

TROPICAL LIMESTONE FOREST RESILIENCE DURING MIS-2: IMPLICATIONS FOR PLEISTOCENE FORAGING & MODERN CONSERVATION

¹Rabett, R., ²Ludgate, N., ³Stimpson, C., ¹Hill, E., ⁴Hunt, C., ⁵Ceron, J., ⁶Farr, L., ⁷Morley, M., ⁸Reynolds, T., ⁶Zukswert, H., ¹Simpson, D., ¹⁰Nyiri, B., ¹¹Verhoeven, M., ¹⁰Appleby, J., ¹Meneely, J., ⁶Phan, L., ⁶Dong, N-N., ¹⁰Lloyd-Smith, L., ¹³Hawkes, J., ¹⁴Blyth, A., ¹⁵Nguyễn Cao Tân

¹ School of Geography, Archaeology & Palaeoecology, Queen's University Belfast, Elmwood Avenue, Belfast BT7 1NN, UK

² School of Geography, Queen Mary University of London, Mile End Road, London E1 4NS

³ Palaeontology Research Laboratory for Archaeology and the History of Art, University of Oxford, South Parks Road, Oxford OX1 3QY, UK

⁴ School of Natural Sciences & Psychology, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK

⁵ Department of Anthropology & Archaeology, University of Otago, PO Box 56, Dunedin 9054, New Zealand

⁶ Division of Archaeology, University of Cambridge, Downing Street, Cambridge CB2 3DZ, UK

⁷ Centre for Archaeological Science, University of Wollongong, Northfields Avenue, Wollongong NSW 2522 Australia

⁸ Birkbeck College, Faculty of Continuing Education, 26 Russell Square, London WC1B 5DQ, UK

¹⁰ School of Archaeology and Ancient History, University of Leicester, University Road, Leicester, LE1 7RH, UK

¹¹ RAAP Archaeological Consultancy, De Savornin Lohmanstraat 11, 6004 AM Weert, The Netherlands

¹³ Department of Asia, The British Museum, Great Russell Street, London, WC1B 3DG, UK

¹⁴ Department of Chemistry, Organic and Isotope Geochemistry Centre, Bentley Campus, Curtin University, GPO Box U1987 Perth, Western Australia 6845, Australia

¹⁵ Tràng An Landscape Complex Management Board, Ninh Binh, Ninh Binh province, Vietnam

† Corresponding author: r.rabett@qub.ac.uk

ABSTRACT

In this paper we present a multi-proxy study of tropical limestone forest and its utilization by human groups during the major climatic and environmental upheavals of MIS-2 (29-11.7 ka BP). Our data are drawn from new field research within the Tràng An World Heritage property, on the edge of the Red River Delta, northern Vietnam. Key findings from this study include ¹ that limestone forest formations were resilient to the large-scale landscape transformation and inundation of the Sunda continent at the end of the last glaciation; ² that prehistoric human groups were probably present in this habitat through-out MIS-2; and ³ that the forested, almost insular, karst of Tràng An provided foragers with a stable resource-base in a wider changing landscape. These results have implications for our understanding of the prehistoric utilization of karst environments and resonance for conservation efforts in the face of climate and environmental change today.

1. INTRODUCTION

Profound climate and landscape changes were witnessed at a global scale during Marine Isotope Stage 2 (MIS-2) 29-11.7 cal. KBP. As conditions deteriorated into the Last Glacial Maximum (LGM) 26-19 cal. KBP (Clark *et al.* 2009), heightened aridity was experienced in

many parts of the dry tropics (e.g. [Barton et al. 2005](#); [Cook 2009](#); [Weyhenmeyer et al. 2000](#)). Both here and at higher latitudes, which were more directly under the influence of LGM ice-sheet expansion, biotic and human communities contracted into refugia (see e.g. [Husemann et al. 2014](#); [Pala et al. 2012](#); [Rose et al. 2013](#); [Williams et al. 2013](#)). While the effects of the LGM were more muted in the humid tropics of Southeast Asia – the area of focus here (e.g. [Huang et al. 1997](#); [Pelejero et al. 1999](#); [Shintani et al. 2011](#); [Visser et al. 2003](#)) – local marine, terrestrial and lacustrine archives indicate that changes in regional aridity and vegetation cover did, nonetheless, occur ([Huang et al. 1997](#); [Sun & Li 1999](#); [Sun et al. 2000](#)). In the post-LGM late glacial especially, climatic variability and environmental changes had far-reaching and transformative effects on Pleistocene landscapes. The onset of deglaciation at higher northern and southern latitudes initiated sustained sea-level rise and inundation of regional coasts ([Hanebuth et al. 2000](#); [2009](#); [Hunt & Gilbertson 2014](#); [Kienast et al. 2003](#); [Kopp 2012](#); [Schimanski & Stattegger 2005](#); [Verleyehn et al. 2005](#)). Ultimately, this would claim approximately 75 per cent of Southeast Asia's low-lying Pleistocene landmass, 'Sunda Land' ([Molengraaf & Weber 1921](#)) – that incorporated the Greater Sunda Islands (Borneo, Sumatra and Java) together with numerous smaller islands and island chains, and that extended Asia into the Southern Hemisphere.

By 11.7 cal. KBP, the geography of this sub-continent existed in attenuated form only, and the familiar interglacial configuration of land and sea was already apparent (see [Sathiamurthy & Voris 2006](#)). With rates of inundation ranging from *c.* 0.4-5.0 m per 100 years, the effects on humans and biological communities would have been considerable. For example, genetic evidence from modern Southeast Asian populations has inferred that a severe and likely associated bottleneck may have followed in the wake of rapid sea-level rise during the period 14.6-14.3 cal. KBP, and linked to Meltwater Pulse 1A from the Eastern Antarctic ice sheet ([Soares et al. 2008](#)).

The final resurgence of near-fully glacial conditions during GS-1 (Younger Dryas) 12.7-11.7 cal. KBP in the circum-Atlantic does not seem to have impacted equatorial latitudes in Southeast Asia ([Partin et al. 2007](#)); however, its impact at more northerly tropical latitudes such as Vietnam is tenable. The increased aridity associated with the earlier (*c.* 17.5-14.7 cal. KBP) Heinrich Event 1 (H1) brought a tangible impact ([Huang et al. 2011](#); [Marwick & Gagan 2011](#); [Standford et al., 2011](#); [Partin et al. 2015](#); [Wang et al. 2001](#)). Environmental and socio-economic transformations wrought by deglaciation in this region continued into the Holocene, with heightened precipitation and sediment movement under enhanced summer monsoon conditions ([Dai & Weng in press](#); [Wu et al. 2012](#)), pronounced regional oceanic high-stands between 7-4 cal. KBP and 2.6-1.5 cal. KBP ([Nguyen Dai Trung et al. 2012](#); [Zhao & Yu 2002](#)), and an emerging maritime-based Neolithic (e.g. [Rabett in press](#)).

Palaeoclimate proxies, such as those available through ice and sedimentary cores, are already being used to create long-term models of environmental change that extend well beyond the reach of historical records ([IPCC 2012](#)). These models do not attempt to incorporate data about how people coped through the cycles of change that such palaeoproxies track, nor do they yet deal adequately with the record of specific ecozones, particularly in the tropics. Both are topics we seek to contribute towards herein. Archaeology has enormous potential to enhance our understanding of socio-cultural adaptive capacities in IPCC models (e.g. [Roscoe 2014](#); [Van de Noort 2011](#)). Indeed, less is currently known about human adaptive capacities than about the responses to climate change by many natural systems ([IPCC 2007-II: 336](#)).

The effects of climate change on modern tropical environments had been seen as secondary to that predicted from deforestation and extractive industry (Sala *et al.* 2000). Without doubt these drivers remain of critical concern; however, the projected climate-driven impact on communities and environments in Southeast Asia has risen significantly in the last decade. Coastal and low-lying island habitats and populations are now known to face an acute threat from climate-driven inundation and environmental transformation in a region where sea-levels are rising approximately three times faster than the global mean (Nicholls & Cazenave 2010; Rietbroek *et al.* 2016). While the corpus of literature on the impact to coastal habitats globally continues to grow (e.g. Holland 2012; Hunter *et al.* 2015; Kirwan *et al.* 2010; Mendoza-González *et al.* 2013; Virah-Sawmy *et al.* 2009); with few exceptions (e.g. Faridah-Hanum *et al.* 2014; Latinne *et al.* 2015; Wetzel *et al.* 2012) the effect of climate and sea-level change to tropical terrestrial or marine systems is still an under-represented field.

Our contribution to this body of research focuses on a tropical limestone forest formation of northern Vietnam. There are three reasons for this. Firstly, limestone forest habitats in Southern China and Southeast Asia are known for their high levels of biodiversity and species endemism (e.g. Adam & Mamat 2005; Clements *et al.* 2006, 2008; Furey *et al.* 2010; Gao *et al.* 2015; Sodhi *et al.* 2007; Sterling *et al.* 2006); features that arise out of the insular-like character of karstic landforms. The need for long-term studies that can establish the sustainability of these forests has been identified as a conservation priority in the face of both climate change and deforestation (Sodhi *et al.* 2010). Secondly, these environments have played host to early human and archaic hominin occupation for almost a hundred millennia in Southeast Asia (e.g. Barker 2013; Brown *et al.* 2004; Mijares *et al.* 2010; Rabett 2012; Stimpson 2012; van den Bergh *et al.* 2009; Yi *et al.* 2008) and continue to present huge archaeological, palaeo-environmental and palaeontological heritage value (e.g. Bacon *et al.* 2015; Bird *et al.* 2007; Ludgate 2013; Nguyen Gia Doi *et al.* 2012). Thirdly, the Tràng An limestone massif, where this study is set, contains evidence of repeated marine transgressive and regressive cycles. It is also recognized internationally as an exemplar of the combined natural and cultural heritage value that is preserved within karstic landscapes. In this paper we present a multi-proxy terrestrial study that tracks local vegetation history and human landscape-use within Tràng An over a twelve thousand year period, from c. 24.4-12 ka BP.

2. TRÀNG AN LANDSCAPE COMPLEX

This World Heritage property is situated within the province of Ninh Bình in northern Vietnam, on the southern margin of the Song Hong (Red River) Delta, and is centred on an isolated massif of Upper Palaeozoic massively-bedded limestone karst of shallow marine lagoon and reef origin (figure 1). The core property is forested and covers 6,226 hectares or 62.2 km² (surrounded by a buffer zone of 6,026 hectares, of mostly rural land with rice paddy fields). Tràng An is administered by the Ninh Binh Province People's Committee and a semi-autonomous management board. The property exemplifies an outstanding humid tropical tower-karst landscape in the final stages of geomorphic evolution, comprising karst cones and towers, enclosed depressions and an intricate system of fresh water-filled foot-caves. Although currently emergent, this landscape has invaded by the sea several times in the recent geological past and is often compared to the flooded tower karst seascape of Halong Bay. Tràng An's inscription also recognizes its prehistoric archaeology, which spans in excess of the last 30,000 years and contains one of the country's oldest archaeological sites: Hang Trống and principal site of the current study.

<< Figure 1 >>

3. HANG TRỐNG

The cave site of Hang Trống (20.250444N, 105.890111E) is situated approximately 142.3 metres above sea level, and 60 m below the apex of a limestone karst tower in the central part of the Trảng An massif. The cave forms a tunnel that is orientated along a north-south axis through the apex, with a total exposed floor area of *c.* 170 m² (figure 2). A significant feature of the cave is the intense air movement. Hang Trống's elevated position, coupled with a marked difference in the size of its two apertures, promotes air flow, accelerating it substantially when winds are northerly. Aeolian processes have been a major force in site formation: affecting not only rates of deposition but also rates of the erosion and transportation of sediments from the cave (probably exiting via the southern aperture). The noticeable loss of *c.* 1 m of sediment (indicated by surviving material adhering to the walls), was probably lost through aeolian erosion.

<< Figure 2 >>

2.1 Chronology

Radiocarbon dates have been obtained using the accelerator mass spectrometer (AMS) at the 14CHRONO Centre, Queen's University, Belfast (table 1 – ¹⁴C ages were calibrated by Calib 6.0 on the 2nd January 2013, using the INTCAL09 calibration curve, Reimer *et al.* 2009). All ages are quoted in calibrated age before present (BP), with BP being AD 1st January 1950; the abbreviation 'KBP' is used to describe calibrated thousands of years. Aside from one surface-modern age from mixed deposits, all ¹⁴C dates are in sequence and demonstrate the potential for accurately determining a time-depth profile at the site, pushing evidence of human occupation here deep into the LGM. The aeolian processes at work within Hang Trống have probably aided the chronological stratigraphy, bringing sediments in to Hang Trống regularly and preventing post-depositional mixing of the shell midden. The onset of the LGM coincides with the base of excavation in Trench 1 (2010).

<< Table 1 >>

4. METHODOLOGIES

Hang Trống was surveyed using a Geo Fennell 20x automatic level and mapped at high resolution using a Leica HDS3000 LiDAR scanner. Systematic excavation began in the middle of the cave with Trench 1 in 2009 and then, in the second season (2010), concurrently in two additional trenches, Trenches 2 and 3, close to the western and eastern walls, respectively (figure 3). All three trenches contained cultural evidence, including hearths. In addition to macroscopic data from these material remains, geochemical analysis was undertaken on the sediments (and shell), providing a multi proxy approach to interpreting the location its occupation and local environment.

<< Figure 3 >>

4.1 Macro-botanical remains

Samples of macro-botanical remains were collected from dry sieving (2 mm mesh) on site and also in bulk sediment samples that had been processed using bucket flotation (1 mm). Data on carbonized plant remains, in particular, provides a useful line of evidence on vegetation composition, fuel collection and plant processing strategies (Ceron n.d.). In each case samples were counted, weighed, measured and assessed for state of preservation. A total of 502 fragments were identified to family or higher taxonomic level (table 2). Specimens were mounted and photographed with a NIKON Eclipse Ci with 4x.15 to 100xA/1.25 magnification. The taxonomic identifications were based on comparisons with identified specimens, from the nearby Vietnamese Palaeolithic site of Con Moong (Nguyen Viet pers. comm. to Ceron 2011), from Ille Cave, Palawan (Carlos 2010; Ceron pers. observ.), on published material (Paz 2001), and with the assistance of the Forest Product Research and Development Institute (FPRDI), Los Baños, Laguna. Following established criteria relating to characteristics such as pore topography, tracheids and fibre (e.g. Ella et al. 2009; Thompson 1996) a pilot SEM study of four pieces of charred parenchymous material was also undertaken. The chosen material had been recovered through flotation from contexts: (8002), (8101), (8103) from Trench 1 at Hang Trống and from (8215) from Trench 2.

<< Table 2 macro-botanical >>

4.2 Palynology

Sediment samples were collected from the north-facing section of Trench 1 for palynological analysis. The surface of the section was cut back to remove loose material and ensure there was no modern contamination. Palynological analysis has been widely used as a method to determine past vegetation history (e.g. Birks 1980; Birks & Birks 1981). In upland cave sites the sediments are dry and highly oxic; unlike in water lain environments where available oxygen (and hence degradation) is limited. As a result pollen grains oxidize rapidly and/or become 'crumpled'. This level of degradation of pollen grains can pose problems to the reliability when standard palynological techniques (those applied here) are employed. Due to the high concentration of cyclophorids at the site, all samples were sieved to remove shell fragments prior to standard pollen analysis (after Fægri & Iversen, 1989). Pollen was successfully found in all six of the samples investigated, though in varying concentrations as shown in table 3. Owing to the importance of aeolian processes in site formation here, the pollen record is likely to be drawn from a wide catchment, extending beyond Tràng An onto the plains that surround the massif.

