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HUMAN ADAPTATION TO COASTAL EVOLUTION: LATE QUATERNARY EVIDENCE FROM SOUTHEAST ASIA (SUNDASIA) - A REPORT ON THE SECOND YEAR OF THE PROJECT

RYAN RABETT* ET AL.

1. Introduction

The 3.5 year SUNDASIA project is a collaborative venture between Vietnamese and UK institutions that is reconstructing a detailed picture of the impact changing sea levels and environmental conditions had on prehistoric socioeconomic systems in the Song Hong River delta area of northern Vietnam. The project is centred in the Tràng An World Heritage Site (WHS) of Ninh Binh province and is co-funded through the UK Arts and Humanities Research Council portion of the British Government's 'Global Challenges Research Fund', and the Xuan Truong Construction Enterprise. At the end of the project's second year, field data-collection is now largely complete. Data collection locales have been catalogued across the WHS, with highest resolution recovery within a 2 km wide corridor extending (west-east) through the centre of the massif: an area of c. 1500 ha (or 25% of the core zone of WHS). In order to integrate different lines of evidence within a searchable Geographic Information Science (GIS)

*Archaeology & Palaeoecology, Queen's University Belfast, UK

Fiona Coward, Rachael Holmes (*Department of Archaeology, Anthropology & Forensic Science, Faculty of Science & Technology Bournemouth University*); Ioanna Bachtsevanidou Strantzali, Emilie Green, Evan Hill, Thorsten Kahlert, Ciaran Kelly, Meghan McAllister, Shawn O'Donnell, Sean Pyne-O'Donnell, Aaron Redmond, Christopher Stimpson (*Archaeology & Palaeoecology, Queen's University Belfast, UK*); Nguyen Dai Trung, Tran Tan Van (*Vietnam Institute of Geosciences and Mineral Resources (VIGMR), Ministry of Natural Resources and Environment, Hanoi, Vietnam*); Bui Van Manh (*Ninh Binh Department of Tourism, Vietnam*); Natalie Ludgate (*School of Geography, Queen Mary University of London, UK*); Ruairidh Macleod, (*Homerton College, University of Cambridge, UK*); Benjamin Utting (*Division of Archaeology, University of Cambridge*); Nguyen Cao Tan (*Ninh Binh Department of Culture & Sport, Vietnam*); Nguyen Thi Hao, Nguyen Thi Mai Huong (*Vietnam Institute of Archaeology*); Nguyen Thi Loan, Sinh Pham Khanh, Truong Thi Quynh Trang, Vu Duy Linh, Vu Thuy Linh, Vu Thi Lien (*Tràng An Landscape Complex Management Board, Ninh Binh, Vietnam*); Tran Thi Kim Quy (*Senckenberg Research Institute, Germany*); Marcus Verhoeven (*RAAP Archaeological Consultancy, The Netherlands*).

data base, and to aid future natural and cultural heritage management, site-specific information is referenced within a 4 x 4 km alpha-numeric grid covering the core and buffer zones of the property. While not exhaustive, data obtained will provide an authoritative picture of human responses to changing conditions from c. 37,000 years ago to the present; incorporating archaeological and palaeoecological reconstruction with heritage management and landscape conservation priorities. This report draws on published and grey literature to detail the work being undertaken and is presented in the context of the project's three central research questions.

2. How do coastal environments shape human behaviour?

2.1. Tracking the prehistoric cultural and economic change through time

The Trảng An massif contains evidence of human presence across the last three major marine transgression episodes: the Quang Xuong (c. 2600 - 1500 cal. years before present [BP]), the Dong Da (Flandrian) (c. 7000 - 4000 cal. BP) and the Vinh Phuc transgression (c. 59,000 - 30,000 BP) (UNESCO Nomination Document - 1438 2014). Utilising a range of archaeological, palaeoecological and palaeoclimate proxies, the SUNDASIA project is refining existing models of timing and extent of these marine incursions, and the impact they had on humans living in Trảng An. Progress in the collection of these data is summarised below. The project research is directed towards reconstructing past events and human adaptation to them, but simultaneously towards improving the accuracy of predictive models used to assess the impact of climate-induced sea level rise today.

