry conditions between 5.4 k and 4 k cal. BP (Wohlfarth et al. 2016; Chabangborn and Wohlfarth 2014). There are multiple long hiatuses in the northeast Thailand sequences between c. 6.4 k and 1.8 k cal. BP (Wohlfarth et al. 2016), and climate proxies from this period are complicated by inputs resulting from humans burning forests and cultivating crops (White et al. 2004; Kealhofer and Penny 1998). Hydrogen isotope data shows that moisture availability was low around 2.7-2.3 k cal. BP, and macroscopic charcoal was high between approximately 3.5 k and 2.1 k cal. BP (Wohlfarth et al. 2016). However, some caution may be required with these results because the Wohlfarth et al. (2016) hydrogen isotope summary does not appear to account for the potential of atmospheric exchange between the sample location and analysis lab (see Chawchai et al. 2016). Regardless, these signals are consistent with the dryer conditions observed at 3-2 k cal. BP at KTC.

The XRD data show variation in the proportion of kaolinite throughout the deposit. The kaolinite is probably derived from the weathering of feldspars and other silicate minerals, and may relate to changes in weathering on the landscape around the site (Nesbitt and Young 1989; Nesbitt et al. 1997). Substantial changes in surface geochemistry are unlikely, due to the absence of correlations between changes in magnetic susceptibility and minerals identified by XRD analysis. If these were correlated, it might suggest episodes of soil formation on the landscape surrounding the site. Thus, we interpret the geoarchaeological data as indicating generally constant conditions over time, rather than resulting from massive large scale bioturbation.

The relationships among the elements measured by ICP-AES suggest a single source for the sediments throughout the entire period of deposition. Cluster analysis of the contexts using the elemental data suggests low-level groupings resulting from minor variation (Figure 7). The cluster containing context 1 of trench B, and trench A's contexts 4, 7U and 7L are notable because they are relatively enriched with Ca and Mg, but this is not correlated with carbonates measured by loss on ignition. Overall, the element distributions suggest low variation over time. This homogeneity in the composition of the deposits is consistent with a single source of sediment throughout the history of site formation at KTC.

Zooarchaeological assemblage

KTC rockshelter has a relatively undisturbed mammalian, reptilian, fish, and molluscan assemblage. Of the taxa recovered at KTC, the riparian fauna is the best indicator of changing forager behavior during the "missing millennia," highlighting the environmental constraints on resource availability. *Neoradina prasongi* shells constitute the bulk of molluscan food waste in the archaeological assemblage. These gastropods inhabit fresh water stream environments (Brandt 1974), which were likely close in proximity to the rockshelter during this time. Peak discard rates for *N. prasongi* at KTC occurred at c. 9 k cal BP, suggesting that the most intensive use of the rockshelter for subsistence purposes occurred during the Early Holocene. The abundant turtle or tortoise remains at KTC also suggest that fresh water stream habitats were found near the site. Since KTC was close in proximity to a number of other cave and rockshelter sites with relatively similar chronological and subsistence regimes, it is possible that foragers in this region employed a complex mobility strategy to access fresh water resources and shelter (Brantingham 1991; Conrad et al. 2016; Mheetong 2014; Rabett and Barker 2010; Shoocongdej 2000).

A decline in freshwater *N. prasongi* mollusk exploitation occurred in the Holocene, reaching a minimum at 6 k cal BP. Two possibilities may explain this decline; either there is a regional ecological shift from freshwater to mangrove swamp habitats, or changes in the foraging behaviours of prehistoric groups (Shoocongdej 2000, 2010). The timing of the lowest amount of shells in the deposit coincides with the peak sea levels, as noted above. Rising sea-levels throughout the Holocene would have shifted mangrove environments closer to the rockshelter over time, which may have influenced the abundance and distribution of locally available resources and freshwater stream environments (Anderson 1990; Horten et al. 2005; Tjia 1996; Sinsakul 1992). These initial faunal data from KTC describe a pattern of forager groups utilizing a diverse range of locally available taxa in the tropical rainforest environment, suggesting that foragers at KTC were able to effectively adapt to shifts in local environmental conditions. Additionally, our radiocarbon dates suggest that the decline in intensive harvesting of *N. prasongi* during the Middle Holocene may be associated with the emergence of rice agriculture and farming in mainland Southeast (Castillo 2011; Fuller 2011; White et al. 2004). Thus, declines in mollusk utilization may reflect a pattern of rising sea levels. The mechanism here may be a reduction in the availability of suitable mollusk procurement locations, favoring the adoption of agriculture during the Mid and Late Holocene in Peninsular Thailand as a response to these sea level changes. Shell exploitation picks up again at KTC at c. 3 k cal BP, coincident with the regressive phase at 3.7 k to 2.7 k cal. BP described by Sinsakul (1992). This is also when site use changes, with more frequent visits suggested by peaks in the discard of ceramics and lithics.

Our data from KTC not only suggest that a subsistence change occurred at the Pleistocene-Holocene transition, but that foragers utilizing the rockshelter displayed a pattern of faunal exploitation not widely noted at archaeological sites in Thailand. Elsewhere in Thailand, large abundances of shellfish in rockshelter sites tend to date to the Middle Holocene when a transition towards a broad-spectrum diet may have occurred, not during the terminal Pleistocene (Bulbeck 2003; Conrad 2015). The earlier peak in the molluscan assemblage at KTC suggests that a different pattern of shellfish exploitation occurred here. We link this pattern to local environmental conditions controlled by sea level changes (see also Van Vlack 2014:79-96). Further afield, we find that KTC is very similar to Bubog I and II in the Philippines (Pawlik et al. 2014), where there is a transition from exploiting mangrove invertebrate species (due to lowered sea levels and increased mangrove habitats) during the Late Pleistocene to an exploitation of brackish and shallow marine invertebrate species during the Early Holocene, when sea levels rise and inundate the mangroves. By the Mid Holocene the invertebrates at Bubog I an II are almost entirely marine species, indicating that lagoons are present.