Despite the degraded state of pollen at the site, unique identifying features could still be recognized (table 4). The top context sample (8000-8002) displays a considerably higher concentration of identifiable pollen than other contexts (a value of 60 % recoverable identification). It is deduced that this better preservation is largely due to modern wind-blown pollen becoming trapped within the sediments as erosion and localised micro-re-deposition of these takes place. Consequently, these data could provide an example of the modern vegetation surrounding the site, though admixture with Pleistocene sediments has probably distorted this picture. The underlying and, by comparison, undisturbed Pleistocene deposits exhibited a much reduced level of preservation, with only 2-6 % of recovered pollen being identifiable using standard preparation techniques. Nonetheless, a range of plant types was identified and provided a workable dataset.

<< Table 3 pollen counts >>

<< Table 4 pollen identification >>

4.3 Plant biogeochemical markers

Cave locations can provide chemically stable environments suitable for the preservation of biogeochemical compounds from higher plants (Blyth *et al.* 2007; Huang *et al.* 2008). Plant biomarkers are released into the environment by plant metabolic processes and decomposition; they can be isolated from other organic molecules and used as environmental markers (see Eglinton & Hamilton 1967; Van Bergen *et al.* 1997). *n*-Alkanes in plants are hydrocarbons that are mainly synthesized in the leaf wax for protection against incoming solar radiation (insolation), desiccation and pathogens (see e.g. Hadley 1980; Koch & Ensikat 2008; Kosma *et al.* 2009). The longer the *n*-alkane chain length the more energy and resources are required for creation, but the greater the protection provided (Rommerskirchen *et al.* 2003). Within equatorial regions where insolation is high plants produce the long *n*-alkane chains, provided there is also sufficient moisture. During periods of climate change that place stress on plants, they either produce shorter *n*-alkane chain lengths or are unable to survive. *n*-Alkanes preserve well in Quaternary deposits, and as the environment and climate are important controls on chain length distribution, they can furnish an independent and complementary record into past conditions (Blyth *et al.* 2007; Ludgate 2013; Meyers & Ishiwatari 1993; Schwark *et al.* 2002).

Bulk and compound-specific $\delta^{13}\text{C}$ analyses of sedimentary organic carbon preserved *n*-alkanes and *n*-alkanoic acids and provide information about the photosynthetic pathway of the plants they derive from and, therefore, the environment in which the plant grew. Ranges in carbon isotope values represent plants using different photosynthetic pathways. The $\delta^{13}\text{C}$ value can range from *c.* -35 to *c.* -15 ‰ (relative to the Vienna Pee Dee Belemnite international standard) depending on a number of variables, including (but not limited to) plant genus, moisture stress or plant longevity (Lockheart *et al.* 1997; Quade *et al.* 1989). Plants using the C_3 photosynthetic pathway require sufficient amounts of water during their growing season to photosynthesise and give $\delta^{13}\text{C}$ values typically within the range -25 ‰ to -35 ‰ (O'Leary 1981; Osborne & Slack 2012). Plants that follow the C_4 photosynthetic pathway (including, in particular, most grass families) are able to survive in more arid conditions. C_4 plants have an average $\delta^{13}\text{C}$ value of -13 ‰ and range between -12 ‰ to -16 ‰ (O'Leary 1981; Osborne & Slack 2012).

Rabett *et al.* (2011) demonstrate that plant biomarkers, preserved for over 10 KBP in sediments at another cave site in Tràng An, Hang Boi (*c.* 1 km from Hang Trống), display similarity to the biomarkers of plants within the surrounding vegetation today. For the biogeochemical analysis at Hang Trống samples were collected from the North face of Trench 1. The section surface was cleaned to remove cross-context contamination and some whole shells were removed to increase the mass of sediment. In the laboratory the bulk lipid fraction was Soxhlet-extracted from the sediment using dichloromethane (95%) and methanol (5%) to maximise recovery (Banjoo & Nelson 2005; Wang *et al.* 2010). The recovered organic matrix was then analysed using Agilent 6890 Series gas chromatogram coupled to an Agilent 5973 mass spectrometer (GC-MS). Chemstation software was utilised to identify and quantify the *n*-alkanes. $\delta^{13}\text{C}$ values of *n*-Alkanoic acids was determined using Delta V Advantage ThermoFisher isotope-ratio mass spectrometer interfaced with GC-

Isolink Trace GC Combustion conversion system. *n*-Alkanes were removed using off-line chromatography and analysed for compound specific $\delta^{13}\text{C}$ using Agilent gas chromatogram coupled to a Thermo MAT 253 isotope ratio mass spectrometer (GC-IR-MS). Sediment total organic carbon content and total organic carbon $\delta^{13}\text{C}$ values were determined using a Thermo Flash High Temperature Elemental Analyzer (Flash EA) coupled to a Thermo MAT 253 isotope ratio mass spectrometer (IR-MS). All $\delta^{13}\text{C}$ values were normalized to the Vienna Pee Dee Belemnite standard.

n-Alkanes recovered from sediments have a greater proportion of odd-*n*-alkane carbon chain lengths rather than even; indicating that the sediments at Hang Trống contain a robust plant-derived lipid signal, similar to that observed at Hang Boi. The most abundant *n*-alkanes (over 10% of the total measured) include C_{29} , C_{31} and C_{33} , these are all known to be of higher plant origin and therefore of importance here. *n*-Alkane C_{31} is the most dominant through the sediment column, with an average value of *c.* 40 per cent. This demonstrates that plants growing locally are subjected to some environmental stress (high levels of insolation) but, generally, the nutrients and water required for the growth of protective lipids occur in abundance. Percentage histograms of the samples (figure 4) demonstrate a consistent trend.

The $\delta^{13}\text{C}$ value of *n*-alkanes and *n*-alkanoic acids recovered from cave sediments clearly indicate a C_3 photosynthetic pathway and therefore plants that require comparatively moisture-rich conditions in which to thrive. The slightly higher $\delta^{13}\text{C}$ value for bulk organic carbon within the sediments highlights that preserved organic material is likely to be derived from multiple sources, including microbial and anthropogenic (Kohn and Cerling 2002; Nguyen Tu 2011). Food sources introduced by early human groups into the cave from farther afield could, for example, have contributed a biasing factor in the recovery plant biomarkers – a vector for which we are seeking further clarification. Our current hypothesis, based on the available evidence, suggests that limestone forest similar to that seen around Hang Trống today has existed in the vicinity of the cave through-out MIS-2.

<< Figure 4 >>

4.4 Zooarchaeological evidence

4.4.1 Macro-vertebrate fauna

Bones from larger vertebrates were a relatively infrequent component of the excavated material in all three trenches (table 5). Analysis of these assemblages showed them to be predominantly mammalian, highly fragmented, desiccated and in many cases coated with sediment adhered by calcium carbonate deposition. All recovered fragments >5 mm in length were counted and wherever possible refitted. A total of 670 fragments (hereafter, Number of Specimens: 'NSP') were recorded, of which a total of 85 (12.7 %) was found to be diagnostic (to element and taxa, hereafter, Number of Identified Specimens: 'NISP'). The majority was only identifiable to family, but in exceptional cases higher order identification were possible. Comparative materials included those held within the Grahame Clark laboratory, Cambridge, supplemented by collections of digital images and relevant textual sources (notably, Lekagul & McNeely 1988). Despite the relatively low occurrence of bones, inspection of the data indicated that burnt fragments were present throughout the excavated sequence (figure 5). Both the high degree of fragmentation and the evidence of burning give us confidence in the anthropogenic origin of this material.

<< Table 5 vertebrate fauna >>

<< Figure 5 composite section T1 >>

3.4.2 Micro-vertebrate fauna

On-site observations and the characteristics of ground surface concentrations of micro-vertebrate bone near the western wall of the cave strongly suggested that these assemblages accumulated via pellet deposition beneath a contemporary owl roosting site. This record provides a valuable taphonomic control for the range and density of micro-faunal remains recovered during on-site excavations, and how they are to be interpreted.

A total of 2517 bones were identified to element and order from a collected sample of the surface assemblages. Frog bones (Order: Anura) dominated ($n = 2230/2517$, or 89%), with all identifiable ilia attributed to the genus *Rana*. All parts of the skeleton were represented and the bones exhibited minimal breakage and weathering, with no signs of burning or any marked damage from digestive acids (after Andrews 1990; Stahl 1996). The remainder of the sample comprised a minor component of small mammal bones, including *Rattus* sp., *Mus* sp., *Suncus* sp., and *Eonycteris* sp. as well as, as yet, unidentified fish remains. The taxonomic composition of the assemblage with its strong bias toward amphibians, combined with the relative size of the prey items, inferred from skeletal elements, suggests that the bones were accumulated by a species of fish owl (*Bubo* sp. syn. *Ketupa* sp.) (Zukswert 2014).

Prehistoric pellet deposition from generations of owls using this particular roost could also have been a pathway for the introduction of bones into the archaeological deposits of the site. However, inspection of the distribution of the small vertebrate component of assemblages recovered in the three excavated trenches from Hang Trống indicated that the majority was concentrated in the uppermost excavated contexts (table 5). We conclude that the small mammal component of the upper archaeological contexts is most likely the result of mixing between modern and Late Pleistocene material and, therefore, we used their presence as a taphonomic marker and proxy for disturbance. Notably, such evidence was mostly confined to the upper few centimetres of deposit indicative both, that contexts below these carried no more than minor mixing through this particular non-anthropogenic vector, and that the roosting site itself may be of comparatively recent age – though still conceivably hundreds if not thousands of years in duration.

3.4.3 Molluscs

A stand-out feature of many Mainland Southeast Asian archaeological assemblages dating from the Late- to early Post-Pleistocene are riverine or terrestrial shell middens (Rabett *et al.* 2011). To explore the taxonomic diversity and frequencies of represented molluscs within the Hang Trống midden, with respect to changes in site formation and wider environmental conditions, a column was removed (20 x 10 cm) from the north-facing section of Trench 1 to a depth of 1.33 m below the current ground surface (figure 5).

The majority of the species identified were terrestrial molluscs (table 6). This included three species from the genus *Cyclophorus*: *Cyclophorus theodori*, *Cyclophorus unicus* and *Cyclophorus* cf. *cambodjiensis* – all of which live on or around trees. In addition to *Cyclophorus*, other terrestrial species were also identified, namely *Cryptozona* cf. *chrysoraphe*, and Zonitidae cf. *Oxychilus* sp. A further two examples of gastropods were noted for which

only genus level attributions could be made; *Camaena* sp. and *Amphidromus* sp. both favour trees and shrub habitats.

Little data is available in the literature for the habitats of *Cryptozonia* cf. *chrysoraphe*, and Zonitidae cf. *Oxychilus* sp. other than that the genera concerned have affinities with woodland settings. They continue to be found locally. A small number of aquatic taxa were also identified: *Unio* spp. and *Planorbis* sp. both favour larger bodies of freshwater such as lakes, ponds and rivers; *Cerithrium* sp. and *Ellobium aurisjudae* can occupy a broad range of aquatic/semi-aquatic habitats including estuaries, mangroves, shallow water and rivers. Total unburnt and burnt shell MNI counts are plotted by depth and are presented for comparison against vertebrate faunal remains from Trench 1 in figure 5.

<< Table 6 mollusc >>

3.5 Technological evidence

The Hang Trống lithic assemblage was studied using techno-typological and attribute analysis approaches. The latter approach, in particular, examines the variability that exists within the different groups of industries (or techno-facies) that have become subsumed within the northern Vietnamese 'Hoabinhian', and how that variability can be understood in relation to human adaptive strategies (for detailed methods see Phan 2014; Reynolds 1989).

An initial study of selected pieces from the 2009 excavations (context 8016) identified a core rejuvenation flake with at least two or three previous hard-hammer flake removals; a blade-flake, possibly struck using a soft-hammer technique (see Rabett 2012, figure 6:17); a large, thick secondary flake with a plain platform – this piece had slight rounding along the distal edge and evidence on its dorsal surface that many small flakes had been removed prior to this one – and finally a 'steep-edged' core that may also have been used as a pounder. These pieces suggested on-site production, including basic core preparation and possible use of soft-hammer reduction. Both study samples covered herein are drawn from the most extensive period of excavations at the site (in 2010). Material studied consists of, that recovered from LGM deposits in the lower half of Trench 1 (8201-8111) and post-LGM (MIS-2) deposits (and likely post-LGM deposits) from trenches 3 and 2, respectively.

Techno-typological analysis identified ($n = 73$ intentionally modified pieces, table 7, with a further 14 of ambiguous origin). The industry to be based on single-platformed hard hammer reduction, with no evidence for core preparation, platform edge maintenance or platform preparation. There are a small number of silet flakes that may derive from the use of larger or heavier hammers (silet flakes are split longitudinally through the bulb of percussion). Secondary and tertiary flakes dominate the sample, indicative of non-intensive use of materials and possibly the reduction of materials elsewhere (either on site or off site). The formal flake tool-type list is limited to two scrapers and a burin (table 7, artefacts 11 [from cleaning], 17 & 42, respectively). The pebble-based portion of the inventory includes a hammer/pounder with patches of hammering, pitting and micro-flaking on both ends. Seven pieces that can be defined as 'short axe' fragments – following the northern Vietnamese Hoabinhian nomenclature – were also identified at varying depths (table 7, artefacts 1, 7, 10, 13, 29, 46 & 87). The latter of these is from a secure context overlying the deepest current date from Hang Trống (c. 24.4 cal. KBP), indicating an age close to that of the earliest proposed evidence for the Hoabinhian in Vietnam (cf. Yi et al. 2008). Attribute analysis of the sample (Phan 2014, Appendix B) identified $n = 76$ modified pieces (with 63 confidently defined as cores, pebble tools, flakes, retouched flakes or flake fragments) (table

7). The sample may be regarded as the background debris of lithic tool assisted activities. In-situ knapping could not, though, be further demonstrated and refits were not identified. Patterning in the frequency of artefact categories, form of platform (i.e. cortical, plain, pointed, crushed), flaking direction, striking platform thickness and exterior platform angle) appeared within the lithic assemblage that is suggestive of a shift in knapping behaviour between the LGM and the post-LGM (Phan 2014).

<< Table 7 lithics >>

5. RESULTS

Distinct patterning within the results of the various proxy analyses permitted separation into four depositional phases: a mixed phase and three largely undisturbed phases of site use. Phases are described from the base of excavation upwards.

4.4 Phase III (140.5 - 139.70 m asl.)

This phase incorporates material from contexts identified between the current excavation base, dated to 24,244-24,887 BP (UBA-17272), and the appearance of a large shell midden (commencing in Phase II). Data are drawn exclusively from Trench 1 (contexts 8100-8111) (figure 5). Compared to contexts higher in the stratigraphic sequence, sediments at this depth are almost devoid of cyclophorids; however, infrequent freshwater shells, charcoal and small numbers of bone fragments and cultural material was recovered to full depth. Notable amongst the modest vertebrate fauna recovered (table 5) was a complete metapodial from a *Manis* sp. (pangolin) in context (8111). This piece is slightly damaged on the dorsal distal surface (lateral side) and proximally on the lateral side, preventing clear identification to element. Two species of pangolin are presently found in Vietnam: *Manis pentadactyla* (Chinese pangolin) in the north and centre of the country, and *M. javanica* (Sunda pangolin) in the centre and south (Lekagul & McNeely 1988; Sterling *et al.* 2006).