2.1.1. Hang Thung Binh 1 (Site ID code : 2B-001)

Hang Thung Binh 1 (TB1) is one of six caves within an isolated limestone hill of the same name in the NW corner of the Trảng An core zone, c. 1 km west of the main massif and set within cultivated alluvial plains. TB1 is a small two-chambered east-facing cave (20.26162N, 105.86474E) (12 x 5 x 2.5m) c. 20.4 m asl. Initial survey (2008) by the Vietnamese Institute of Archaeology (VIA) was followed their excavation of a 2 x 2m trench (2012) towards the back of the main chamber. The cultural remains recovered appeared to span the Early to Mid-Holocene (UNESCO Nomination Document-1438 2014: 54; Suet *al.* 2012: 9); however, ¹⁴C dates indicated greater antiquity: 14-16,000 calendar years before present (cal. BP) (Ito *et al.* n.d. 2012; Su n.d). In 2017 an exploratory trench (Trench 1) was opened by SUNDASIA in the small secondary chamber, with cultural material dating to 17,500-17,940 cal. BP (UBA-34739) (*see* Rabett *et al.* 2017b,d).

Trench 2 was opened in the front of the main chamber, first as a 2 x 1m excavation following recommendations from a ground-penetrating radar survey in 2016 (Green 2016), and subsequently to an area of c. 5 m². Full details of its excavation to-date are available in the following site reports lodged with the Trảng An Management Board (Rabett *et al.* 2017c, d, 2018). Sediment was dry-sieved on-site (2 mm mesh). Bulk sediment samples (1-2 litres) were taken from each stratigraphic unit for flotation. Archival sediment samples were also retained. The upper contexts (E900 - E902) contained a mixture of modern and historic material. The most significant find archaeologically in these upper levels was a shouldered axe (context E902). Underlying these, the silty clay (E903) was found to contain a moderate frequency of animal bone fragments and shell spreading across all four squares of the trench. As spit excavation (c. 10 cm per spit) progressed within this context, sherds of coarse-ware

pottery (black fabric with red colouration to the outer surface) began to appear in increasing frequency. Occasional quite large marine shells/shell fragments also began to appear. Two areas of 'brown/dark brown' clay silts appeared within context (E903) - labelled (E905) and (E906). The initial interpretation that these may be pit features was refuted when further excavation revealed both patches to be raised areas in the surface of an undulating cultural midden (E908).

As digging progressed within those areas of the trench where (E903) was still exposed, isolated human bone extremities and teeth began to be recovered, notably from spit 4, where a large ceramic sherd was recovered in almost direct association with a human first pedal phalange, another (smaller) shouldered axe - the second of three excavated from Trench 2. Small (*c.* 7 mm) perforated shell discs were also now being recovered in notable numbers. These finds likely related to a much larger concentration of nine sherds of narrow-walled coarse-ware, plausibly from a single vessel in an area 0.6 x 0.6 m, extending into the southern wall of the trench. All sherds were superficially cleaned *in situ*, photographed and planned before being lifted and conserved in acid-free tissue for transport. A large (*c.* 20 cm) mussel shell was also recovered in association.

The first confirmed sherds of Da But pottery began to appear near the base of the first 10 cm spit of the next stratigraphic context (E907). After *c.* 0.4 m, there was a noticeable change in deposit character. The 'brown' silty clay of the new context (E908) contained a higher proportion of crushed and whole cyclophorid shell, riverine gastropods, animal bone and lithics. Frequent charcoal also hints at a shift in site use compared to higher in the stratigraphy. One sample from the first spit of (E908) was AMS ¹⁴C dated to 9120-9433 cal. BP (UBA-36018), providing a minimum age for the end of accumulation of this apparent midden. Infrequent small (*c.* 5 x 5 mm) fragments of coarse-ware fabric from the immediately beneath contact with overlaying deposits were likely to be intrusive. Beneath the interface layers recovery within the midden became wholly aceramic.