A broader implication of these results is that the patterns at KTC may offer some support to the model proposed by Hunt and Rabett (2014) for the transition from foraging to farming. They consider widespread forest disturbance in the Early Holocene as part of a trajectory toward predominantly agricultural subsistence. Using evidence from Borneo, they propose that palynological signatures of disrupted forest successions are linked to human translocation and propagation of economically-useful plants. Unfortunately our pollen and phytolith analysis was not informative about forest disturbance at KTC. However, the decline in the use of the site for exploiting mollusks may be part of a shift towards a greater focus on plant foods. We might speculate that as shellfish became less important in the diet of foragers occupying KTC, their pursuit of alternative resources initiated a distinct trajectory of economic change (cf. Rabett 2012). This may have involved a protracted process of wild plant food production (Fuller et al. 2007; Harris 1989) or cultivation without domestication (Zhao 2011), eventually resulting in reliance on farmed crops seen at Late Holocene sites in the region.

Conclusion

Archaeological excavations revealed human occupation at KTC from recent times back to over 13,000 years ago, without any major interruptions, disturbances or discontiunities. The changes in artefact technology were subtle during the time represented by the excavated deposit, and there is some uncertainty about the effect of bioturbation on artefact distributions. That said, the site is unique because it has not been extensively disturbed by Late Holocene human burials. 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 rockshelter and Moh Khiew cave. The foragers occupying KTC practiced a complex strategy of molluscan resource procurement and exploitation. The most striking find is the association between the abundance of shellfish and past sea levels. Low sea levels at the Early Holocene correspond to a peak in shellfish discard, followed by a decline in shellfish and lithic discard at c. 6 k cal. BP, at the same time as the peak Holocene sea levels.

There is another small peak in shellfish at c. 3 k cal. BP during a regressive phase, this time accompanied by relatively large amounts of ceramics and lithics. During the Mid Holocene, when the *Neoradina prasongi* exploitation ceased at KTC, the water table and sea levels were rising while abundances in charcoal (regional fires) became more prevalent (Kealhofer 2003:80; Maloney 1999). During this time, more arboreal taxa were exploited and economic plants begin to appear archaeologically. This faunal discard sequence suggests that local sea levels influenced the intensity of site use. Past 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.

Sea level changes have not previously been recognized as important mechanisms in prehistoric human adaptations in mainland Southeast Asia. For example, Wohlfarth et al. (2016) propose that transitions between wet and dry conditions caused by summer monsoon fluctuations in the later Holocene (after 2 k cal. BP) resulted in social adaptations to managing the water supply to agricultural areas in northeast Thailand. These adaptations include the expansion of the moat reservoirs and the rise in social elites. The period of the emergence of agriculture in mSEA is not well-represented in the data from Wohlfarth et al. (2016) because gaps in their data during c. 6.4 k and 1.8 k cal. BP. However, Kealhofer (2002; Kealhofer and Penny 1998) has interpreted the microbotanical record from northeast Thailand as reflecting a shift in land management providing evidence for agriculture in the region at 5–4.5 k cal. BP. At KTC, our key finding is a human-environment adaption in the form of a change in the role of shellfish in subsistence behaviours, and changes in the intensity of site use that are consistent with a long trajectory of land management leading to full-time agriculture in the Late Holocene. Unlike northeast Thailand where Wohlfarth et al. (2016) link archaeological sequences to regional summer monsoon patterns, the changes we have observed at KTC in southern Thailand are more closely tied to fluctuations in local sea levels.

The results from KTC confirm the "missing millennia" as a period of important subsistence and technological changes in mainland Southeast Asia. One one hand, we see at KTC a recapitulation of a common sequence in mainland Southeast Asian prehistory. This includes foragers using the site for brief subsistence-related tasks during the Late Pleistocene and Early Holocene, then a transition in the Middle Holocene to people using the site less for foraging activities, but now with ceramics and possibly practicing agriculture, as suggested by the polished adzes. On the other hand, we also see a unique pattern of shellfish exploitation at KTC that is related to the local sea level changes. This relationship highlights the importance of the local context in understanding the mechanisms of change from foragers to agriculturalists. The model proposed by Hunt and Rabett (2014), of a locally contingent protracted process of human modification of plant resources may be relevant in understanding how Early Holocene foragers at KTC relate to the Late Holocene occupants here and elsewhere in mainland Southeast Asia.

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References

Alam, A., Xie, S., Saha, D., & Chowdhury, S. (2008). Clay mineralogy of archaeological soil: an approach to paleoclimatic and environmental reconstruction of the archaeological sites of the Paharpur area, Badalgacchi upazila, Naogaon district, Bangladesh. *Environmental Geology*, 53(8), 1639-1650.

Anderson, D. D. (1990). *Lang Rongrien rockshelter: A Pleistocene, early Holocene archaeological site from Krabi, southwestern Thailand* University of Pennsylvania Museum of Archaeology and Anthropology, University Museum Monograph, 71. Pennsylvania.

Anderson, D. D. (1997). Cave archaeology in southeast Asia. *Geoarchaeology*, 12(6), 607-638.

Anderson, D. (2005). The use of caves in peninsular Thailand in the Late Pleistocene and early and middle Holocene. *Asian Perspectives*, 137-153.

Araujo, A. G., Feathers, J. K., Arroyo-Kalin, M., & Tizuka, M. M. (2008). Lapa das boleiras rockshelter: stratigraphy and formation processes at a paleoamerican site in Central Brazil. *Journal of Archaeological Science*, 35(12), 3186-3202.