Techno-typological analysis (table 7) produced a diverse range of pieces, a greater predominance of which was made on limestone (60%, $n = 9/15$), including: one core, five flakes, one flake fragment (from section cleaning), one short axe and a burnt limestone pebble fragment. Shale pieces were less common (26.6% $n = 4/15$): two flakes and two short-axes. This phase also yielded the site's only quartzite piece: a retouched scraper, and the only piece of sandstone – a flaked pebble fragment. Fourteen modified pieces were also identified during the attribute analysis. These comprised: one core, three pebble tools, eight complete flakes, one flake fragment and one retouched flake. Based on macroscopic physical characteristics 71.4 per cent of this assemblage was made on one raw material, with the remaining 28.6 per cent split between four different raw materials, each represented by a single piece.

As this phase broadly covers the LGM it is significant that fragments of Dipterocarpaceae (*cf. Dipterocarpus*) and Sapotaceae (*cf. Manilkara* or *Palaquium*) were found in contexts (8100, 8103 & 8110, & in 8105) (table 2). The genus *Dipterocarpus* contains *c.* 70 species of large (*c.* 60 m) rainforest trees, with a wide geographic distribution through the tropics (see Ashton 1988). Sapotaceae (*cf. Manilkara* sp. or *Palaquium* sp.) is a pantropical family of flowering plants, most species of which produce edible fruit. Pinaceae and two endocarps of *Celtis* sp. (Family: Ulmaceae) were also recovered. The former ranges from subarctic to tropical environments, including limestone karst (Sterling *et al.* 2006) and also yields edible seeds. On the basis of the available comparatives, the Hang Trông *Celtis* sp.

specimens are more likely to be *C. australis* L. (Mediterranean hackberry) or less likely the *C. elim. sinensis* Piers (Chinese hackberry). *C. australis* is a component of more open dry deciduous forest regionally (e.g. Sun *et al.* 1986).

The *n*-alkane data from this depth in the excavation indicates a vegetation cover that is similar to today (figure 4). The plants around the cave do not seem to have been adversely effected by the climate downturn. Compound-specific isotope analysis of both *n*-alkanoic acid and *n*-alkane higher plant lipids also indicate that the prevailing occurrence of C₃ vegetation. Pollen records from the South China Sea during this time indicate that herbs and grasses, with some temperate broad leaf plant types dominated most lowland landscapes (Sun *et al.* 2003). The well-watered and enclosed environment within the Trảng An massif appears to have provided a stable set of conditions for sub-tropical plants despite the climatic downturn.

4.3 Phase II (141.63 - 140.50 m asl.)

The deposits Phase II span a period of approximately 1000 years: from 17,845-18,520 (UBA-14885) to 18,229-18,708 BP (UBA-14886). Macro-vertebrate faunal remains are comparatively rare (NISP *n* = 57), with indeterminate large mammal fragments making up the bulk of this total (table 5). Deer (Cervidae) are represented only by distal elements (including a burnt phalange and carpal). Cercopithecidae also feature, with notable finds including two mandibular fragments with partial *in-situ* dentition. The first of these was recovered from near the base of the shell midden in Trench 1 context (8016). Charcoal from this context is dated to 18,229-18,708 cal. BP. The specimen consists of a right M₁ with alveoli for M₂ and M₃ – indicating an adult of five or more years of age (Smith *et al.* 1994) and is attributable to *Macaca* cf. *mulatta* based on biometric data (Swindler 2002, table 112). The second was recovered from Trench 3 context (8312) was from a juvenile, comprising a (left) dp₁ in wear a dp₂ and an erupting M₁ in one fragment, with a similarly faceted dp₂ in a second associated fragment (from the right of the mandible). Evidence of other terrestrial-arboreal and arboreal taxa includes: Sciuridae, from mandible fragments equivalent in size to *Sciurus* sp., Hystricidae by isolated teeth, and one avian family, Phasianidae, from a fragment of left coracoid, identified as being from a gallopheasant (*Lophura* sp.) also recovered from near the base of the shell midden in Trench 1 context (8107). Micro-vertebrate remains are noticeably rare compared to higher in the sequence, where they are linked to cave-roosting birds. Infrequent freshwater crab chelae were also identified.

The lower part of this phase yielded molluscan evidence from four consecutive and approximately equal spits within context (8019) and the highest quantities (MNI) of molluscs in the phase (table 6). Cyclophorids dominated but a number of other taxa were also represented. These too are associated with forested/arboreal environments, such as *Amphidromus* sp., which lives on trees and shrubs. Three fragments of the freshwater mussel *Unio* spp. appear at this point, as do fragments of *Ellobium aurisjudae*. Unionidae generally inhabit freshwater environments, such as slow rivers, lakes or ponds; while *Ellobium aurisjudae* can inhabit quite a broad range of aquatic environments, from muddy estuaries to mangroves (Nguyen Ngoc Thach 2005). From the top of the phase (contexts 8010 & 8011) only a low quantity of molluscs were recovered and three species of *Cyclophorus*. The molluscan data from Phase II, though, supports the picture that the area around the cave was at this time forested and contained a source of freshwater in its vicinity.

Techno-typological analysis yielded *n* = 29 artefacts, 89.6 per cent (*n* = 26/29) made on shale including, shale flakes, flake fragments and one short axe. The three remaining pieces

were limestone flakes/flake fragments (table 7). Attribute analysis identifications were slightly lower at $n = 24$, comprising: one pebble tool, 13 complete flakes and 10 flake fragments; 83 per cent ($n = 20/24$) of the artefacts were made on one unidentified raw material, likely shale, the remaining 17% ($n = 4/24$) on two other materials.

Although palynological work was hampered by the degraded state of pollen grains, some identification was nonetheless possible for Phase II, including tree families: Brassicaceae (Crucifer), Rubiaceae, Leguminosae (Fabaceae/Mimosa), Betulaceae and *Pinus* or *Podocarpus*; and more diverse families, such as Moraceae or Urticaceae, which are both mixed families of trees, herbs, climbers or succulents, preferring warm tropical and lowland forest regions; Ulmaceae trees and shrubs persist, and Poaceae, which is an open ground grass taxa also appears. Proximal pollen records from comparable conditions within China reflect the findings from Hang Trống, whereby sub-tropical forests dominate (Wang *et al.* 2012). Charred fragments of Dipterocarpaceae (cf. *Dipterocarpus*) were recovered from contexts (8016 & 8100); as were specimens of Pinaceae and Sapotaceae (context 8100). Fragments of Rhizophoraceae (cf. *Rhizophora*) tree and shrub taxa came from the top of the phase (context 8010) in Trench 1. These latter are significant components of mangrove forest (Nguyen Ngoc Chinh *et al.* 1996) though the potential proximity of the site to this habitat at this time has yet to be determined. Leguminosae (cf. *Dialium* sp.) fragments were identified from this phase in Trench 3, context (8308). Remains of *Celtis* sp. endocarps are notably increased from Phase III, while those of the nut *Canarium* spp. (Family: Burseraceae) appear for the first time (table 2). It is unclear if these changes relate to more intensive use of the site during Phase II (see figure 5) or to a shift in (through continuing presence of) forest conditions.

Towards the base of this phase (141.0 m. asl.) the n -alkane data display a slight increase in average chain length. This potentially signals that a resurgent wet monsoon during the early post-LGM provided a more favourable growing environment; something that may also have been linked to more intensive use of the site. Compound-specific isotope analysis of both n -alkanoic acid and n -alkane higher plant lipids remains stable through-out the phase, indicating a predominantly C_3 vegetation cover, contradictory to evidence from islands further south where C_4 plant-type dominate at this time (Wurster *et al.* 2010). The n -alkane data indicate vegetation broadly similar to that seen in the property today.

4.2 Phase I (142.15-141.55 m asl.)

The final intact occupational phase in the excavation is associated with an age 14,056-14,902 BP (UBA-21288) from Trench 3 and 15,522-16,663 BP (UBA-14884) in Trench 1. Representatives from five macro-vertebrate mammalian families were identified: Cervidae, Hystricidae, Mustelidae (*Arctonyx collaris*), Cercopitidae (cf. *Macaca* sp.) and Sciuridae. The deer (Cervidae) remains were represented by elements from the distal appendicular skeleton, namely phalanges and a left tarsal. Evidence of porcupines (Hystricidae) comprised of isolated teeth; the vector of introduction for this animal is unclear as porcupines are known to frequent caves in this region (e.g. Bacon *et al.* 2008). A well preserved right distal humerus belonging to a hog badger (*Arctonyx collaris*), provides one of the few intact element recoveries from Trench 1. A discrete assemblage of bone fragments from this phase in Trench 3 included pieces of humerus, ulna and femur from a monkey (cf. *Macaca* sp.), together with a complete femur and burnt mandible from a squirrel (Sciuridae). This concentration of remains – unique on the site – was found within context (8308) (sq. 610/715) and dated 14,056-14,902 BP (UBA-21288). The faunal remains were also found in

association with three stone implements, with patches of charcoal and possibly ochre adhering to their surfaces (table 7, artefacts 48 & 52) and several flakes, all clustered underneath a single whole large freshwater mussel. This context was excavated beneath a large slab of roof fall, which also carried red and black linear pigmentation on its western face: it is as yet unclear if this colouration was deliberately applied or was the result of burning from hearths in the immediate vicinity, though the concentrated nature of these finds certainly bears the hallmarks of having been deliberately placed.

This phase also included low frequencies of micro-vertebrate remains. These were dark in colour (compared to examples from the taphonomic control and mixed contexts above) with calcium carbonate deposition clearly evident. Included among these remains were bones of birds, fish, rodents and shrews. The presence of this material is likely to be an indication that owls were roosting in this part of the cave; though the filtering of micro-vertebrate bones through the coarse matrix of shells cannot be completely discounted. The bones of insectivorous bats are also present, including *Taphozous* sp. (tomb bats). These are also interpreted as cave-dwelling fauna and, therefore, almost certainly natural introductions. Small quantities of crab chelae were again found, including burnt specimens. These are more reliably considered to have been introduced to the site by people.

Data from the molluscan column sample from Trench 1 (table 6) that relates to the lower part of this phase includes material from three contexts (8007a-c & 8009), which is again dominated by *Cyclophorus* sp., *Cryptozona* cf. *chrysoraphe* and Zonitidae cf. *Oxychilus* sp., present also now is *Camaena* sp. – an herbivorous terrestrial mollusc that lives in and around shrubs and trees. This taxonomic representation is again indicative of a forested local environment. Single pieces of the aquatic *Unio* spp. and *Cerithrium* sp. were also identified; indications that nearby freshwater habitats were being exploited. Burnt shell suggests hearths were set in the middle of the cave. The molluscan sample from the upper part of this phase (contexts 8006, 8005, 8004, 8003b & 8003a) was found to be dominated by *Cyclophorus* sp. Quantities of *Cryptozona* cf. *chrysoraphe* and Zonitidae cf. *Oxychilus* sp. were also identified. *Camaena* sp., which is found deeper in this part of the sequence were not present. This may indicate a shift in local conditions or a change in human gathering patterns.

Techno-typological analysis of the lithic assemblage from the 2010 excavations identified $n = 21$ artefacts from Phase I in Trenches 2 and 3 (table 7). This consisted: a predominance of shale flakes, flake fragments and blade/flake (with one a burin) specimens; as well as a shale chopper/core and short-axe were also recovered – 71.4 per cent ($n = 15/21$) of the total. Other modified pieces were flakes, core and pounder, all of limestone; and a burnt pebble fragment. A total of $n = 27$ modified pieces were identified as part of the attribute analysis study. Four out of a possible seven different types of raw material occurring at the site were allocated to Phase I by the attribute analysis study in the following percentages: 55.5, 25.9, 14.8 and 3.7. Eighteen complete flakes, six flake fragments, two pebble tools and a core were identified.

The climate is likely to have been variable during this phase: insolation levels were increasing; however the phase is also punctuated by H1, a noticeably cold-dry period, indicated by sea surface records from the Gulf of Tonkin and the Hulu Cave speleothem record (e.g. Huang 1997; Oppo & Sun 2005; Pelejero *et al.* 1999; Shintani *et al.* 2011; Wei *et al.* 2007; Visser *et al.* 2003; Wang *et al.* 2001). Pollen recovered from within this phase was noticeably degraded, though appears synchronous with a proximal lake pollen record from South China (Wang *et al.* 2012). Grains of Brassicaceae (Crucifer) and Rubiaceae were, also

identified, as were pollen grains of Hamamelidaceae, a family formed of tropical trees and shrubs. Betulaceae and Cyperaceae represent other community components from this phase. Dipterocarpaceae were confirmed in the macro-botanical data (table 2). At this time the coastline is thought to have been still up to 500 km from the Trảng An massif (Yao *et al.* 2009). Sedimentary facies from coring in the Song Hong Delta (core ND-1, 20.372778 N, 106.146667 E) show that c. 14,900 cal. KBP the low-lying landscape beyond the massif contained channels from a meandering river system (Tanabe *et al.* 2006).

Close to the onset of this phase (141.7 m asl) *n*-alkane chain lengths are noticeably shorter (average *n*-alkane chain length C₂₉). It is hypothesized that this reflects the change to colder and dryer conditions in H1. Taken together with increased post-glacial insolation, these factors inhibited production of the protective long-chain *n*-alkanes needed in this subtropical environment; plants only had sufficient resources to maintain shorter *n*-alkanes. Towards the end of the phase, and the expected increase in temperature and moisture, longer *n*-alkane lengths were being produced by the vegetation. Compound-specific isotope analysis of *n*-alkanoic acid and *n*-alkane higher plant lipids from Hang Trống sediments all indicate that the interior of the massif was still characterized by a dominant C₃ vegetation signal that was distinct from the environment setting that lay beyond it.

4.1 Mixed Phase (142.30-142.15 m asl.)

Surface contexts (corresponding to approximately the upper-most 10 cm in each trench) were allocated to a mixed phase due to the likelihood of modern contamination of the sediments. This is borne out through the two radiocarbon dates obtained: 12,594-12,854 BP (UBA-09301) from our reconnaissance test-pitting here in 2007 and a contrasting date of 32-355 BP (UBA-14883) from context (8001) in Trench 1 in 2009. In faunal terms, these contexts are dominated (NISP) by the remains of rodents (Muridae), amphibians (Ranidae: *Rana* sp.), bird bones (small passerines) and small numbers of fish bones. All are considered most likely to derive from owl pellets from roosting sites in the roof of the cave. Bones of insectivorous bats (Chiroptera) and reptiles (*cf.* Gekkonidae) likely represent natural deaths of cave-dwelling fauna. The bones of larger mammals were rare in this phase, but included a fragment of vertebrae from a non-human primate, possibly relating to historic occasional use of the site by hunters.

Molluscan evidence is relatively diverse, including *Clausilia cf. proctostoma* – a species was only otherwise observed during the LGM (*see* Phase III), which may point to a cooling from within the Pleistocene data of these mixed deposits. Aquatic taxa are present, with *Planorbis* sp. a species of freshwater snail and a spike in the percentage quantities of *Cyclophorus*, from c. 65 per cent of the sample to 85 per cent in little more than a couple of centimetres. All of the terrestrial species identified from this phase are known to live in, around or beneath trees, and in the case of other identifications, such as *Cryptozona cf. chrysoraphe* and Zonitidae *cf. Oxychilus* sp., they are likely to inhabit very broad environmental spheres that encompass arboreal environments.

Technologically, the upper-most contexts (8200-8203) in Trench 2 and (8300-8302) in Trench 3 produced eight lithics through techno-typological analysis, and eight through attribute analysis. In a lithological environment where naturally fractured limestone is common-place, such consistency is encouraging. Techno-typologically, the identified pieces included one possible limestone core, three shale flake fragments, three limestone flakes and a limestone short axe (table 7). Attribute analysis of the same sample identified one core, five complete flakes, one pebble tool and one flake fragment. Raw materials were not formally

identified, but artefacts were also grouped by material and fell into three groups (with seven of the artefacts falling into just two groups).