2.1.1.1. Pleistocene inhumation

Approximately 0.4 m deep into the midden, in context (F905), an assemblage of long-bones was encountered in near-articulated position going into the section walls in the NE corner of the trench. Compared to the highly fragmented state of animal bone that was characteristic of the midden this marked a significant change. Excavation of the assemblage proceeded with dental tools, sterile gloves and face masks when it became clear that these were human remains - specifically, a flexed partial right arm.

With permission a slot was cut into the north section wall of the trench to where the skull might likely be resting. Cranial remains and associated bone were located here. These appeared to be fragmentary and further exposure of them carried the risk of losing information about positioning and association. 3D photogrammetry was carried out on all material before it was recovered. The cranial remains were then lifted within two blocks of sediment (Block A & B). Each was immediately wrapped in acid-free tissue paper and, together with all other bone fragments thus far recovered, transferred to a secure cold-storage facility. Detailed analysis of

this material commenced in January 2018 (Wilshaw 2018). The left (L) petrous was also CT-scanned (with appropriate shielding) to assess the optimum sampling location and sampled for aDNA analysis.

In April 2018, Trench 2 was extended by *c.* 1 m² eastward towards the cave mouth to facilitate recovery of the remainder of the skeleton. Excavation proceeded following the natural stratigraphic boundaries that had been identified during previous seasons (Rabett *et al.* 2018). The assemblage of post-cranial bones began to appear at 31.25 m, towards the base of midden context (F907) spit 4, and concluded at 31.15 m. The assemblage was orientated *c.* 340°, dipping -15° from N-S. The legs and feet were in approximate anatomical order. The fragmented rib cage, clavicle and remnant arm elements were also recovered. The bones had clearly been compressed and fragmented with many non-recent breaks evident. Their arrangement suggested that the body may have been interred in a foetal position. All remains were planned, recorded photographically, then lifted in six sections and transferred to cold storage. Preliminary chemical-free cleaning and basic curation of the bones revealed a notable absence of vertebrae. It is possible that these remain in the unexcavated base of the trench; however degradation and loss of vertebrae is also feasible. The epiphyses of the long bones were highly degraded, but initial refits indicated reconstruction should be sufficient to take reliable biometrics.

The likely antiquity of the inhumation was determined through ¹⁴C dates submitted through the AMS 14 Chrono Centre, Queen's University Belfast (QUB) with separate funds. An attempt at dating residual bone dust left over from sampling of the left petrous bone of the TB1 skeleton for aDNA failed through lack of collagen, three others were on charcoal, and returned stratigraphically consistent dates: 9120-9433 cal. BP (as above), 11,949-12,249 cal. BP (UBA-36372), associated with the upper right arm bones of the TB1 skeleton, and 12,702-13,089 cal. BP (UBA-3867) found in direct association with the principal post-cranial remains from the skeleton at a slightly greater depth.

2.1.1.2. Micro-botanical analysis

Organic residue analysis using Raman Spectroscopy was applied to a small sample of five Da But sherds from this site, though did not yield any significant results (Green 2018). However, in order to broaden the picture of cave use during the period attributed to the Da But and how these populations utilised local habitats a programme of phytolith analysis was undertaken at two sites in Trảng An, TB1 and Hang Moi (Holmes 2018). Plant phytoliths, microfossils composed of solid silicon dioxide/silica (SiO₂) preserve even when the organic structure of the plant has decomposed and are less susceptible to temperature and humidity, making them a particularly useful marker at tropical latitudes (Piperno 2006). Full results are pending. It is notable that the more sparing TB1 and the more abundant Hang Moi phytolith assemblages may reflect differences in the use of local vegetation or alternatively differences in the post-depositional processes affecting each site.