Arroyo-Kalin, M., Neves, E. G., & Woods, W. I. (2009). Anthropogenic dark earths of the Central Amazon region: remarks on their evolution and polygenetic composition. In Amazonian Dark Earths: Wim Sombroek's Vision. Springer Netherlands. pp. 99-125.

Auetrakulvit, P. (2004). Faunes du pléistocène final à l'holocène de Thaïlande: approche archéozoologique (Doctoral dissertation, Aix Marseille 1).

Auetrakulvit, P., Forestier, H., Khaokhiew, C., & Zeitoun, V. (2012). New Excavations at Moh Khiew Site, Southern Thailand. In *Crossing Borders: Selected Papers from the 13th International Conference of the European Association of Southeast Asian Archaeologists*. NUS Press, Singapore. pp. 60-73.

Balcerzak, M. (2002). Sample digestion methods for the determination of traces of precious metals by spectrometric techniques. *Analytical sciences*, 18(7), 737-750.

Brandt, R.A.M. 1974. The nonmarine aquatic Mollusca of Thailand. *Arch. Molluskenkunde.* 105, 1-423.

Brantingham, P.J. (1991). Astride the Movius Line: Pleistocene Lithic Technological Variability in Northeast Asia. PhD. Dissertation, Department of Anthropology, University of Arizona, Tuscon.

Bulbeck, F. 2003. Hunter-gatherer occupation of the Malay Peninsula from the Ice Age to the Iron Age. In: J. Mercader (ed.), *Under the canopy: The archaeology of tropical rain forests*. Piscataway: Rutgers University Press.

Carter, M. R. (1993). *Soil sampling and methods of analysis*. Boca Raton: Lewis Publishers.

Castillo, C. (2011). Rice in Thailand: the archaeobotanical contribution. *Rice*, 4(3-4), 114-120.

Chabangborn, A. and B. Wohlfarth (2014). "Climate over mainland Southeast Asia 10.5–5 ka." *Journal of Quaternary Science* 29(5): 445-454.

Chawchai, S., Yamoah, K.A., Smittenberg, R.H., Kurkela, J., Valiranta, M., Chabangborn, A., Blaauw, M., Fritz, S.C., Reimer, P. and Wohlfarth, B. (2016). LakeKumphawapi revisited - The complex climate and environmental record of a tropical wetland in NE Thailand. *The Holocene* 26(4): 614-626.

Chi, Z., & Hung, H. C. (2010). The emergence of agriculture in southern China. *Antiquity*, 84(323), 11-25.

Chitkament, T. (2007). Lithic analysis of Moh Khiew rockshelter (Locality I) in Krabi river valley, Krabi province, southwestern Thailand. Unpublished MA thesis, Department of Prehistory in the National Museum of Natural History, Paris, France.

Conrad, C. (2015). Archaeozoology in Mainland Southeast Asia: Changing Methodology and Pleistocene to Holocene Forager Subsistence Patterns in Thailand and Penisular Malaysia. Open Quaternary 1(7):1-23.

Conrad, C., H. G. Van Vlack, B. Marwick, C. Thengcharoenchalklt, R. Shoocongdej and B. Chaisuwan (2013). "Summary of Vertebrate and Molluscan Assemblages Excavated from Late-Pleistocene and Holocene Deposits at Khao Toh Chong Rockshelter, Krabi, Thailand." *The Thailand Natural History Museum Journal* 7(1): 11-22.

Conrad, C., Higham, C., Eda, M. and Marwick, B. (2016). Palaeoecology and Forager Subsistence Strategies during the Pleistocene-Holocene Transition: A Reinvestigation of the Zooarchaeological Assemblage from Spirit Cave, Mae Hong Son Province, Thailand. *Asian Perspectives* 55(1): 2-27.

Cook, S. F. (1965). *Studies on the Chemical Analysis of Archaeological Sites*. University of California Press, Berkeley.

Cook, C. G. and R. T. Jones (2012). "Palaeoclimate dynamics in continental Southeast Asia over the last~ 30,000 Calyrs BP." *Palaeogeography, Palaeoclimatology, Palaeoecology* 339: 1-11.

Costa, M. L. and D. C. Kern, 1999. Geochemical signatures of tropical soils with archaeological black earth in the Amazon, Brazil. *Journal of Geochemical Exploration*, 66, 369–385.

Dalan RA, Banerjee SK (1998) Solving archaeological problems using techniques of soil magnetism. Geoarchaeology 13:3–36

Dearing, J. (1999). *Environmental Magnetic Susceptibility. Using the Bartington MS2 System*. Bartington Instruments Ltd.

Dearing, J. A., Dann, R. J. L., Hay, K., Lees, J. A., Loveland, P. J., Maher, B. A., & O'grady, K. (1996). Frequency-dependent susceptibility measurements of environmental materials. *Geophysical Journal International* 124(1), 228-240.

Deines, P. (1980). Chapter 9 - THE ISOTOPIC COMPOSITION OF REDUCED ORGANIC CARBON A2 - FRITZ, P. *The Terrestrial Environment, A.* J. C. Fontes. Amsterdam, Elsevier: 329-406.

DeNiro, M. J. (1987). Stable Isotopy and Archaeology. *American Scientist*, 75, 2.

Eidt, R. C. (1985). Theoretical and practical considerations in the analysis of anthrosols. In (ed) G. Rapp Jr., *Archaeological Geology*, Yale University Press, New Haven, pp. 155–190

Ellwood, B. B., K. M. Petruso, F. B. Harrold and J. Schuldenrein (1997). High-Resolution Paleoclimatic Trends for the Holocene Identified Using Magnetic Susceptibility Data from Archaeological Excavations in Caves. *Journal of Archaeological Science* 24(6): 569-573.

Ehleringer, J. R., N. Buchmann and L. B. Flanagan (2000). "CARBON ISOTOPE RATIOS IN BELOWGROUND CARBON CYCLE PROCESSES." *Ecological Applications* 10(2): 412-422.