This phase contains the only substantial concentration (60%) of identifiable pollen recovered. This is almost certainly due to modern wind-blown grains becoming trapped within the sediments as erosion and localized micro-re-deposition of these takes place, given the cave's morphology. Charred fragments from samples taken within this phase reveal a number of Dipterocarpaceae specimens; together with *Celtis* sp. and *Canarium* spp. fragments (table 2). The climate signal contains both evidence of warm, moist conditions and also indications of sediment accumulating under cooler conditions. *n*-Alkane biomarkers average high chain lengths, possibly simply a reflection of contemporary sub-tropical conditions.

6. DISCUSSION AND CONCLUSION

The results of work conducted at Hang Trống highlight the potential resilience of limestone forest habitats in northern tropical zone of mainland Southeast Asia. Multiple lines of evidence suggest that these forest formations can sustain themselves through substantial local climatic and environmental change. The data also indicate, however, that they may be susceptible to the impact of rapid climate shifts, such as that associated regionally with H1.

Palynological and macro-botanic evidence point to the persistence of tropical forest cover within Trảng An through-out the LGM, during a period when the surrounding lowlands were characterised by grassland environments. Invertebrate and vertebrate fauna data corroborate the strong arboreal nature of the local habitats within the massif and their durability across this climate downturn. Compound specific analysis of plant biomarkers shows a common C₃ photosynthetic pathway for local vegetation. The *n*-alkanes recovered from Hang Trống indicate that the most dominant chain length in the modern vegetation (C₃₁) was also predominant in the sedimentary record at the site. This is concurrent with other plant zones from this latitude. Thus we can be confident that evidence from our analysis of *n*-alkanes reflects, with some clarity, regional climatic conditions. At *c.* 15 KBP a change in the forest dynamics is indicated by a reduction in C₃₁ *n*-alkane and an increase in C₂₇ *n*-alkane. The dramatic change in *n*-alkane chain length at *c.* 15 KBP coincides with the H1 event and can be attributed to the reduction in summer monsoon during this time.

The occupational record from Hang Trống appears to indicate intervals of more and less intensive site-use, peaking in the period immediately after the LGM, but always at a relatively low scale compared, for example to the later midden deposits from elsewhere in the massif, such as Hang Boi (Rabett *et al.* 2011). The abundance of particularly cyclophorids during the wet summer monsoon is taken as a likely indicator that this was probably the main season of use, though visits outside of this time cannot be ruled out. There are hints of caching activity that, if correct, are suggestive of provisioning. The nature of this through-cave certainly raises the possibility that it was utilised primarily as a corridor to travel between valleys; the generally equitable conditions providing a useful temporary stopping point. Also from a mobility perspective, artefactual evidence from the site suggests a shift in lithic raw material sourcing, from one where limestone predominated, but where a wider range of materials were utilised, during the Phase III (LGM) use of the site, to sourcing that more particularly focused on shale. A higher observed frequency of dorsal flake scar counts is also suggestive of greater reduction intensity during the LGM compared to later phases of site-use. The frequency of flakes and flake fragments is also considerably lower than is seen

during the later phases. Both raise the possibility that occupation during the LGM involved a shift in curation and 'technological organization' (after Nelson 1991) if not in site-use (Phan 2014). Equally notable is that the types of artefacts recovered appear to have been largely consistent through-out (e.g. with short-axes appearing in all three phases and the mixed phase): changes were primarily in technological strategies rather than technologies themselves. Indications are that foraging groups may have focused attention on resources available within the massif, at least on a seasonal basis, chiefly owing to their reliability. Such apparent stability (and diversity) in resources may have regional implications. The consistent recovery of occupational evidence from limestone environments may have significance beyond the simple fact of preservation (and research focus) within these settings; they may turn out to have been genuine islands of humanity. Furthermore, early human presence in Tràng An, even under conditions when vegetation was more stressed, does not appear to have been adverse to forest survival. That being so, there is an argument to be made that with careful management the impact of modern visitors to this and similar properties should also be sustainable.

Taken together, the results of our analysis suggest the presence of forests within this massif though the course of the last twelve thousand years of MIS-2, and provide testament to their resilience to large-scale climate and environmental change. Forest continuity in Tràng An into the Holocene and present day (see also Ludgate *et al.* forthcoming) would seem to underscore this. Faced now with the prospect of no lesser transformation through climate change and regional sea-level rise (Nicholls & Cazenave 2010; Rietbroek *et al.* 2016) our findings give reason for optimism about the chances of survival of these biodiverse, richly endemic and archaeologically bountiful landscapes. With careful management the impact of modern visitors to this and similar properties should be sustainable, though this does not lessen the crucial importance that diligent conservation will play in extending the longevity of limestone forest habitats.

REFERENCES

- Adam, J.H. and Mamat, Z. 2005. Floristic composition and structural comparison of limestone forests at three different elevations in Bau, Kuching, Sarawak, Malaysia. *Journal of Biological Sciences* 5(4): 478-485.
- Andrews, P. 1990. *Owls, Caves, and Fossils*. University of Chicago Press, Chicago.
- Ashton, P.S. 1988. Dipterocarp biology as a window to the understanding of tropical forest structure. *Annual Review of Ecological Systems* 19: 347-370.
- Bacon, A-M., Demeter, F., Durringer, P., Helm, C., Bano, M., Vu The Long, Nguyen Thi Kim Thuy, Antoine, P-O., Bui Thi Mai, Nguyen Thi Mai Huong, Dodo, Y., Chabaux, F., Rihs, S. 2008. The Late Pleistocene Duoi U'Oi cave in northern Vietnam: palaeontology, sedimentology, taphonomy and palaeoenvironments. *Quaternary Science Reviews* 27: 1627-1654.
- Bacon, A-M., Westaway, K., Antoine, P-O., Durringer, P., Blin, A., Demeter, F., Ponche, J-L., Zhao, J-X., Barnes, L.M., Sayavonkhamdy, T., Nguyen Thi Kim Thuy, Vu The Long, Patole-Edoumba, E., Shackelford, L. 2015. Late Pleistocene mammalian assemblages of Southeast Asia: new dating, mortality profiles and evolution of the predator-prey relationships in an environmental context. *Palaeogeography, Palaeoclimatology, Palaeoecology* 422: 101-127.

- Banjoo, D.R. & Nelson, P.K. 2005. Improved ultrasonic extraction procedure for the determination polycyclic aromatic hydrocarbons in sediments. *Journal of Chromatography A* 1066: 9-18.
- Barker, G. 2013. *Rainforest foraging and farming in island Southeast Asia: the archaeology of the Niah Caves, Sarawak*. Vol. 1. McDonald Institute Monographs and Sarawak Museums.
- Barton, R.N.E., Bouzouggar, A., Collcutt, S.N., Gale, R., Higham, T.F.G., Humphrey, L.T., Parfitt, S., Rhodes, E., Stringer, C.B., Malek, F. 2005. The Late Upper Palaeolithic occupation of the Moroccan northwest Maghreb during the Last Glacial Maximum. *African Archaeological Review* 22(2): 77-100.
- Bird, M., Boobyer, E.M., Bryant, C., Lewis, H.A., Paz, V., Edryd Stephens, W. 2007. A long record of environmental change from bat guano deposits in Makangit Cave, Palawan, Philippines. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 98: 59-69.
- Birks, H.J.B., 1981. The use of pollen analysis in the reconstruction of past climates: a review. *Climate and History*, 11: 137.
- Birks, H.J.B. & Birks, H.H. 1980. *Quaternary Palaeoecology*. Edward Arnold, London.
- Blyth, A.J., Asrat, A., Baker, A., Gulliver, P., Leng, M.J., Genty, D. 2007. A new approach to detecting vegetation and land-use change using high-resolution lipid biomarker records in stalagmites. *Quaternary Research* 68(3): 314-324.
- Brown, P., Sutikna, T., Morwood, M.J., Soejono, R.P., Jabniko, Wayhu Saptomo, E. Rokus Awe Due. 2004. A new small-bodied hominin from the Late Pleistocene of Flores, Indonesia. *Nature* 431: 1055-1091.
- Carlos, A.J.B. 2010. Inferring Subsistence Patterns in the Ille Cave and Rockshelter Site: The Macrobotanical Evidence. MS Thesis. University of the Philippines
- Ceron, J. n.d. Report on archaeological wood collected from Tràng An cave sites. Unpublished project report.
- Clark, P.U., Dyke, A.S., Shakun, J.D., Carlson, A.E., Clark, J., Wohlfarth, B., Mitrovica, J.X., Hostetler, S.W., McCabe, A.M. 2009. The Last Glacial Maximum. *Science* 325: 710-714.
- Clements, R., Sodhi, N.S., Schilthuizen, M., Ng, P.K.L. 2006. Limestone karsts of Southeast Asia: imperiled arks of biodiversity. *BioScience* 56(9): 733-742.
- Clements, R., Nga, P.K.L., Lub, X.X., Ambu, S., Schilthuizen, M., Bradshaw, C.J.A. 2008. Using biogeographical patterns of endemic land snails to improve conservation planning for limestone karsts. *Biological Conservation* 141: 2751-2764.
- Cook, E.J. 2009. A record of late Quaternary environments at lunette-lakes Bolac and Turangmoro, Western Victoria, Australia, based on pollen and a range of non-pollen palynomorphs. *Review of Palaeobotany and Palynology* 153: 185-224.
- Dai, L. & Weng, C. *in press*. Marine palynological record for tropical climate variations since the late last glacial maximum in the northern South China Sea. *Deep Sea Research II*.
- Eglinton G. & Hamilton, R.J. 1967. Leaf Epicuticular Waxes. *Science* 156: 1322-1335.
- Ella, A.B., Meniado, J.M., Escobin, R.P., Maruzzo, M.M., America, W.M. 2009. Anatomical Identification Handbook of Philippines Dipterocarps. FPRDI-DOST College, Laguna.
- Fægri, K. & Iversen, J. 1989. *Textbook of pollen analysis*. 4th edition. John Wiley & Sons, Chichester.
- Faridah-Hanum, I., Latiff, A., Khalid Rehman Hakeem, Ozturk, M. 2014. *Mangrove Ecosystems of Asia: Status, Challenges and Management Strategies*. Springer: New York.
- Furey, N.M., Mackie, I.J., Racey, P.A. 2010. Bat diversity in Vietnamese limestone karst areas and the implications of forest degradation. *Biodiversity Conservation* 19: 1821-1838.

- Gao, Y., Ai, B., Kong, H., Kang, M., Huang, H. 2015. Geographical pattern of isolation and diversification in karst habitat islands: a case study in the *Primulina eburnea* complex. *Journal of Biogeography* 42: 2131-2144.
- Hadley, N.F. 1980. Surface Waxes and Integumentary Permeability: Lipids deposited on or associated with the surface of terrestrial plants and animals help protect them from a lethal rate of desiccation. *American Scientist* 68(5): 546-553.
- Hanebuth, T., Stattegger, K., Grootes, P.M. 2000. Rapid flooding of the Sunda Shelf: a late-glacial sea-level record. *Science* 288:1033-1035.
- Hanebuth, T.J.J., Stattegger, K., Bojanowski, A. 2009. Termination of the Last Glacial maximum sea-level lowstand: the Sunda-Shelf data revisited. *Global and Planetary Change* 66: 76-84.
- Holland, S.M. 2012. Sea level change and the area of shallow-marine habitat: implications for marine biodiversity. *Paleobiology* 38(2): 205-217.
- Huang, C.Y., Liew, P.M., Zhao, M., Chang, T.C., Kuo, C.M., Chen, M.T., Wang, C.H., Zheng, L.F., 1997. Deep sea and lake records of the Southeast Asian paleomonsoons for the last 25 thousand years. *Earth and Planetary Science Letters* 146(1): 59-72.
- Huang, E., Tian, J., Steinke, S. 2011. Millennial-scale dynamics of the winter cold tongue in the southern South China Sea over the past 26 ka and the East Asian winter monsoon. *Quaternary Research* 75: 196-204.
- Huang, X., Cui, J., Pu, Y., Huang, J., Blyth, A.J. 2008. Identifying “free” and “bound” lipid fractions in stalagmite samples: An example from Heshang Cave, Southern China. *Applied Geochemistry* 23(9): 2589-2595.
- Hunt, C.O. & Gilbertson, D.D. 2014. Shorelines, mangroves and human environments in the coastal lowlands of northeastern Borneo during the Late Quaternary. *Living in the Landscape*. Boyle, K., Rabett, R. & Hunt, C. (eds.) (McDonald Institute Monographs) Cambridge: McDonald Institute for Archaeological Research, p. 121-136.
- Hunter, E.A., Nibbelink, N.P., Alexander, C.R., Barrett, K., Mengak, L.F., Guy, R.K., Moore, C.T., Cooper, R.J. 2015. Coastal vertebrate exposure to predicted habitat changes due to sea level rise. *Environmental Management* 56: 1528-1537.
- Husemann, M., Schmitt, T., Zachos, F.E., Ulrich, W., Habel, J.C. 2014. Palaeartic biogeography revisited: evidence for the existence of a North African refugium for Western Palaeartic biota. *Journal of Biogeography* 41(1): 81-94.
- Intergovernmental Panel on Climate Change (IPCC) 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Special report. Cambridge University Press: Cambridge.
- Intergovernmental Panel on Climate Change (IPCC) 2007-II. *Impacts, Adaptations and Vulnerability*. Special report. Cambridge University Press: Cambridge.
- Kienast, M., Hanebuth, T.J.J., Pelejero, C., Steinke, S. 2003. Synchronicity of meltwater pulse 1a and the Bølling warming: new evidence from the South China Sea. *Geology* 31(1): 67-70.
- Kirwan, M.L., Guntenspergen, G.R., D’Alpaos, A., Morris, J.T., Mudd, S.M., Temmerman, S. 2010. Limits on the adaptability of coastal marshes to rising sea level. *Geophysical Research Letters* 37: L23401.
- Koch, K. & Ensikat, H. 2008. The hydrophobic coatings of plant surfaces: epicuticular wax crystals and their morphologies, crystallinity and molecular self-assembly. *Micron*, 39(7): 759-772.