2.1.1.3. Artefact analysis

Refitting and reconstruction of recovered ceramics from TB1 was not undertaken by this project. Technological analysis of lithics recovered from the site is ongoing as part of a doctoral thesis (by BU). Excavation of the midden deposits in Trench 1 ($n = 45$) and 2 ($n = 26$) has yielded highly variable informal flakes, flake fragments, small cores and core tools, in similar dataclass proportions - affirming the prospect of cultural affiliation between these two spatial units. Informality in tool production has been found to be characteristic of other assemblages from Trảng An, where an attribute analysis approach (Tostevin 2013) has proven effective for recovering temporal and spatial patterning within such material (Phan 2014; Rabett *et al.* 2017a; Utting 2017) and is being applied to the TB1 site assemblage. Typologically referential pieces included, in addition to the informal tools, three edge-ground shouldered axes, a flaked pebble core tool, and a number of blades.

Study of the edge-ground shouldered axes is outside the immediate work of this project but has the potential to expand understanding of the Neolithic in northern Vietnam through consideration of raw material sourcing (and from this, insights into exploitation and trade networks), use-wear and geometric morphometric analyses to examine utilization and form. A flaked pebble core tool recovered out of context in Trench 1 broadly resembles in manufacture a classic 'sumatralith', recognized traditionally as the '*fossile directeur*' of the Hoabinhian (e.g. van Stein Callenfels & Evans 1928; White & Gorman 2004). The pebble is not knapped around its entire circumference and therefore does not fulfil all requirements of this typological designate; however, it contributes to previously sparing links between Trảng An stone tool assemblages and the Hoabinhian technocomplex as it is currently defined. The retouched and unretouched blades were made on siliceous limestone and sandstone and recovered from midden context (F907) in Trench 2. Although no cores were found, the high ratio of blades in this assemblage suggests reduction strategies at TB1 were significantly different from those at other sites (e.g. Rabett *et al.* 2017a; Utting 2017). As such, study of the TB1 assemblage should contribute significantly to our understanding of Late Pleistocene technological and subsistence practises here and at a regional scale.

2.1.2. Hang Moi (Site ID-2B-001)

This single-chambered cave (23 x 11 m) is located in the north-central part of the Trảng An massif (20.254111N, 105.894889E) *c.* 6 m asl. Two trenches were excavated here in 2011 (Rabett 2013): the first (T1), measured 1 x 2 m and was situated close to the west wall; the second (T2) 1 x 3 m adjacent to the north wall. The principal deposits excavated (capped by only a few centimetres of more recent stratigraphy) could be attributed to the Da But and indicated a mixed economy, with a particular focus on marine resources. Charcoal samples from the T1 and T2 base of excavation (2011) gave dates of 5464-5591 cal. BP (UBA-19757) and 5436-5611 cal. BP (UBA-19756), respectively. In 2012, colleagues from VIA opened a third trench, from which they recovered a similar sequence in the upper layers (e.g. Layer 5a dated to 5643-5747 cal. BP [PLD-21641]), overlying earlier site use with a terrestrial and riverine economic base, from as early as 14,801-15,204 cal. BP (PLD-21636) in Layer 11 (Masanari & Toan 2012; Su *n.d.*).

A SUNDASIA team returned to the site in late 2016 together with colleagues from VIA to gather additional data about the Da But from the midden in T2. That trench was expanded by 2 m² and dug to a depth of 0.8 m in close stratigraphic correspondence to the 2011 excavation (*see* UNESCO 7B - VietNam - Trang An_20171206_public-1 Sub-Annex 1.1.). In late 2017 (Rabett *et al.* 2017d) with further expansion due to sub-surface rocks, excavation proceeded, securing further data on the Da But, including a concentration of *c.* 10-15 fish skulls from midden context (6509), identified as a species of brackish water bream. The frequency of ceramic sherds decreased with depth and deposits became aceramic by (6514) and (6515). Charcoal from the latter was ¹⁴C dated to 14,226-15,017 cal. BP (UBA-36373) (Layer 11 of the VIA trench). Intrusive rocks prompted work to shift to T1.