Fassbinder JWE, Stanjekt H, Vali H (1990) Occurrence of magnetic bacteria in soil. Nature 343(6254):161–163

Forestier, H., Sophady, H., Puaud, S., Celiberti, V., Frère, S., Zeitoun, V., ... & Billault, L. (2015). The Hoabinhian from Laang Spean Cave in its stratigraphic, chronological, typo-technological and environmental context (Cambodia, Battambang province). *Journal of Archaeological Science: Reports*, 3, 194-206.

Fournier, J., Gallon, R. K., & Paris, R. (2014). * G2Sd: a new R package for the statistical analysis of unconsolidated sediments*._ Géomorphologi_e, 1(1), 73-78.

Francis, C. (2008). *A Guide to the Mammals of Southeast Asia.* Princeton: Princeton University Press.

Fu, X. G. 2002. The Dingsishan site and the prehistory of Guangxi, southern China. *Bull. Indo-Pacific Prehist. Assoc.* 22:63–72.

Fuller, D. Q. (2011). Pathways to Asian civilizations: Tracing the origins and spread of rice and rice cultures. *Rice*, 4(3-4), 78-92.

Fuller, D.Q., R.G. Allaby, C. Stevens (2007). Domestication as innovation: the entanglement of techniques, technology and chance in the domestication of cereal crops. *World Archaeology,* 42(1),. 13–28

Gale, S. J., & Hoare, P. G. (1991). *Quaternary sediments: petrographic methods for the study of unlithified rocks*. New York: Belhaven Press.

Gorman, C. (1970). Excavations at Spirit Cave, North Thailand: Some interim interpretations. *Asian Perspectives*, 13, 79-107.

Geyh, M. A., Kudrass, H-R. and Streif, H. 1979. Sea-level changes during the late Pleistocene and Holocene in the Straits of Malacca. Nature 278, 441-443.

Harris, D.R. (1989). An evolutionary continuum of people-plant interaction, In D.R. Harris, G.C. Hillman (Eds.), *Foraging and Farming: the Evolution of Plant Exploitation*, Routledge, London, pp. 11–26

Hartman, G. (2011). Reconstructing Mid-Pleistocene paleovegetation and paleoclimate in the Golan Heights using the d13C values of modern vegetation and soil organic carbon of paleosols. *Journal of Human Evolution*, 60(4), 452-463.

Haslett, J., & Parnell, A. (2008). A simple monotone process with application to radiocarbon- dated depth chronologies. *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, 57(4), 399-418.

Higham, C. F. and R. Thosarat (1998). *The Excavation of Nong Nor: A Prehistoric Site in Central Thailand* Otago: University of Otago Studies on Prehistoric Anthropology, No. 18.

Higham, C. F. W., & Thosarat, R. (2004).*The Excavation of Khok Phanom Di, Vol. 7: Summary and Conclusions*. London: Society of Antiquaries of London.

Higham, C., Guangmao, X., & Qiang, L. (2011). The prehistory of a Friction Zone: first farmers and hunters-gatherers in Southeast Asia. *Antiquity*, 85(328), 529-43.

Higham, C. F. W., X. Guangmao and L. Qiang (2011). The prehistory of a Friction Zone: first farmers and hunters-gatherers in Southeast Asia. *Antiquity* 85(328): 529-543.

Higham, C., & Kijngam, A. (Eds.). (2011). *The Origins of the Civilization of Angkor, Volume 4: The Excavation of Ban Non Wat. Part II: the Neolithic Occupation (Vol. 4)*. Fine Arts Department of Thailand.

Higham, C. (2013). Hunter-gatherers in Southeast Asia: From prehistory to the present. *Human biology*, 85(1), 21-43.

Higham, C. (2014). Early Mainland Southeast Asian: From First Humans to Angkor. River Books, Bangkok.

Hesp, P. A., Hung, C. C., Hilton, M., Ming, C. L. and Turner, I. M. 1998: A first tentative Holocene sea-level curve for Singapore. Journal of Coastal Research, 14, 308-314.

Horton, B.P., P.L. Gibbard, G.M. Milne, R.J. Morley and C. Purintavaragul. (2005). Holocene sea levels and palaeoenvirorunents, Malay-Thai Peninsula, southeast Asia. *The Holocene* 15 (8): 1199-1213.

Huang, Y. a., F. A. Street-Perrott, S. E. Metcalfe, M. Brenner, M. Moreland and K. Freeman (2001). "Climate change as the dominant control on glacial-interglacial variations in C3 and C4 plant abundance." *Science* 293(5535): 1647-1651.

Hunt, C. O., & Rabett, R. J. (2014). Holocene landscape intervention and plant food production strategies in island and mainland Southeast Asia. *Journal of Archaeological Science*, 51, 22-33.

Hutterer, K. L., (1976). "An evolutionary approach to the Southeast Asian cultural sequence." Current Anthropology: 221-242.

Jobbágy, E. G. , and R. B. Jackson (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* 10: 423–436.

Kahle, D and H. Wickham. (2013). ggmap: Spatial Visualization with ggplot2. The R Journal, 5: 144–162

Kamaludin, H. (2001) Holocene sea level changes in Kelang and Kuantan, Peninsula Malaysia. PhD thesis, University of Durham, 290 pp.

Kealhofer, L. (2003). Looking into the gap: land use and the tropical forests of southern Thailand. *Asian Perspectives* 42(1): 72-95.

Kealhofer L (2002) Changing perspectives of risk: The development of agro-ecosystems in Southeast Asia. *American Anthropologist* 104: 178–194.

Kealhofer, L. and D. Penny (1998). "A combined pollen and phytolith record for fourteen thousand years of vegetation change in northeastern Thailand." *Review of Palaeobotany and Palynology* 103(1-2): 83-93.