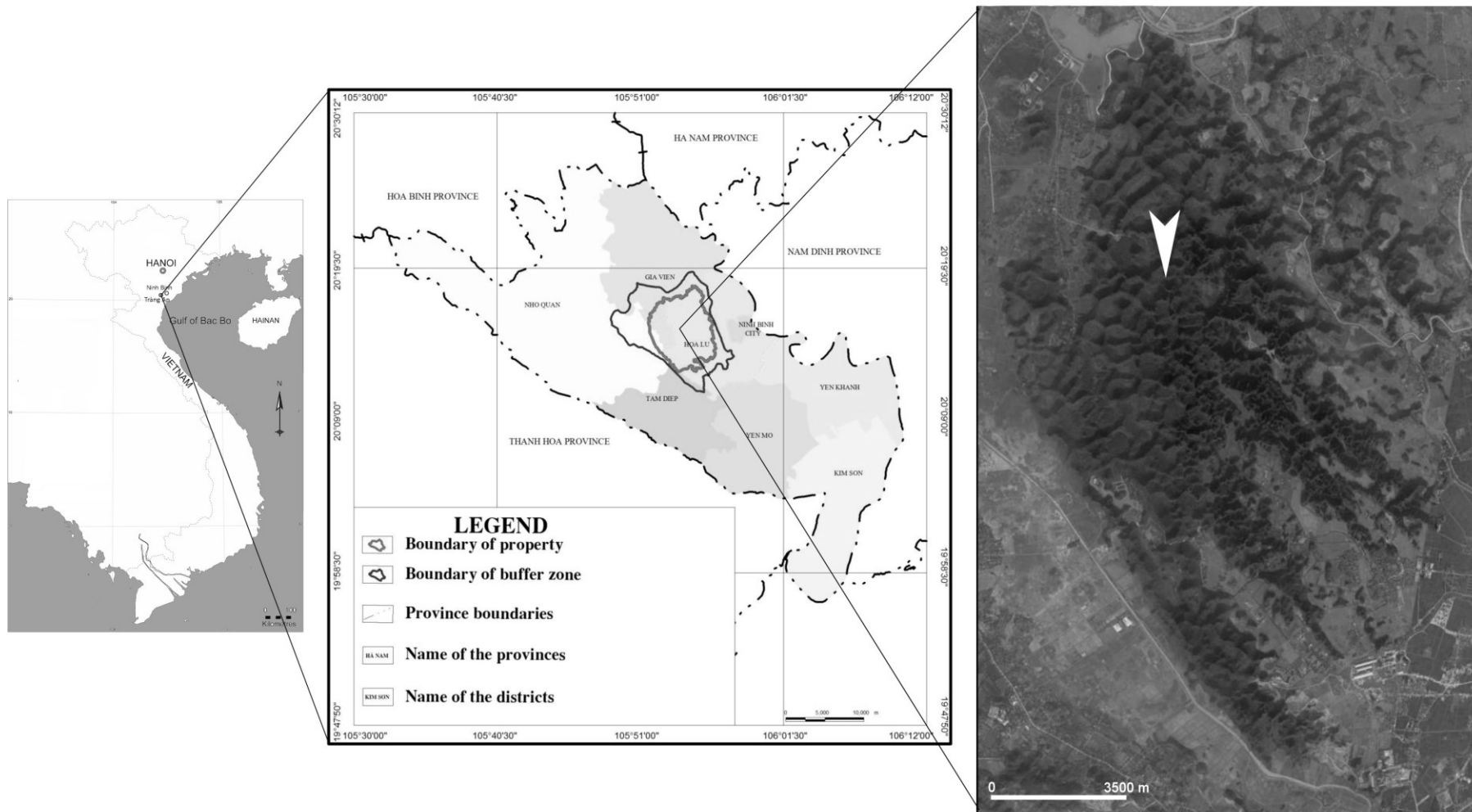
- Kohn, M.J. and Cerling, T.E. 2002. Stable isotope compositions of biological apatite. *Reviews in mineralogy and geochemistry*, 48(1): 455-488.
- Kopp, R.E. 2012. Palaeoclimate: Tahitian record suggests Antarctic collapse. *Nature* 483: 549–50.
- Kosma, D.K., Bourdenx, B., Bernard, A., Parsons, E.P., LÜ, S., Joubès, J., Jenks, M.A. 2009. The impact of water deficiency on leaf cuticle lipids of *Arabidopsis*. *Plant Physiology*, 151(4): 1918-1929.
- Latinne, A., Meynard, C.N., Herbreteau, V., Waengsothorn, S., Morand, S., Michaux, J.R. 2015. Influence of past and future climate changes on the distribution of three Southeast Asian murine rodents. *Journal of Biogeography* 42: 1714-1726.
- Lekagul, B. and McNeely, J.A. 1988. *Mammals of Thailand*. Association for the Conservation of Wildlife, Darnsutha Press, Bangkok.
- Li, Z., Saito, Y., Matsumoto, E., Wang, Y., Haruyama, S., Hori, K., Le Quoc Doanh, 2006. Palynological record of climate change during the last deglaciation from the Song Hong (Red River) delta, Vietnam. *Palaeogeography, Palaeoclimatology, Palaeoecology* 235: 406-430.
- Lockheart, M.J., Van Bergen, P.F., Evershed, R.P. 1997. Variations in the stable carbon isotope compositions of individual lipids from the leaves of modern angiosperms: implications for the study of higher land plant-derived sedimentary organic matter. *Organic Geochemistry*, 26(1-2): 137-153.
- Ludgate, N.F. 2013. *Biogenic matter preserved in cave sediments: a new environmental proxy?* Unpublished PhD dissertation, Open University.
- Ludgate, N.F., Blyth, A.J. Gilmore, I., Gilmour, M. *Forthcoming*. Leaf wax biomarkers and their use in reconstructing Pleistocene environment from Trang An; an area of archaeological cave investigations from Northern Vietnam.
- 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: 3088-3098.
- Mendoza-González, G. *, Martínez, M.L., Rojas-Soto, O.R., Vázquez, G., Gallego-Fernández, J.B. 2013. Ecological niche modeling of coastal dune plants and future potential distribution in response to climate change and sea level rise. *Global Change Biology* 19: 2524-2535.
- Meyers, P.A. & Ishiwatari, R. 1993. Lacustrine organic geochemistry—an overview of indicators of organic matter sources and diagenesis in lake sediments. *Organic Geochemistry* 20(7): 867-900.
- Mijares, A.S., Détroit, F., Piper, P., Grün, R., Bellwood, P., Aubert, M., Champion, G., Cuevas, N., DeLeon, A., Dizon, E. 2010. New evidence for a 67,000-year-old human presence at Callao Cave, Luzon, Philippines. *Journal of Human Evolution* 59(1): 123-132
- Molengraaff, G.A.F. & Weber, M. 1921. On the relation between the pleistocene glacial period and the origin of the Sunda sea (Java and South China-sea), and its influence on the distribution of coral reefs and on the land- and freshwater fauna, Netherlands *Academy of Arts and Sciences (KNAW) Proceedings* 23(1): 395-439.
- Nelson, M.C. 1991. The Study of Technological Organization. *Archaeological Method and Theory* 3: 57-100.
- Nguyen Dai Trung, Tran Tan Van, Vu Van Ha, Trinh Thi Thuy, 2012. Sea levels and occupation of prehistoric people in karst valleys in Tràng An Scenic Complex (Ninh Binh). *Vietnam Archaeology* 7: 12-23.

- Nguyen Gia Doi, Nguyen Anh Tuan, Le Hai Dang, 2012. Palaeoenvironmental conditions and human adaptation at Tràng An. *Vietnam Archaeology* 7: 38-51.
- Nguyen Ngoc Chinh, Cao Thuy Chung, Vu Van Can., Xuan Dung Nguyen, Vu Van Dung, Nguyen Kim Dao, Tran Hop, Tran, Tuyet Oanh, Nguyen Boi Quynh, Nguyen Nghia Thin, 1996. *Vietnam Forest Trees*. Agricultural Publishing House: Hanoi.
- Nguyen Ngoc Thach, 2005. *Shells of Vietnam*. Conch Books, Hackenheim.
- Nguyen Tu, T.T., Egasse, C., Zeller, B., Bardoux, G., Biron, P., Ponge, J., David, B., Derenne, S. 2011. Early degradation of plant alkanes in soils: A litterbag experiment using ¹³C-labelled leaves. *Soil Biology and Biochemistry*, 43(11): 2222-2228.
- Nicholls, R.J. & Cazenave, A. 2010. Sea-level rise and its impact on coastal zones. *Science* 328: 1517-1520.
- O'Leary, M.H. 1981. Carbon isotope fractionation in plants. *Phytochemistry*, 20(4): 553-567.
- Oppo, D.W. & Sun, Y. 2005. Amplitude and timing of sea-surface temperature change in the northern South China Sea: Dynamic link to the East Asian monsoon. *Geology* 33(10): 785-788.
- Osborne, C.P. & Sack, L. 2012. Evolution of C4 plants: a new hypothesis for an interaction of CO₂ and water relations mediated by plant hydraulics. *Philosophical Transactions of the Royal Society (B)*, 367(1588): 583-600.
- Paillard, D., Labeyrie, L., Yiou, P. 1996. Macintosh program performs time-series analysis, *Eos Trans. AGU*, 77: 379 . http://www.agu.org/eos_elec/96097e.html: AGU.
- Pala, M., Olivieri, A., Achilli, A. *et al.* 2012. Mitochondrial DNA signals of Late Glacial recolonization of Europe from Near Eastern refugia. *The American Journal of Human Genetics* 90: 915-924.
- Partin, J.W., Cobb, K.M., Adkins, J.F., Clark, B., Fernandez, D.P. 2007. Millennial-scale trends in west Pacific warm pool hydrology since the Last Glacial Maximum. *Nature* 449: 453-455.
- Partin, J.W., Quinn, T.M., Shen C.-C., Okumura, Y., Cardenas, M.B., Siringan, F.P., Banner, J.L., Lin, K., Hu, H.-M., Taylor, F.W. 2015. Gradual onset and recovery of the Younger Dryas abrupt climate event in the tropics. *Nature Communications* 6: 8061 (DOI: 10.1038/ncomms9061).
- Paz, V.J. 2001. Archaeobotany and Cultural Transformation: Patterns of Early Plant Utilization in Northern Wallacea, Ph.D dissertation, University of Cambridge.
- Pelejero, C., Grimalt, J.O., Heilig, S., Kienast, M., Wang, L., 1999. High-resolution U^{K37} temperature reconstructions in the South China Sea over the past 220 kyr. *Palaeogeography, Palaeoclimatology, Palaeoecology* 14(2), 224-231.
- Phan, L. 2014. *Late Pleistocene lithic technology at Hang Trống cave, Vietnam: climate change and Hoabinhian lithic organization*. Unpublished MPhil dissertation, University of Cambridge.
- Quade, J., Cerling, T.E., Bowman, J.R. 1989. Development of Asian monsoon revealed by marked ecological shift during the latest Miocene in northern Pakistan. *Nature* 342: 163-166.
- Rabett, R.J. 2012. Human Adaptation in the Asian Palaeolithic: Hominin Dispersal and Behaviour during the Late Quaternary. Cambridge University Press: Cambridge.
- Rabett, R.J. *in press* Foragers, cultivators and mariners: the complex emergence of the Neolithic in Southeast Asia. HEADS 6 (World Heritage Papers).
- Rabett, R., Appleby, J., Blyth, A., Farr, L., Gallou, A., Giffiths, T., Hawkes, J., Marcus, D., Marlow, L., Morley, M., Nguyễn Cao Tân, Nguyễn Văn Sơn, Penkman, K., Reynolds,

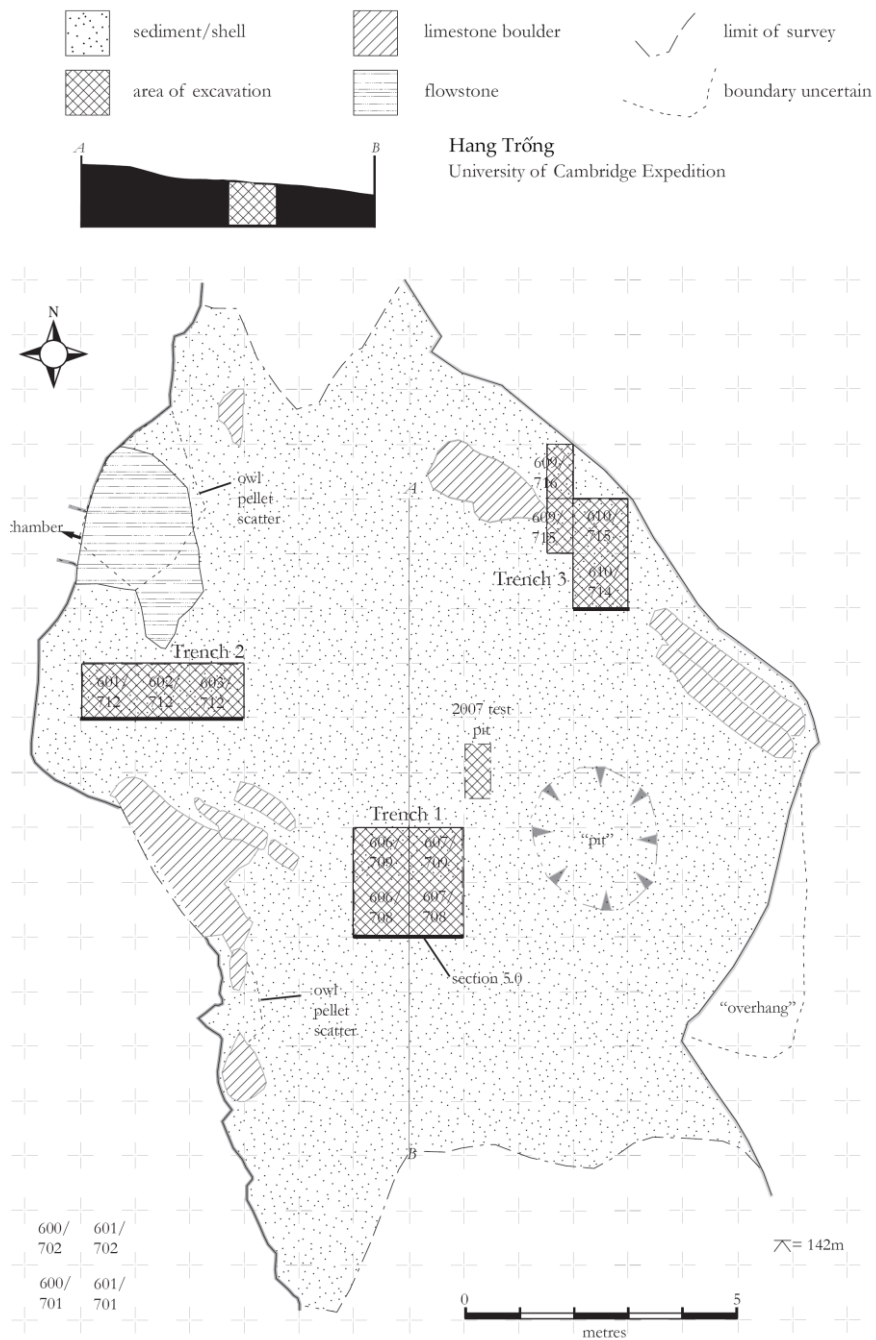
- T., Stimpson, S., Szabó, K. 2011. Inland shell midden site-formation: investigation into a late Pleistocene to early Holocene midden from Trảng An, northern Vietnam, *Quaternary International* 239: 153-169.
- Rasmussen, S.O., Seierstad, I.K., Andersen, K.K., Bigler, M., Dahl-Jensen, D., Johnsen, S.J. 2006. Greenland Ice Core Calcium and Oxygen Isotope Data . Data Contribution Series # 2006-120. NOAA/NCDC Paleoclimatology Program, Boulder CO, USA: IGBP PAGES/World Data Center for Paleoclimatology.
- Reimer, P.J., Baillie, M.G., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., van der Plicht, J., Weyhenmeyer, C.E. 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0-50,000 years cal. BP. *Radiocarbon* 51(4): 1111-1150.
- Reynolds, T.E.G. 1989. Techno-typology in Thailand: a case study of the Tham Khao Khi Chan. *Indo-Pacific Prehistoric Association* 9: 33-43.
- Rietbroek, R., Brunnabend, S-E., Kusche, J., Schröter, J., Dahl, C. 2016. Revisiting the contemporary sea-level budget on global and regional scales. PNAS (Early edition) doi/10.1073/pnas.1519132113
- Rommerskirchen, F., Eglinton, G., Dupont, L., Günter, U., Wenzel, C., Rullkötter, J. 2003. A north to south transect of Holocene southeast Atlantic continental margin sediments: Relationship between aerosol transport and compound- specific $\delta^{13}\text{C}$ land plant biomarker and pollen records. *Geochemistry Geophysics Geosystems* 4(12): 1101.
- Roscoe, P. 2014. A changing climate for Anthropological and Archaeological research? Improving the climate-change models. *American Anthropologist* 116(3): 535-48.
- Rose, J.I., Černý, V., Bayoumi, R. 2013. *Tabula rasa* or refugia? Using genetic data to assess the peopling of Arabia. *Arabian Archaeology and Epigraphy* 24: 95-101.
- Sala, O.E., Chapin III, F.S., Armesto, J.J. et al. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* 287: 1770-1774.
- Sathiamurthy, E. & Voris, H.K. 2006. Maps of Holocene sea level transgression and submerged lakes on the Sunda Shelf. *The Natural History Journal of Chulalongkorn University* (Supplement) 2: 1-44.
- Schimanski, A. & Statteger, K. 2005. Deglacial and Holocene evolution of the Vietnam shelf: stratigraphy, sediments and sea-level change. *Marine Geology* 214: 365-387.
- Schwark, L., Zink, K., Lechterbeck, J. 2002. Reconstruction of postglacial to early Holocene vegetation history in terrestrial Central Europe via cuticular lipid biomarkers and pollen records from lake sediments. *Geology*, 30(5): 463.
- Shintani, T., Yamamoto, M., Chen, M. 2011. Paleoenvironmental changes in the northern South China Sea over the past 28,000 years: A study of TEX86 derived sea surface temperatures and terrestrial biomarkers. *Journal of Asian Earth Sciences* 40(6): 1221-1229.
- Smith, B.H., Crummett, T.L., Brandt, K.L. 1994. Ages of eruption of primate teeth: a compendium for aging individuals and comparing life histories. *Yearbook of Physical Anthropology* 37: 177-231.
- Soares, P., Trejaut, J. A., Jun-Hun Loo, Hill, C., Mormina, M., Lee, C-L., Chen, Y-M., Hudjashov, G., Forster, P., Macaulay, V., Bulbeck, D., Oppenheimer, S., Lin, M., Richards, M. B. 2008. Climate Change and Postglacial Human Dispersals in Southeast Asia. *Molecular Biology Evolution* 25(6): 1209-1218.