Two shallow pit-like depressions were quickly identified in the base of T1. The first of these (6100) had been dug into a series of red/brown loam and white-grey ash layers in the NE corner; the second (more elongate) had been dug into the surface of context (6103), the uppermost of the cyclophorid-dominated shell midden layers (7d) identified in the VIA Trench. Layer 7d was undated, but the overlying Layer 7c was dated (on charcoal) to the Early Holocene: 9492-9548 cal. BP (PLD-21646). A circular hearth (*c.* 0.7 x 0.7 m) containing three depositional units was uncovered in the NW corner of the trench; the base (context 6105) included *c.* 60 fragments of fire-cracked angular limestone fragments (*c.* 50 x 50 mm). Charcoal samples from (6015) and (6108) gave similar ages: 10,366-10,661 cal. BP (UBA-38669) and 10,254-10,582 cal. BP (UBA-38670), respectively.

2.1.2.1. Holocene inhumation

Beneath (6103) and cutting through (6108) cranial bones, upper arm and isolated ribs from a human burial were encountered. This inhumation lay immediately adjacent to (and disappearing into) the west-facing section between T1 and the baulk between this trench and the VIA trench. The visible portion of the burial cut is *c.* 0.4 x 0.7m and rectilinear. Initial inspection of the teeth suggested the interred individual was a sub-adult. The fill around the bones was a grey-brown loose loam including many cyclophorids; however the antiquity of the burial is unclear. Close examination of the southern section revealed stratigraphic irregularities that could indicate the burial pit was dug from higher in the sequence. Recovery of a small Da But sherd in (6108) may support this hypothesis.

2.1.2.2. Micro-botanical analysis

Residue and fabric analysis utilising Raman Spectroscopy, X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) techniques was carried out on a sample of six (of the many) Da But sherds collected from T2 during the 2011 and 2016 excavation seasons. The small sample size means results are only suggestive and may not necessarily reflect the wider assemblage; however, they present new insights into cave use during the Mid-Holocene that steer interpretation away from the wholly residential, as well as potentially novel insights about fabric tempering methods in vessel construction (Green 2018).

Phytolith sampling at Hang Moi was confined to sub-sampling of a 2011 archived sample column 0.57 m long, producing a total 30 sub-samples with a 10-30 mm sampling interval across 20 discrete stratigraphic contexts. Contexts that contained evidence of *in situ* burning (*i.e.* context 6011 and below) returned high frequencies of phytoliths, which were

often charred, lending support to these being anthropogenic rather than naturally introductions to the cave. Indications are that these microfossils included some edible taxa and significant quantities of woody plants likely used for fuel. The absence of phytoliths belonging to the tree family Dipterocarpaceae is notable for contrasting with data recovered in a previous analysis (unpublished data: Ceron 2012 n.d.) of charcoal samples from the site – including from context (6011). This discrepancy could be a result of limited available modern reference phytolith samples of Dipterocarpaceae with which to compare the archaeological specimens or suggest that there is probably a taphonomic pathway that separates these proxies and which will need to be taken into account in the final interpretation of the site use. Indications are though that onsite fires may have exceeded temperatures usually required for domestic cooking activities (Holmes 2018).

2.1.2.3. Artefact analysis

Ceramic reconstruction and seriation has not yet been attempted, though the cultural affiliation is demonstrably Da But (Nyiri 2011 n.d.). With the exception of a small polished trapezoidal jade adze from context (6009) in T1 and isolated fragments of ground stone and indeterminate flakes from T1 (6025) and (6039), and T2 (6303=6203) – which proved comparatively rich in lithics-artefact recovery from Hang Moi has been otherwise surprisingly sparse from levels attributed to the Da But. A ceramic contexts in both trenches have been noticeably more productive, with high ratios of limestone and quartz flakes.