Knudson, K.J. , L. Frink, B.W. Hoffman, T.D. Price (2004). Chemical characterization of Arctic soils: activity area analysis in contemporary Yup'ik fish camps using ICP-AES *Journal of Archaeological Science*, 31, 443–456.

Kohl, L., J. Laganière, K. A. Edwards, S. A. Billings, P. L. Morrill, G. Van Biesen and S. E. Ziegler (2015). "Distinct fungal and bacterial δ13C signatures as potential drivers of increasing δ13C of soil organic matter with depth." _Biogeochemistry _124(1): 13-26.

Lampert, C., Glover, I., Hedges, R., Heron, C., Higham, T., Stern, B., Thompson, G. (2003). Dating resin coating on pottery: The Spirit Cave early ceramic dates revised. *Antiquity*, 77(295), 126-133.

Le Borgne E (1960) Influence de feu sur les proprietes magnetiques du sol et sur celles du schist et du grantie. Ann Geophys 16:159–195

Lerch, T. Z., Nunan, N., Dignac, M.-F., Chenu, C., & Mariotti, A. (January 01, 2011). Variations in microbial isotopic fractionation during soil organic matter decomposition. *Biogeochemistry*, 106, 1, 5-21.

Linford N, Linford P, Platzman E (2005) Dating environmental change using magnetic bacteria in archaeological soils from the upper Thames Valley, UK. *Journal of Archaeological Science* 32(7):1037–1043

Llyod-Smith, L.R. (2014). Death in the Landscape: The Locality of Ancestors in Neolithic Island Southeast Asia. In *Living in the Landscape: Essays in Honour of Graeme Barker* (eds. Boyle, Katherine, Ryan J. Rabett and Chris O. Hunt). McDonald Institute for Archaeological Research, Cambridge.

Lyman, R. Lee (2008). *Quantitative Paleozoology*. Cambridge, Cambridge University Press.

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwells.

Maher BA, Taylor RM (1988) Formation of ultrafine-grained magnetite in soils. *Nature* 336:368–371

Maloney, B. K. (1999). A 10,600-year pollen record from Nong Thale Song Hong, Trang Province, South Thailand. *Bulletin of the Indo-Pacific Prehistory Association (Melaka Papers, Volume 2)* 18: 129-137.

Marwick, B. (2016). "Computational reproducibility in archaeological research: Basic principles and a case study of their implementation". *Journal of Archaeological Method and Theory*. in press, doi:10.1007/s10816-015-9272-9

Marwick, B., & Gagan, M. K. (2011). Late Pleistocene monsoon variability in northwest Thailand: an oxygen isotope sequence from the bivalve Margaritanopsis laosensis excavated in Mae Hong Son province. *Quaternary Science Reviews*, 30(21), 3088-3098.

Matsumura, H., & Pookajorn, S. (2005). A morphometric analysis of the Late Pleistocene human skeleton from the Moh Khiew Cave in Thailand. *HOMO-Journal of Comparative Human Biology*, 56(2), 93-118.

McCune, B., Grace, J. B., & Urban, D. L. (2002). *Analysis of ecological communities*. Gleneden Beach, OR: MjM software design.

McGrath, R. J., Boyd, W. E., & Bush, R. T. (2008). The paleohydrological context of the Iron Age floodplain sites of the Mun River Valley, Northeast Thailand. *Geoarchaeology*, 23(1), 151-172.

Mheetong, S. (2014). An Analysis of Reptile from an Excavation at Moh Khiew Cave, Krabi Province. Unpublished M.A. Thesis, Department of Archaeology, Silpakorn University, Bangkok, Thailand.

Midwood, A. J., & Boutton, T. W. (1998). Soil Carbonate Decomposition by Acid Has Little Effect on 13C of Organic Matter. *Soil Biology & Biochemistry*, 30, 1301.

Middleton, W.D. (2004). Identifying chemical activity residues on prehistoric house floors: a methodology and rationale for multi-elemental characterization of a mild acid extract of anthropogenic sediments *Archaeometry*, 46, 47–65

Middleton, W.D. and T.D. Price (1996). Identification of activity areas by multi-element characterization of sediments from modern and archaeological house floors using inductively coupled plasma-atomic emission spectroscopy *Journal of Archaeological Science*, 23, 673–687

Misarti, N., Finney, B. P., & Maschner, H. (2011). Reconstructing site organization in the eastern Aleutian Islands, Alaska using multi-element chemical analysis of soils. *Journal of Archaeological Science*, 38(7), 1441-1455.

Moser, J. (2001). Hoabinhian: Geographie und Chronologie eines steinzeitlichen Technokomplexes in Sudostasien. Linden Soft: Koln.

Mudar, K., & Anderson, D. (2007). New evidence for southeast asian pleistocene foraging economies: Faunal remains from the early levels of Lang Rongrien rockshelter, Krabi, Thailand. *Asian Perspectives*, 46(2), 298-334.

Nesbitt, H., & Young, G. (1989). Formation and Diagenesis of Weathering Profiles. *The Journal of Geology* 97(2), 129-147

Nesbitt, H., Fedo, C., & Young, G. (1997). Quartz and Feldspar Stability, Steady and Non- Steady- State Weathering, and Petrogenesis of Siliciclastic Sands and Muds. *The Journal of Geology* 105(2), 173-192.

Oxenham, M. F., H. Matsumura and N. Kim Dung (2011). *Man Bac: the excavation of a Neolithic site in Northern Vietnam*, ANU Press.

Pagani, M., K. H. Freeman and M. A. Arthur (1999). "Late Miocene atmospheric CO2 concentrations and the expansion of C4 grasses." *Science* 285(5429): 876-879.