- Sodhi, N.S., Brook, B.W., Bradshaw, C.J.A. 2007. *Tropical Conservation Biology*. Blackwell Publishing: Oxford.
- Sodhi, N.S., Koh, L.P., Clements, R., Wanger, T.C., Hill, J.K., Hamer, K.C., Clough, T., Tschardtke, T., Posa, M.R.C., Tien, M.L. 2010. Conserving Southeast Asian forest biodiversity in human-modified landscapes. *Biological Conservation* 143: 2375-2384.
- Stahl, P.W. 1996. The recovery and interpretation of micro-vertebrate bone assemblages from archaeological contexts. *Journal of Archaeological Method and Theory* 3: 31-75.
- Sterling, E.J., Hurley, M.M., Le Duc Minh. 2006. *Vietnam: A Natural History*. Yale University Press: New Haven and London.
- Stimpson, C. M. 2012. Local-scale, proxy evidence for the presence of closed-canopy forest in Northwestern Borneo in the Late Pleistocene: bones of Strategy I bats from the archaeological deposits of the Great Cave of Niah, Sarawak. *Palaeogeography, Palaeoclimatology, Palaeoecology* 331-332: 136-149.
- Sun, X., Wu, Y., Qiao, Y., Walker, D. 1986. Late Pleistocene and Holocene vegetation history at Kunming, Yunnan Province, southwest China. *Journal of Biogeography* 13(5): 441-476.
- Sun, X., Li, X. 1999. A pollen record of the last 37 ka in deep sea core 17940 from the northern slope of the South China Sea. *Marine Geology* 156: 227-244.
- Sun, X., Li, X., Luo, Y., Chen, X., 2000. The vegetation and climate at the last glaciation on the emerged continental shelf of the South China Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology* 160: 301-16.
- Sun, X., Luo, Y., Fei, H., Tian, J., Wang, P., 2003. Deep-sea pollen from the South China Sea: Pleistocene indicators of East Asian monsoon. *Marine Geology* 201: 97-118.
- Swindler, D.R. 2002. *Primate Dentition: An Introduction to the Teeth of Non-Human Primates*. Cambridge University Press, Cambridge.
- Tanabe, S., Saito, Y., Vu, Q.L., Hanebuth, T. J.J., Kitamura, A., Ngo, Q.T. 2006. Holocene evolution of the Song Hong (Red River) delta system, northern Vietnam. *Sedimentary Geology* 187: 29-61.
- Thompson G.B. 1996. The Excavation of Khok Phanom Di, a Prehistoric Site in Central Thailand. Volume IV: Subsistence and Environment: The Botanical Evidence (The Biological Remains, Part II). The Society of Antiquaries of London, London.
- Van Bergen, P.F., Bull, I. D., Poulton, P.R., Evershed, R.P. 1997. Organic geochemical studies of soils from the Rothamsted classical experiments - I. Total lipid extracts, solvent insoluble residues and humic acids from broadbalk wilderness. *Organic Geochemistry*, 26: 117-135.
- Van de Noort, R. 2011. Conceptualising climate change archaeology. *Antiquity* 85: 1039-48;
- van den Bergh, G.D., Meijer, H.J.M., Rokus Awe Due, Morwood, M.J., Szabó, K., van den Hoek Ostende, L.W., Sutikna, T., Saptomo, E.W., Piper, P.J., Dobney, K.M. 2009. The Liang Bua faunal remains: a 95 kyr. sequence from Flores, East Indonesia. *Journal of Human Evolution* 57(5): 527-537.
- Verleyen, E., Hodgson, D.A., Milne, G.A., Sabbe, K., Vyverman, W. 2005. Relative sea-level history from the Lambert Glacier region, East Antarctica, and its relation to deglaciation and Holocene glacier readvance. *Quaternary Research* 63: 45-52.
- Virah-Sawmy, M., Willis, K.J., Gillson, L. 2009. Threshold response of Madagascar's littoral forest to sea-level rise. *Global Ecology and Biogeography* 18: 98-110.
- Visser, K., Thunell, R., Stott, L. 2003. Magnitude and timing of temperature change in the Indo-Pacific warm pool during deglaciation. *Nature* 421(6919): 152- 155.

- Wang, S., Lu, H., Han, J., Chu, G., Liu, J. and Negendank, J.F. 2012. Palaeovegetation and palaeoclimate in low-latitude southern China during the Last Glacial Maximum. *Quaternary International*, 248: 79-85.
- Wang, P., Zhang, Q., Wang, Y., Wang, T., Li, X., Ding, L., Jiang, G. 2010. Evaluation of Soxhlet extraction, accelerated solvent extraction and microwave-assisted extraction for the determination of polychlorinated biphenyls and polybrominated diphenyl ethers in soil and fish samples. *Analytica Chimica Acta* 663(1): 43-48.
- Wang, Y.J., Cheng, H., Edwards, R.L., An, Z.S., Wu, J.Y., Shen, C.C., Dorale, J.A. 2001. A high-resolution absolute-dated late Pleistocene monsoon record from Hulu Cave, China. *Science* 294: 2345-2348.
- Wei, G., Deng, W., Liu, Y., Li, X. 2007. High-resolution sea surface temperature records derived from foraminiferal Mg/Ca ratios during the last 260 ka in the northern South China Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology* 250(1): 126-138.
- Wetzel, F.T., Kissling, W.D., Beissmann, H., Penn, D.J. 2012. Future climate change driven sea-level rise: secondary consequences from human displacement for island biodiversity. *Global Change Biology* 18: 2707-2719.
- Weyhenmeyer, C.E., Burns, S.J., Waber, H.N., Aeschbach-Hertig, W., Kipfer, R., Loosli, H.H., Matter, A. 2000. Cool glacial temperatures and changes in moisture source recorded in Oman ground waters. *Science* 287: 842-845.
- Williams, A.N., Ulm, S., Cook, A.R., Langley, M.C., Collard, M. 2013. Human refugia in Australia during the Last Glacial Maximum and Terminal Pleistocene: a geospatial analysis of the 25-12 ka Australian archaeological record. *Journal of Archaeological Science* 40: 4612-25.
- Wu, X., Zhang, Z., Xu, X., Shen, J. 2012. Asian summer monsoonal variations during the Holocene revealed by Huguangyan maar lake sediment record. *Palaeogeography, Palaeoclimatology, Palaeoecology* 323-325: 13-21.
- Wurster, C.M., Bird, M.I., Bull, I.D., Creed, F., Bryant, C., Dungait, J.A., Paz, V. 2010. Forest contraction in north equatorial Southeast Asia during the Last Glacial Period. *PNAS*. 107(35): 15508-15511.
- Yao, Y.T., Harff, J., Meyer, M., Zhan, W.H. 2009. Reconstruction of paleocoastlines for the northwestern South China Sea since the Last Glacial Maximum. *Science in China Series D: Earth Sciences* 52(8): 1127-1136.
- Yi, S., Lee, J.-J., Kim, S., Yoo, Y., Kim, D. 2008. New data on the Hoabinhian: investigations at Hang Cho cave, northern Vietnam. *Bulletin of the Indo-Pacific Prehistory Association* 28: 73-79.
- Zhao, J. & Yu, K. 2002. Timing of Holocene sea-level highstands by mass spectrometric U-series ages of a coral reef from Leizhou Peninsula, South China Sea. *Chinese Science Bulletin* 47(4): 348-352.
- Zukswert, H. 2014. Characterisation of an owl pellet assemblage from Hang Tr6ng, Vietnam: a study of taphonomy and taxonomy. Unpublished MPhil Dissertation in Archaeological Science, University of Cambridge.

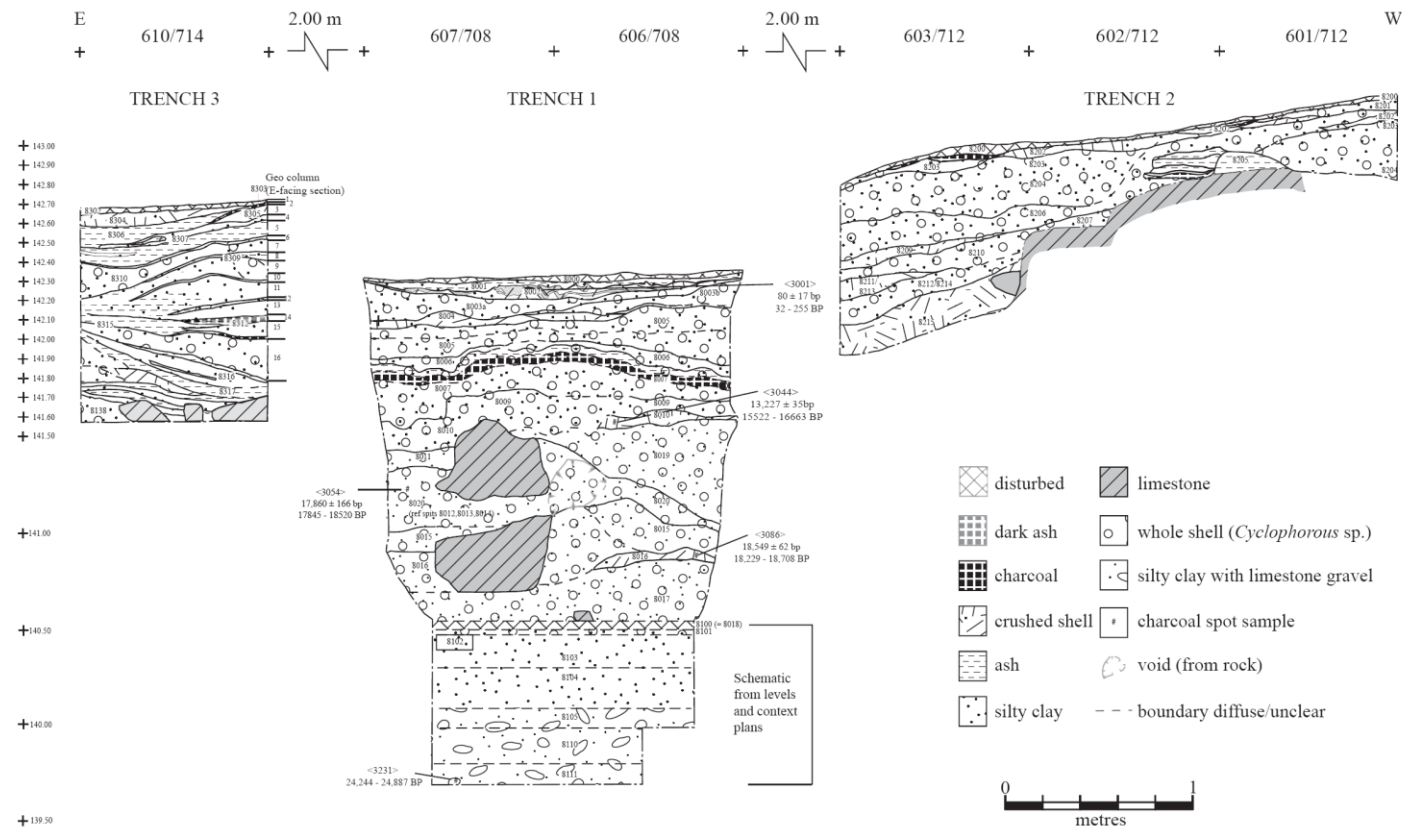


<< Figure 1, the location of Tràng An, Ninh Binh province; the World Heritage Site core and buffer zone boundaries of the property; and the location of Hang Trống within the Tràng An limestone massif. (right-hand image: Google Earth) >>



Survey: J. Hawkes, C. Stimpson & M. Verhoeven. Drawing: C. Stimpson

<< Figure 2, plan of Hang Trống showing pertinent site features, including geoaerchaeological sampling points, the locations of the 2007 test pit and of TR1-3. Survey: J. Hawkes, C. Stimpson & M. Verhoeven. Drawing: C. Stimpson. >>

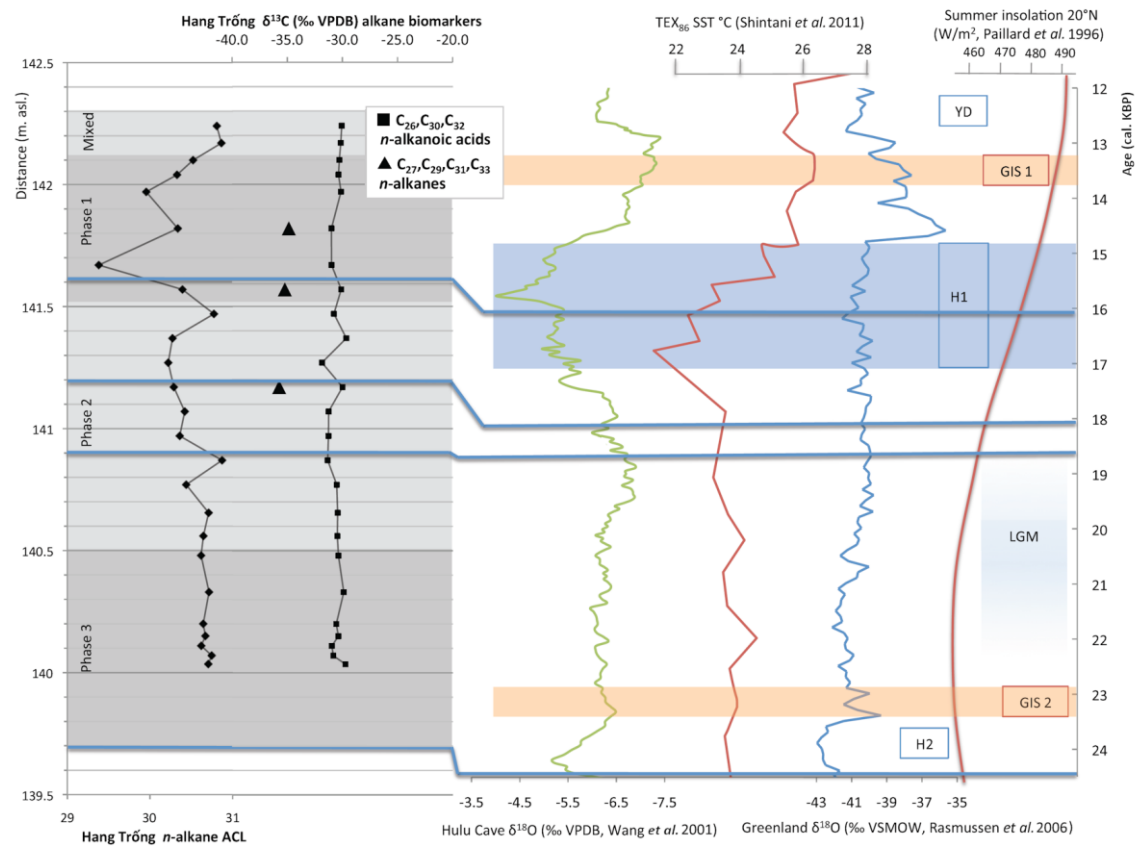


HANG TRONG NORTH FACING SECTIONS- COMPOSITE v. 2 (12/12)