Parnell, A. C., Haslett, J., Allen, J. R., Buck, C. E., & Huntley, B. (2008). A flexible approach to assessing synchroneity of past events using Bayesian reconstructions of sedimentation history. *Quaternary Science Reviews*, 27(19), 1872-1885.

Pawlik, A. F., P. J. Piper, M. G. P. G. Faylona, S. G. Padilla, J. Carlos, A. S. Mijares, B. Vallejo, M. Reyes, N. Amano and T. Ingicco (2014). Adaptation and foraging from the terminal Pleistocene to the early Holocene: excavation at Bubog on Ilin Island, Philippines. *Journal of Field Archaeology* 39(3): 230-247.

Pookajorn, S. (1996). Human activities and environmental changes during the late Pleistocene to middle Holocene in southern Thailand and Southeast Asia. In: L. Guy Straus et al. (eds.), *Humans at the End of the Ice Age*. New York,

Pookajorn, S. (1994). *Final report of excavations at Moh Khiew cave, Krabi province, Sakai cave, Trang province and ethnoarchaeological research of hunter-gatherer group so-called "Sakai or Semang" at Trang province. Bangkok*, Department of Archaeology, Silpakorn University Press, Bangkok

Rabett, R. and Barker, G. (2010). Late Pleistocene and Early Holocene Forager Mobility in Southeast Asia. In *50 Years of Archaeological in Southeast Asia: Essays in Honour of Ian Glover* (eds. Berenice Bellina, Elizabeth A Bacus, Thomas Oliver Pryce, and Jan Wisseman Christie). River Books, Bangkok.

Rabett, R., Appleby, J., Blyth, A., Farr, L., Gallou, A., Griffiths, T., & Tâń, N. C. (2011). Inland shell midden site-formation: Investigation into a late Pleistocene to early Holocene midden from Tràng An, Northern Vietnam. *Quaternary International*, 239(1), 153-169.

Rabett, R. J. (2012). *Human adaptation in the Asian Palaeolithic: hominin dispersal and behaviour during the Late Quaternary*. Cambridge University Press.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., & Grootes, P. M. (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. *Radiocarbon* 55(4), 1869-1887.

Rispoli, F. (2007). The Incised & Impressed Pottery Style of Mainland Southeast Asia: Following the Paths of Neolithization. *East and West* 57(1/4): 235-304.

Sage,R. F. *C4 Plant Biology*, R. F. Sage, R. K. Monson, Eds. (Academic Press, San Diego, CA, 1999), pp. 3–16

Sathiamurthy, E. and H. K. Voris (2006). Maps of Holocene sea level transgression and submerged lakes on the Sunda Shelf. *The Natural History Journal of Chulalongkorn University* Supplement 2: 1-43.

Sawada, J., Thuy, N. K., & Tuan, N. A. (2011). Faunal Remains at Man Bac, in Oxenham, M. F., & Matsumura, H. (eds) *Man Bac: the Excavation of a Neolithic Site in Northern Vietnam*. Terra Australis, 33, Australian National University E Press. pp. 105-116.

Schefuß, E., S. Schouten, J. F. Jansen and J. S. S. Damsté (2003). "African vegetation controlled by tropical sea surface temperatures in the mid-Pleistocene period." *Nature* 422(6930): 418-421.

Schweizer, M., Fear, J., & Cadisch, G. (1999). Isotopic (13C) Fractionation During Plant Residue Decomposition and its Implications for Soil Organic Matter Studies. *Rapid Communications in Mass Spectrometry* 13(13), 1284-1290.

Scoffin, T. P., and le Tissier, M. D. A. 1998: Late Holocene sea level and reef-flat progradation, Phuket, South Thailand. Coral Reefs, 17, 273-276.

Scott-Jackson, J. E., & Walkington, H. (2005). Methodological issues raised by laser particle size analysis of deposits mapped as Clay-with-flints from the Palaeolithic site of Dickett's Field, Yarnhams Farm, Hampshire, UK. *Journal of Archaeological Science*, 32(7), 969-980.

Shoocongdej, R. 2010. Subsistence-Settlement Organization during the Late Pleistocene- Early Holocene: The Case of Lang Kamnang Cave, Western Thailand. In: B. Bellina et al. (eds.), *50 Years of Southeast Asian Archaeology: Essays in Honor of Ian Glover.* River Books, Bangkok, pp. 51-66.

Shoocongdej, R. (2006). Late Pleistocene activities at the Tham Lod Rockshelter in Highland Pang Mapha, Mae Hong Son Province, Northwestern Thailand. In *Uncovering Southeast Asia's Past: Selected Papers from the 10th Annual Conference of the European Association of Southeast Asian Archaeologists*. NUS Press, Singapore. pp. 22-37

Shoocongdej, R. (2000). Forager mobility organization ill seasonal tropical environments of western Thailand. *World Archaeology*. 32(1): 14-40.

Sinsakul, S. (1992). Evidence of quarternary sea level changes in the coastal areas of Thailand: a review. *Journal of Southeast Asian Earth Sciences*, 7(1), 23-37.

Sophady, H., Forestier, H., Zeitoun, V., Puaud, S., Frère, S., Celiberti, V., & Billault, L. (2015). Laang Spean cave (Battambang province): A tale of occupation in Cambodia from the Late Upper Pleistocene to Holocene. *Quaternary International*, doi:10.1016/j.quaint.2015.07.049 in press

Srisuchat, Amara (1997). Report of archaeological excavations in response to environmental impact of the construction of the hydroelectric project Cheo Lan Dam. Bangkok: Division of Fine Arts, Archaeology Division. (In Thai.)

Srisuchat, Tharapong and Amara Srisuchat (1992). Archaeological Analysis No.1: An Application of Technology and Science in Archaeological Work in Thailand. Bangkok: Division of Fine Arts, Archaeology Division.

Streif, H. 1979: Holocene sea-level changes in the Straits of Malacca. Proceedings of the 1978 International Symposium on coastal evolution in the Quaternary, Sao Paolo, Brazil, 552-572.

Tieszen, L. L. (1991). Natural Variations in the Carbon Isotope Values of Plants: Implications for Archaeology, Ecology, and Paleoecology. *Journal of Archaeological Science*, 18, 3, 227

Tjia, H. D. (1996). Sea-level changes in the tectonically stable Malay-Thai Peninsula. *Quaternary International*, 31, 95-101.

Van Vlack, H. (2014). Forager subsistence regimes in the Thai-Malay peninsula: An environmental archaeological case study of Khao Toh Chong rockshelter, Krabi, Thailand. Published M.A. Thesis, Department of Anthropology, San José State University. ProQuest ID: 1622150080.

Viet, N. (2007). The Da But Culture: evidence for cultural development in Vietnam during the middle Holocene. Bulletin of the Indo-Pacific Prehistory Association, 25, 89-94.

Voris, H. K. (2000). Maps of Pleistocene sea levels in Southeast Asia: shorelines, river systems and time durations. Journal of Biogeography 27(5): 1153-1167.

White, J. C. (1989). Ethnoecological observations on wild and cultivated rice and yams in northeastern Thailand. *One World Archaeology*. D. R. Harris and G. C. Hillman. London, Unwin Hyman. 13: 152-158.

White, J.C. (1995). Modeling the Development of Early Rice Agriculture: Ethnoecological Perspectives from Northeast Thailand. Asian Perspectives 34(1):37-68.

White, J. C., Penny, D., Kealhofer, L., & Maloney, B. (2004). Vegetation changes from the late Pleistocene through the Holocene from three areas of archaeological significance in Thailand. *Quaternary International*, 113(1), 111-132.

White, J. C., & Bouasisengpaseuth, B. (2008). Archaeology of the Middle Mekong: introduction to the Luang Prabang province exploratory survey. *Recherches Nouvelles Sur Le Laos. Vientiane and Paris, Études thématiques* (18), 36-52.

White, J. C. (2011). Emergence of cultural diversity in Mainland Southeast Asia: a view from prehistory. (ed) N. J. Enfield, *Dynamics of human diversity*. Canberra: Pacific Linguistics. pp. 9-46

Wickham, Hadley (2015). *R Packages*. Sebastopol, CA: O'Reilly Media, Inc.

Wohlfarth, B., C. Higham, K. A. Yamoah, A. Chabangborn, S. Chawchai and R. H. Smittenberg (2016). "Human adaptation to mid-to late-Holocene climate change in Northeast Thailand." *The Holocene*

Woodroffe, S. A. and B. P. Horton (2005). "Holocene sea-level changes in the Indo-Pacific." Journal of Asian Earth Sciences 25(1): 29-43.

Woods, W.I. (1984). Soil chemical investigations in Illinois archaeology: two example studies, in J.B. Lambert (Ed.), *Archaeological Chemistry III*, American Chemical Society, Washington, DC, pp. 67–77.

Woods, W.I. and B. Glaser (2004). Towards an understanding of Amazonian Dark earths, in B. Glaser, W.I. Woods (Eds.), *Amazonian Dark Earths: Explorations in Space and Time*, Springer, Berlin; London (2004), pp. 1–8

Wynn, J. G. (2007). Carbon isotope fractionation during decomposition of organic matter in soils and paleosols: Implications for paleoecological interpretations of paleosols. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 251, 437-448.

Yoneyama, T., Okada, H., & Ando, S. (2010). Seasonal variations in natural 13C abundances in C3 and C4 plants collected in Thailand and the Philippines. *Soil Science and Plant Nutrition*, 56(3), 422-426.

Zhang, Z., M. Zhao, H. Lu and A. M. Faiia (2003). "Lower temperature as the main cause of C 4 plant declines during the glacial periods on the Chinese Loess Plateau." *Earth and Planetary Science Letters* 214(3): 467-481.

Zhao, Z. (2011). New archaeobotanic data for the study of the origins of agriculture in China. *Current Anthropology* 52 (S4), S295–S306