Original drawings: Borbala Nyiri, Lucy Farr, Mike Morley, Jason Hawkes, Marc Verhoeven, David Simpson and Jo Appleby

Figure prepared by Chris Stimpson

<< Figure 3, composite of the north-facing sections from Trenches 1-3 across Hang Trống. East-West distance between trenches has been fore-shortened for the purpose of this illustration. Original drawings: Borbala Nyiri, Lucy Farr, Mike Morley, Jason Hawkes, Marc Verhoeven, David Simpson and Jo Appleby; composition: C. Stimpson. >>



<< Figure 4, n -Alkane data from Hang Trống compared to published palaeoarchive data during the LGM: thick horizontal lines indicate ^{14}C dates from Hang Trống at respective depths and ages along the cal. KBP scale. Hang Trống $\delta^{13}\text{C}$ biomarkers display the consistent trend of C_3 vegetation surrounding the site. Oxygen isotopes from Hulu cave have been shown to provide evidence of monsoonal changes, which coincide with sea surface temperature changes (SST) in the China Sea. Oxygen isotope records (Rasmussen *et al.* 2006) indicate global temperature changes, specifically Greenland Interstadial 1 (GIS 1) and GIS 2. Both oxygen isotope and SST records indicate little change during the LGM, during which time summer insolation values were low (*c.* 460W/m²). n -Alkane average chain length values (ACL) from Hang Trống also display a consistent trend across the LGM. H1 (*c.* 15 KBP), however, sees a dramatic change: a drop in oxygen isotope values from Hulu Cave, SST from the South China Sea and ACL from Hang Trống. Drawing: N. Ludgate >>

Hang Trống: Trench 1 North-facing section

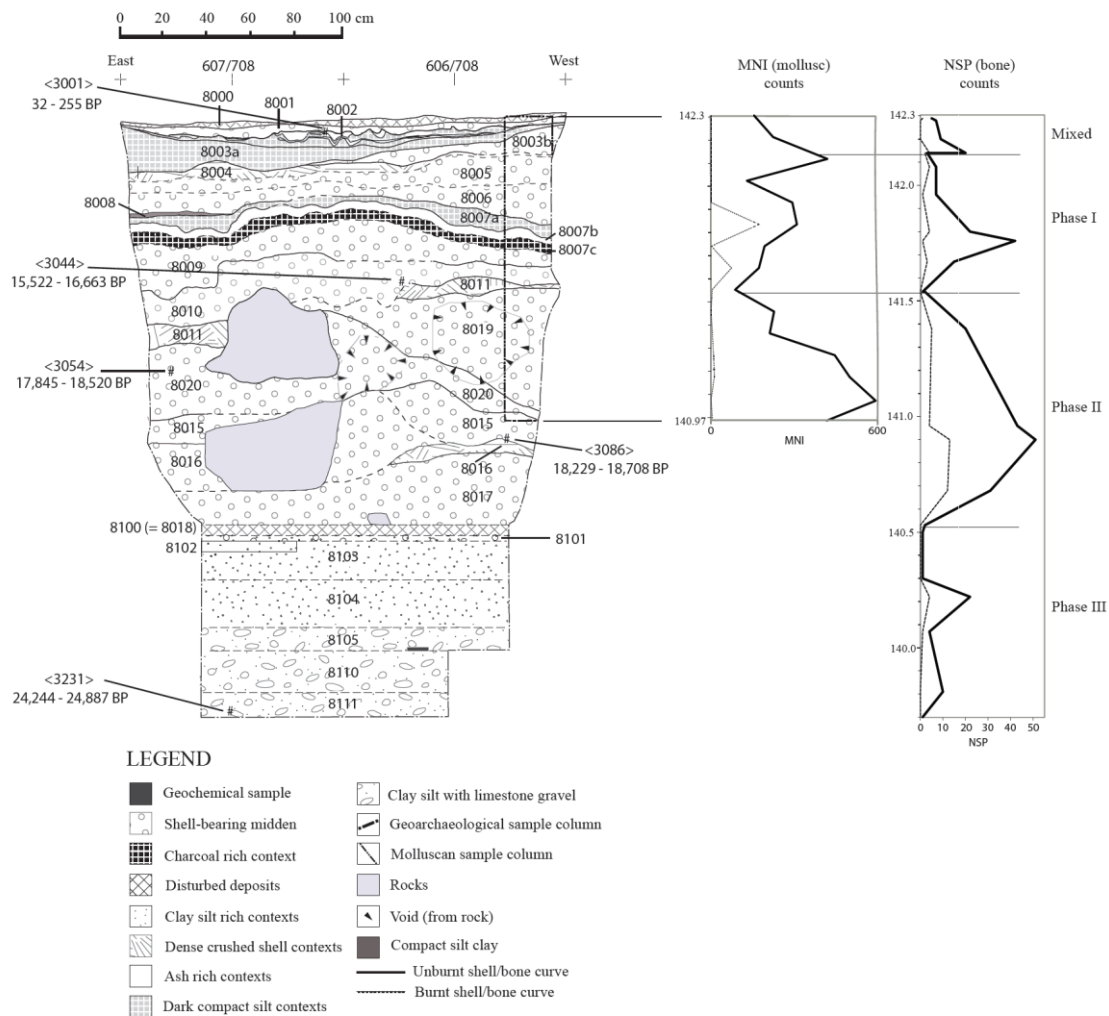


Figure 5, north-facing section of Trench 1 at Hang Trống, showing molluscan sample columns, molluscan (MNI) and vertebrate faunal (NSP) count curves (latter combining data from all three excavated trenches). Drawing: C. Stimpson and R. Rabett. >>

Grid Square	Context	Depth (cm) relative to datum	Material	Radiocarbon years BP	Calibrated years BP	Lab code	Year
607/708	8001	142.25	Charcoal	80±17	32-355	UBA-14883	2009
Test pit	Layer 3	Surface -3 cm*	Charcoal	10,827±32	12,594-12,854	UBA-09301	2007
610/715	8308	142.00	Charcoal	12,363±51	14,056-14,902	UBA-21288	2010
606/708	8010	141.57	Charcoal	13,227±35	15,522-16,663	UBA-14884	2009
607/708	8013(=8020)	141.22	Charcoal	14,878±45	17,845-18,520	UBA-14885	2009
606/708	8016	140.89	Charcoal	15,300±38	18,229-18,708	UBA-14886	2009
606+607/709	8111	139.71	Charcoal	20,537±61	24,244-24,887	UBA-17272	2010

<< Table 1, ¹⁴C dates obtained from excavations at Hang Trống during 2007, 2009 and 2010 field-seasons; *the shovel test pit depth measurement is approximate and not relative to site datum. All dates were calibrated using the CALIB 6.1.0 calibration curve (2-sigma). >>

Trench	Context	Phase	Sample	Canarium sp.	Celtis sp.	Dipterocarpaceae	Leguminosae	Pinaceae	Rhizophoraceae	Sapotaceae			
1	8002	Mixed	3004	2							Total	2	
	8003		3016			2							
	8004		3006	1									
	8006		3008			2							
	8007	I	3034			15							
	8007		-		2								
	8009		3027			10							
	8010		3031						1				
												Total	33
	8012(=8020)		3052		5								
	8013(=8020)		-		5								
	8014		-		3								
	8015	II	3088		3								
	8016		-			18							
	8017		-		11								
	8100(=8018)						•	•	•			32	
												Total	77
	8101		3202		1								
	8103		-				16						
8104		3211											
8104		-		1									
8105	III	3213							3				
8107		3218											
8109		3223											
8110		3229				2							
											Total	23	
2	Mixed	8203	3415			16							
		8203	3405		1								
											Total	17	
		8204	-			1							
	I?	8206	-			1							
		8207	3410						4				
	8207	-			1								
	8215	3443			2								
											Total	9	
3	Mixed	8302	3600		1								
											Total	1	
	I	8307	3610		1								
		8308	3619				•	•		•	100		
		8308	-		3								
											Total	104	
		8309	-			2							
		8310	3616				75						
		8312	3626				13						
		8312	-			11							
		8313	-			1							
		8315	3629							19			
		8315	3628			1							
		8316	-			3							
	II	8317	3632				33						
	8317	-			2								
	8317	3638				5							
	8317	3638		1									
	8318	-			2								
	8318	3640			7								
	8318	3640		2									
	8321	-				6							
	8322	-				10							
											Total	193	
											Grand total	459	

<< Table 2, identified macro-botanical remains ($n = 459$) from dry-sieving and flotation of sediments collected during the 2009 and 2010 excavations at Hang Trống. >>

Context:	Phase	Approx. age (¹⁴ C cal. KBP)	Depth (cm)	Identified grain	Unidentified grain	Degraded grain	Pollen grains counted (including unidentifiable grains):	Percentage of identified grains	Lycopodium spore counts (added for reference)
8000- 8002	Mixed	0	142.25	196	77	133	329 grains	60 %	231
8009	I	15.1	141.8	10	25	145	180 grains	5.6 %	2003
8010		15.6	141.6	2	4	24	30 grains	6.7 %	1000
8016		18.5	140.9	4	10	55	69 grains	5.8 %	2008
8019	II	17.1	141.4	22	9	505	536 grains	4.1 %	513
8019		17.6	141.3	5	5	175	185 grains	2.7 %	1001
Totals:				239	130	1037	1329 grains		

<< Table 3, pollen counts from the pilot study at Hang Trống. >>

Context	Phase	Approx. age (¹⁴ C cal. KBP)	Dist. (m) above sea level	Apiaceae (Umbelliferae)	Aquifoliaceae (ca. Ilex)	Areaceae	Betulaceae 3 pore (Carpinus ca.)	Betulaceae 3 pore (Corylus ca.)	Betulaceae 5 pore (ca. Alnus)	Brassicaceae	Cyperaceae	Combretaceae /Melastomataceae	Ericaceae	Euphorbiaceae (ca. Excoecaria)	Fagaceae (Castanopsis)	Hamamelidaceae	Leguminosae (Fab/ Mim)	Mimosaceae	Mimosaceae / Acacia	Moraceae/ Urticaceae	Meliaceae/ Aglaia type or Chrysophyllum type	Pinus/ Podocarpaceae	Poaceae (Gramineae)	Rosaceae	Rubiaceae	Sapotaceae	Ulmaceae	Polyad
8000-8002	Mixed	0	142.25	3	2	1		1			2	5	1	1	15		2	1	1	1	1	3 8	2	2	1 0	5	1 0	1 5
8009	I	15.1	141.8				1	1	2							1									2			3
8010		15.6	141.6											1			1											
8019	II	17.1	141.4				4	5	8											1	2			2				
8019		17.6	141.3						2								1				1			1				
8016		18.5	140.9																	2		2		2		2		
	Identification reference:			1	1, 2, 3		1	1, 2	1	1				3			1			1, 2		1, 2	1		1			

<< Table 4, pollen identification (Trench 1) from families identified using reference collections from Zhuo Zheng (*pers. comm.*), ¹Tseng-Chieng (1972), ²Li *et al.* (2006a) and ³Institute of Botany (1982). >>

Phase	Trench	Context	Malacostraca (crab)	Osteichthyes (fish)	Amphibia (amphibians)	Reptilia (reptiles)	Aves (birds)	Mammalia (small)	Mammalia (large)	Total NISP	NISP (large animal)	Total NISP	Burnt NISP (large animal)
Mixed	1	8000	0	0	11	1	4	26	0	42	5	47	1
	1	8001	0	0	0	0	0	0	1	1	6	7	0
	1	8002	0	0	1	0	0	0	1	2	8	10	0
	2	8200	0	0	47	0	3	34	0	84	4	88	0
	2	8200-8201	0	0	1	0	1	22	2	26	4	30	1
	2	8201	0	0	1	0	5	9	1	16	11	27	0
	2	8202	0	0	0	1	1	6	0	8	1	9	0
	2	8203	2	2	1	0	0	1	1	7	35	42	1
3	8302	0	0	0	0	0	3	0	3	1	4	0	
Totals			2	2	62	2	14	101	6	189	75	264	3
Phase I	1	8003	2	0	0	0	0	0	5	7	15	24	4
	1	8004	0	0	0	0	0	0	0	0	3	3	2
	1	8005	1	0	0	0	0	0	1	2	6	14	4
	1	8006	1	0	0	0	0	0	1	2	6	8	1
	1	8007	0	0	0	0	0	2	2	4	20	24	4
	1	8009	0	0	0	0	0	3	18	21	24	47	1
	2	8204	1	0	0	0	0	0	0	1	2	3	0
	2	8205	0	0	0	0	0	0	0	0	3	5	2
	2	8206	0	0	2	0	0	1	1	4	8	12	0
	2	8207	0	0	0	0	0	1	1	2	6	8	0
	2	8209	1	0	0	0	0	0	0	1	10	11	0
	2	8210	0	0	0	0	0	1	0	1	7	9	0
	2	8210/8211	0	0	0	0	0	0	1	1	2	3	0
	2	8211	0	0	0	0	0	0	1	1	7	8	0
	2	8212	0	0	0	0	0	0	2	2	5	7	0
	2	8215	0	0	2	0	0	1	1	4	3	7	0
	3	8303	6	0	0	0	0	0	1	7	11	18	1
	3	8304	11	0	0	0	0	1	0	12	11	23	3
3	8305	0	0	0	0	0	0	1	1	8	9	2	
3	8306	2	2	0	0	0	0	0	4	8	12	0	
3	8307	4	1	0	0	0	0	2	7	28	35	12	
3	8308	6	3	0	0	0	3	6	18	87	96	11	
Totals			35	6	4	0	0	13	44	102	280	386	47
Phase II	1	8010	0	0	0	1	0	0	1	2	14	18	3
	1	8011	0	0	0	0	0	0	0	0	1	2	0
	1	8019	0	0	0	0	0	0	0	0	2	2	0
	1	8020	1	0	0	0	2	0	4	7	16	23	5
	1	8015	0	0	0	0	0	1	6	7	37	44	4
	1	8016	0	0	0	0	0	1	6	7	45	52	13
	1	8017	0	1	0	0	1	0	2	4	29	35	12
	3	8309	0	0	0	0	0	0	1	1	10	11	0
	3	8310	3	0	0	0	0	1	1	5	13	18	7
	3	8311	0	0	0	0	0	0	0	0	3	3	0
	3	8312	1	0	0	0	0	1	2	4	4	8	2
	3	8313	0	0	0	0	0	0	0	0	2	2	0
	3	8315	0	0	0	0	0	1	1	2	7	9	0
	3	8316	1	0	0	0	0	0	2	3	6	9	2
	3	8317	0	0	0	0	0	2	1	3	16	19	6
	3	8318	0	0	0	0	0	0	1	1	1	1	0
3	8319	2	0	1	0	0	0	0	3	2	5	2	
3	8321	0	0	0	0	0	0	6	6	52	58	18	
3	8322	0	0	0	0	0	0	2	2	22	24	2	
3	8323	0	0	0	0	0	0	0	0	2	2	1	
Totals			8	1	1	1	3	7	36	57	284	345	77
Phase III	1	8018/8100	0	0	0	0	0	0	1	1	1	2	0
	1	8101	0	0	0	0	0	0	0	0	1	1	0
	1	8102	0	0	0	0	0	0	0	0	0	0	0
	1	8103	0	0	0	0	1	1	0	2	1	3	0
	1	8104 (=8109)	0	0	0	0	0	0	1	1	14	15	4
	1	8105	0	0	0	0	0	0	0	0	4	4	1
	1	8110	0	0	0	0	0	0	1	1	9	10	0
1	8111	0	0	0	0	0	0	1	1	1	1	0	
Totals			0	0	0	0	1	1	4	6	31	36	5