This report was generated on 2016-11-07 13:25:40 using the following computational environment and dependencies:

```
##  setting  value
##  version  R version 3.3.1 (2016-06-21)
##  system   x86_64, mingw32
##  ui       RTerm
##  language (EN)
##  collate  English_Australia.1252
##  tz       America/Los_Angeles
##  date     2016-11-07
##
##  package      * version    date       source
##  acepack        1.4.0      2016-10-20 CRAN (R 3.3.1)
##  analogue     * 0.17-0     2016-02-28 CRAN (R 3.3.1)
```

```
##  assertthat     0.1        2013-12-06 CRAN (R 3.3.1)
##  Bchron       * 4.2.5      2016-08-02 CRAN (R 3.3.1)
##  bookdown       0.1.1      2016-08-03 Github (rstudio/bookdown@902a670)
##  brglm          0.5-9      2013-11-08 CRAN (R 3.3.1)
##  chron          2.3-47     2015-06-24 CRAN (R 3.3.1)
##  cluster        2.0.4      2016-04-18 CRAN (R 3.3.1)
##  coda           0.18-1     2015-10-16 CRAN (R 3.3.1)
##  codetools      0.2-14     2015-07-15 CRAN (R 3.3.1)
##  colorspace     1.2-7      2016-10-11 CRAN (R 3.3.1)
##  data.table     1.9.6      2015-09-19 CRAN (R 3.3.1)
##  DBI            0.5-1      2016-09-10 CRAN (R 3.3.1)
##  devtools       1.12.0     2016-06-24 CRAN (R 3.3.1)
##  digest         0.6.10     2016-08-02 CRAN (R 3.3.1)
##  dplyr        * 0.5.0.9000 2016-08-03 Github (hadley/dplyr@8b28b0b)
##  ellipse        0.3-8      2013-04-13 CRAN (R 3.3.1)
##  evaluate       0.10       2016-10-11 CRAN (R 3.3.1)
##  foreign        0.8-66     2015-08-19 CRAN (R 3.3.1)
##  formatR        1.4        2016-05-09 CRAN (R 3.3.1)
##  Formula        1.2-1      2015-04-07 CRAN (R 3.3.0)
##  G2Sd           2.1.5      2015-12-07 CRAN (R 3.3.1)
##  geosphere      1.5-5      2016-06-15 CRAN (R 3.3.1)
##  ggmap          2.6.1      2016-01-23 CRAN (R 3.3.1)
##  ggplot2      * 2.1.0      2016-03-01 CRAN (R 3.3.1)
##  gridExtra      2.2.1      2016-08-03 Github (baptiste/gridextra@478a7d2)
##  gtable         0.2.0      2016-02-26 CRAN (R 3.3.1)
##  highr          0.6        2016-05-09 CRAN (R 3.3.1)
##  Hmisc          3.17-4     2016-05-02 CRAN (R 3.3.1)
##  htmltools      0.3.5      2016-03-21 CRAN (R 3.3.1)
##  httpuv         1.3.3      2015-08-04 CRAN (R 3.3.1)
##  inline       * 0.3.14     2015-04-13 CRAN (R 3.3.1)
##  jpeg           0.1-8      2014-01-23 CRAN (R 3.3.0)
##  knitr        * 1.14       2016-08-13 CRAN (R 3.3.1)
##  ktc11        * 0.2        2016-11-07 local
##  labeling       0.3        2014-08-23 CRAN (R 3.3.0)
##  lattice      * 0.20-34    2016-09-06 CRAN (R 3.3.1)
##  latticeExtra * 0.6-28     2016-02-09 CRAN (R 3.3.1)
##  lazyeval       0.2.0      2016-06-12 CRAN (R 3.3.1)
##  legendMap      1.0        2016-08-03 Github (3wen/legendMap@707f00c)
##  magrittr       1.5        2014-11-22 CRAN (R 3.3.1)
##  mapproj        1.2-4      2015-08-03 CRAN (R 3.3.1)
##  maps           3.1.1      2016-07-27 CRAN (R 3.3.1)
##  maptools     * 0.8-39     2016-01-30 CRAN (R 3.3.1)
##  MASS           7.3-45     2016-04-21 CRAN (R 3.3.1)
##  Matrix         1.2-6      2016-05-02 CRAN (R 3.3.1)
##  mclust         5.2        2016-03-31 CRAN (R 3.3.1)
##  memoise        1.0.0      2016-01-29 CRAN (R 3.3.1)
##  mgcv           1.8-12     2016-03-03 CRAN (R 3.3.1)
##  mime           0.5        2016-07-07 CRAN (R 3.3.1)
##  miniUI         0.1.1      2016-01-15 CRAN (R 3.3.1)
##  munsell        0.4.3      2016-02-13 CRAN (R 3.3.1)
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##  nnet           7.3-12     2016-02-02 CRAN (R 3.3.1)
##  permute      * 0.9-4      2016-09-09 CRAN (R 3.3.1)
##  plyr           1.8.4      2016-06-08 CRAN (R 3.3.1)
##  png            0.1-7      2013-12-03 CRAN (R 3.3.0)
##  princurve      1.1-12     2013-04-25 CRAN (R 3.3.0)
##  proto          0.3-10     2012-12-22 CRAN (R 3.3.0)
##  R6             2.2.0      2016-10-05 CRAN (R 3.3.1)
##  RColorBrewer * 1.1-2      2014-12-07 CRAN (R 3.3.0)
##  Rcpp           0.12.7     2016-09-05 CRAN (R 3.3.1)
##  readr          1.0.0      2016-08-03 CRAN (R 3.3.1)
##  reshape2       1.4.2      2016-10-22 CRAN (R 3.3.1)
##  RgoogleMaps    1.4.1      2016-09-18 CRAN (R 3.3.1)
##  rJava          0.9-8      2016-01-07 CRAN (R 3.3.0)
##  rjson          0.2.15     2014-11-03 CRAN (R 3.3.0)
##  rmarkdown      1.1        2016-10-16 CRAN (R 3.3.1)
##  rpart          4.1-10     2015-06-29 CRAN (R 3.3.1)
##  scales       * 0.4.0      2016-02-26 CRAN (R 3.3.1)
##  shiny          0.14.1     2016-10-05 CRAN (R 3.3.1)
##  sp           * 1.2-3      2016-04-14 CRAN (R 3.3.1)
##  stringi        1.1.2      2016-10-01 CRAN (R 3.3.1)
##  stringr        1.1.0      2016-08-19 CRAN (R 3.3.1)
##  survival       2.39-4     2016-05-11 CRAN (R 3.3.1)
##  tibble         1.2        2016-08-26 CRAN (R 3.3.1)
##  tidyr          0.6.0      2016-08-12 CRAN (R 3.3.1)
##  vegan        * 2.4-1      2016-09-07 CRAN (R 3.3.1)
##  withr          1.0.2      2016-06-20 CRAN (R 3.3.1)
##  xlsx           0.5.7      2014-08-02 CRAN (R 3.3.0)
##  xlsxjars       0.6.1      2014-08-22 CRAN (R 3.3.0)
##  xtable         1.8-2      2016-02-05 CRAN (R 3.3.1)
##  yaml           2.1.13     2014-06-12 CRAN (R 3.3.1)
```

The current git commit of this file is 71d400dbc2df69430a2463a890ae48c15cd9ecbe, which is on the hgvanvlack-patch-1 branch and was made by Ben Marwick on 2016-10-26 00:08:59. The current commit message is "minor edits".