<< Table 5, vertebrate fauna remains from Hang Trong (2009 & 2010) analysed from trenches 1-3 and from all four identified phases. >>

Context	Phase	Distance above sea-level	Depth below surface	<i>Cyclophorus theodori</i>	<i>Cyclophorus unicus</i>	<i>Cyclophorus cf. cambodjiensis</i>	<i>Cyclophorus</i> spp.	<i>Cryptozonia cf. chrysoraphe</i>	<i>Zonitidae cf. Oxychilus</i> sp.	<i>Ellobium aurisjudae</i>	<i>Camaena</i> sp.	<i>Unio</i> spp.	<i>Cerithrium</i> sp.	<i>Amphidromus</i> sp.	<i>Planorbis</i> sp.	Sinistral Gastropod (indet)	Gastropod A. (indet)	Gastropod B. (indet)	Total (unburnt) MNI count	Total (burnt) MNI count
8000 + 8001	Mixed	142.30-142.24	0-6	0	1	0	96	5	2	0	0	0	0	0	1	1	1	0	107	0
																		Total	107	
8003a	I	142.24-142.21	6-9	15	4	5	137	5	3	0	0	0	0	0	0	0	0	0	169	0
8003b		142.21-142.10	9-20	35	24	7	267	6	5	0	0	0	0	0	0	0	0	0	344	0
8004		142.10-142.08	20-22	7	6	2	69	0	0	0	0	0	0	0	0	0	0	0	84	0
8005		142.08-141.96	22-34	31	8	2	186	2	2	0	0	0	0	0	0	0	0	0	231	0
8006		141.96-141.81	34-49	43	8	4	187	2	2	0	0	0	0	0	0	0	0	0	246	155
8007a		141.81-141.75	49-55	38	24	7	69	0	1	0	1	1	0	0	0	0	0	0	141	0
8007b		141.75-141.68	55-62	5	5	0	110	1	1	0	0	0	1	0	0	0	0	0	123	66
8007c + 8009		141.68-141.63	62-67	8	4	2	32	0	0	0	0	0	0	0	0	0	0	0	46	3
																		Total	1384	224
8010	II	141.63-141.56	67-74	33	19	0	120	0	0	0	0	0	0	0	0	0	0	0	172	0
8011		141.56-141.47	74-83	26	27	4	101	0	0	0	0	0	0	0	0	0	0	0	158	4
8019 (S2)		141.47-141.33	83-97	55	28	7	276	0	0	0	0	1	0	1	0	0	0	0	368	8
8019 (S3)		141.33-141.20	97-110	34	43	13	321	0	0	1	0	1	0	2	0	0	0	1	416	10
8019 (S4)		141.20-141.08	110-122	27	8	10	452	0	0	0	0	1	0	1	0	1	0	0	500	0
8019 (S4)		141.08-140.97	122-133	38	60	15	229	0	0	0	0	0	0	0	0	0	0	0	342	4
																		Total	1956	26
Totals				395	269	78	2652	21	16	1	1	4	1	4	1	2	1	1	3447	250

<< Table 6, Hang Trống mollusc sample column from Trench 1, north-facing section: taxonomic identification and quantification by depth and sample number. >>

No.	Trench	Trench/Square	Context	Phase	Blank	Techno-typolog.	Attribute analysis	Length	Width	Thickness	Comments
1		Surface find	-		Secondary shale pebble fragment	Short axe	-	4.9	5.7	1.5	Transverse snap forms butt of tool
2		Deep Sounding	8101		Secondary limestone flake with cortical platform	-	Complete flake	2.7	2.4	0.8	-
3		Deep Sounding	8101		Secondary limestone flake with plain platform	-	Flake fragment	2	1.7	0.5	Stepped
4		Deep Sounding	8101		Burnt limestone pebble fragment	-	?	4.7	2.7	1.4	Transverse snap (natural?)
5		Deep Sounding	8101		Secondary limestone flake with crushed platform	-	Complete flake	4.3	8.1	1.7	-
6		Deep Sounding	8101		Limestone flake core with single platform	Core	Core	6	6.2	3.2	4 removals
7		Deep Sounding	8103		Secondary limestone pebble fragment	Short axe	Pebble tool	3.8	6.1	1.6	Transverse snap forms butt of tool
8		Deep Sounding	8104		Sandstone pebble half fragment	-	Core/Pebble tool	3.1	3.7	1.4	Transverse snap
9	1	Deep Sounding	8104	III	Limestone pebble fragment burnt	-	Complete flake	4.1	2.5	1.4	burnt
10		Deep Sounding	8104		Secondary shale bifacial pebble tool	Short axe	Pebble tool	2.7	5.3	1.5	Transverse snap forms butt of tool; bifacial edge trimming
11		607/709	Cleaning		Secondary limestone fragment	Scraper	-	6.2	7.3	1.8	Retouched natural fragment; transverse snap
12		606/709	8109		Tertiary sired limestone flake with crushed platform	-	Complete flake	3.4	2.5	1.9	Half-moon snaps
13		607/709	8110		Secondary shale pebble fragment	Short axe	Pebble tool	3.7	4.9	1.3	Flattened pebble
14		606/709	8110		Plain platform tertiary shale flake	-	Complete flake	3.2	3.4	0.9	-
15		607/709	8110		Secondary shale flake with plain platform	-	Complete flake	1.7	3.1	0.6	Off pebble
16		606/709	8110		Secondary limestone flake with cortical platform	-	Complete flake	2.2	2.9	0.7	Off pebble
17		609/709	8110/8104		Tertiary quartz flake with crushed platform	Scraper	Retouched flake	2.2	2.5	0.7	Stepped
18		601/712	8200		Flaked limestone pebble fragment	Core?	Core	3.8	5.3	6.3	Steep edged piece; platform on each end; stepped flaking removals
19		601/712	8200		Distal tertiary shale flake fragment	-	Complete flake	2	2.4	0.4	Transverse snap
20		601/712	8200		Distal tertiary shale flake fragment	-	Complete flake	1.6	2.5	0.4	-
21	2	602/712	8201	Mixed	Tertiary limestone flake with plain platform	-	Complete flake	1.7	1.3	0.6	Edge snaps
22		603/712	8200/820		Tertiary limestone flake with crushed platform	-	Complete flake	3.5	2.7	0.6	Oblique transverse snap; half-moon snaps
23		603/712	8200/820		Limestone tertiary flake with crushed platform	-	Complete flake	2.9	2.6	0.6	Edge snaps
24		601/712	8203		Distal primary shale flake fragment	-	Flake fragment	3.2	3.2	0.8	Transverse snap
25		602/712	8203		Elongate shale pebble fragment	-	-	5.8	4.9	2.6	Natural
26		603/712	8207		Tertiary shale shatter fragment	-	Complete flake	2.4	1.5	0.7	Natural?
27	2	603/712	8209	I?	Tertiary shale flake with plain platform	-	-	2.5	4.5	0.8	-
28		603/712	8211		Distal tertiary shale flake/blade fragment	-	Complete flake	2	1.3	0.4	Transverse snap
29	3	609/714	8300	Mixed	Secondary limestone pebble flaked fragment	Short axe	Pebble tool	7.8	9.5	3.2	Transverse snap forms butt of tool
30		610/715	8303		Secondary limestone flake with crushed platform	-	Complete flake	2.6	2.7	0.3	Edge snaps
31		610/715	8303		Secondary pebble fragment	-	-	4.1	3	1.2	Heavily burnt
32		610/715	8303		Secondary limestone flake with crushed platform	-	Complete flake	1.4	1.6	0.1	Edge snaps
33		610/715	8304		Distal tertiary shale flake fragment	-	Flake fragment	2.2	1.8	0.3	Transverse snap and edge faking off it
34		610/715	8304		Tertiary limestone shatter fragment	-	-	1.7	2.4	0.5	Natural
35		610/714	8304		Secondary shale fragment	-	-	-	-	-	Natural
36		610/714	8304		Limestone flake with plain platform	-	Complete flake	3.4	4.4	0.7	Stepped; edge damage
37		610/714	8304		Tertiary limestone pebble fragment	-	-	-	-	-	Natural
38		610/715	8305		Limestone pebble single platform flake core	Core	Core	3.5	5.3	9.4	Elongate pebble; 4 removals
39		610/715	8305		Tertiary shale flake with crushed platform	-	Complete flake	1.6	1.3	0.3	-
40		610/715	8306		Distal tertiary shale flake fragment	-	?	1	1.8	0.2	Transverse and edge snaps
41	3	610/714	8307	I	Secondary shale flake with cortical platform	-	Complete flake	3.6	2.6	0.8	-
42		610/714	8307		Distal primary shale blade fragment	Burin	Complete flake	4.2	1.5	0.8	-
43		610/714	8307		Tertiary shale flake fragment with cortical platform	-	Flake fragment	1.5	1.2	0.4	-
44		610/714	8307		Distal tertiary shale flake fragment	-	Flake fragment	1.3	1.2	0.4	-
45		610/714	8307		Secondary shale shatter fragment	-	Flake fragment	3.2	1.8	0.6	Natural?
46		609/716	8308		Retouched shale pebble fragment	Short axe	Pebble tool	6.4	6.4	1.8	Flattish pebble
47		609/716	8308		Tertiary shale flake fragment with cortical platform	-	-	6.5	4.4	1.1	Half-moon snaps
48		610/715	8308		Flaked secondary shale pebble chopper/core	Chopper	Pebble tool	6.4	9.8	3.9	6 flake removals if this was core
49		610/715	8308		Secondary shale flake with crushed platform	-	Complete flake	2.3	2.8	0.5	-
50		610/715	8308		Secondary shale flake with crushed platform	-	Complete flake	1.7	2.8	0.3	-
51		610/715	8308		Secondary shale flake with plain platform	-	Complete flake	2.2	3.4	0.8	-
52		610/715	8308		Limestone pebble	Pounder	Pebble tool	9.6	9.1	6.7	Battering + flaking damage (opposed ends)
53		610/714	8309		Tertiary shale flake with plain platform	-	Complete flake	1.3	1.8	0.5	-
54		610/715	8312		Tertiary shale flake with crushed platform	-	Complete flake	4.1	3.6	0.9	Lateral snaps
55		610/715	8312		Primary shale flake with cortical platform	-	Complete flake	2.4	3.7	0.7	Half-moon snaps
56		610/715	8312		Tertiary shale blade/flake with crushed platform	-	Complete flake	2.5	1.4	0.3	-
57		610/715	8312		Tertiary shale flake with crushed platform	-	Flake fragment	2.1	4.1	0.5	Large half-moon snaps
58		610/715	8312		Tertiary shale potlid	-	Complete flake	1.3	2	0.3	Natural?
59		610/715	8313		Tertiary shale flake with crushed platform	-	Complete flake	2.3	4.5	0.8	-
60		610/714	8315		Secondary sired shale flake with cortical platform	-	Complete flake	3.4	2.6	1.1	-
61		610/714	8315		Secondary shale flake with cortical platform	-	Complete flake	3.6	6.3	1.4	-
62		610/714	8315		Tertiary shale flake with crushed platform	-	Complete flake	3.2	2.5	0.7	-
63		610/714	8315		Secondary shale shatter fragment	-	Flake fragment	2.8	2.1	0.6	Natural?
64		610/714	8315		Tertiary limestone flake fragment	-	Flake fragment	1.9	3.6	0.6	Snapped around whole edge
65		610/714	8315		Distal tertiary limestone flake fragment	-	Flake fragment	2.3	2.3	0.3	Transverse and edge snaps
66		610/714	8315		Tertiary limestone potlid	-	-	1.4	1.7	0.3	Edge snaps (natural)
67		610/714	8315		Tertiary shale flake with plain platform	-	-	1.3	2.5	0.5	Stepped
68		610/714	8315		Tertiary shale shatter fragment	-	-	1.6	2.1	0.3	Flaking debris or natural?
69		610/714	8315		Distal tertiary shale flake fragment	-	Flake fragment	1.2	2.1	0.3	Transverse snap
70	3	610/714	8316	II	Tertiary shale flake with crushed platform	-	Complete flake	2.2	2.2	0.2	Hinged
71		610/714	8317		Primary sired shale flake with crushed platform	-	Flake fragment	2.4	1.5	0.7	Half-moon snaps
72		609/715	8322		Secondary shale flake with plain platform	-	Flake fragment	0.9	3.2	0.8	-
73		609/715	8322		Tertiary shale shatter fragment	-	-	1.8	2.5	0.2	Natural?
74		609/715	8322		Tertiary shale shatter fragment	-	-	2.6	1.7	0.5	Natural?
75		609/715	8322		Tertiary shale shatter fragment	-	-	3	1.8	0.8	Natural?
76		609/715	8322		Tertiary shale flake with plain platform	-	-	2.8	2.9	0.7	-
77		609/715	8322		Tertiary shale flake with crushed platform	-	-	2.2	2.6	0.9	-
78		609/715	8322		Tertiary shale flake with crushed platform	-	-	2.4	3.2	0.5	-
79		609/715	8322		Distal tertiary shale flake fragment	-	-	1.8	1.8	0.6	-
80		609/715	8322		Tertiary shale flake with plain platform	-	Flake fragment	1.4	1.4	0.3	-
81		609/715	8322		Distal tertiary shale flake fragment	-	Complete flake	1.2	2	0.5	Transverse snap
82		609/715	8322		Distal tertiary shale flake fragment	-	-	1.4	2.4	0.3	Transverse snap
83		609/715	8322		Distal tertiary shale flake fragment	-	Flake fragment	1.4	1.5	0.2	Transverse snap
84		609/715	8322		Tertiary shale flake with plain platform	-	-	1.6	2.2	0.4	-
85		609/715	8322		Distal tertiary shale flake fragment	-	Flake fragment	1.2	1.7	0.4	-
86		609/715	8322		Distal tertiary shale flake fragment	-	-	1.3	1.5	0.2	-
87		610/715	8322		Secondary shale pebble fragment, retouched	Short axe	Pebble tool	4.6	6.4	1.8	Transverse snap forms butt of tool

<< Table 7, techno-typological and attribute analysis classifications on material excavated in 2010 from Trench 1 (Phase III) and Trenches 2 and 3 (all represented phases). >>