2.1.3. Cave survey

Table 1. Caves surveyed and/or test-pitted during the 2nd year of the SUNDASIA Project

Site ID	Site Name	Long.	Lat.	Status	Heritage potential	Finds	Date
2B-014	Thung Binh 6	105.863054*	20.262133*	Unknown	Unknown	Unexcavated	16/04/2018
4B-001	Hang Hop	105.938384	20.25719	Unrecorded	Low	Unexcavated	18/09/2017
2B-018	Mai Da Ui	105.889504*	20.255748*	Unrecorded	Low	Unexcavated	08/04/2018
2C-010	Hang Nuoc	105.8752*	20.2476*	Unrecorded	Colony of several hundred <i>Hipposideros</i> sp.; no archaeology	None	07/04/2018
3B-031	Mai Da Toi	105.903903	105.903903	Unrecorded	10 x 10 m rock-shelter with small alluvium-filled cave	Structural foundations	17/04/2018
1A-003	Hang Trau Bai Dinh	105.84903	20.30166	Recorded	Recent cultural material recovered to a depth of 1.2 m; test-pit was not bottomed so deeper deposits probably exist here; low-moderate potential	Modern ceramics; evidence of localised burning	25/03/2017
1A-004	Hang Beo	105.84879	20.30133	Unrecorded	Partly water-filled passage system; low heritage potential	Unexcavated	09/04/2018
1A-005	Hang Ao Beo	105.848735	20.30152	Unrecorded	Three chambered site; civet cat den; low overall heritage potential	Unexcavated	09/04/2018
2C-007	Hang Quen	105.87163	20.25034	Recorded	Low; small 3-chambered cave system with no archaeological material evident	Small quantity of historic ceramics	27/03/2017
2C-006	Hang Ong Noi	105.87125	20.25152	Recorded	Two principal chambers, low archaeological potential, decorated	Very small quantity of historic ceramics	10/04/2017

The landscape mapping and survey work of the SUNDASIA project has given further opportunities to catalogue nine new caves within Trảng An and to assess three previously recorded caves through limited test-pitting (*Table 1*).

2.2. Digital terrain mapping

2.2.1. Data collection for a digital elevation model (DEM) of Tràng An

Access to remote-sensing data and the creation of DEMs is recognised increasingly as an essential tool in the effective management of World Heritage sites (Megarry *et al.* 2017). Freely available remote sensing technology (e.g. Google Earth) can provide information at coarse spatio-temporal scales, but these are not adequate for assessing vulnerabilities (e.g. environmental) or guiding heritage management on a short-term and at a site-specific scale (WH67 2013). This requires data that describes the changing state of local conditions to higher accuracy (WH30 2011). Airborne LiDAR scanning is the most effective method to accurately scan, model and assess local landscapes (e.g. Fisher *et al.* 2017); however, airborne LiDAR data remains specialised and costly. Satellite-based imaging is an alternative approach. This can also be expensive, though licenced access expressly for scientific use is possible through some governmental portals e.g. TerraSAR-X / TanDEM-X, German Space Agency (DLR). Satellite-based data, however, can not cope with the extreme topography of tower karst. In order to achieve a high-coverage, cost-effective DEM that overcame terrain-related errors a different approach was required.

‘Structure from motion’ (SfM) software and small unmanned aerial vehicles (SUAVs) for low altitude (160-300m) imaging represent just such an alternative (e.g. Cigna *et al.* 2017), though one that has limitations of its own. As an imaging technology, it cannot penetrate vegetation cover and so cannot expose ground features in cluttered environments. The effects of the karst landscape on signal acquisition and battery-life impact on flight-time (e.g. max. distance from launch is 1.5km) also need to be taken into account. Despite these constraints, a high-utility DEM (resolution *c.* 10 cm after ortho-rectification) was obtained using an off-the-shelf SUAV (DJI MAVIC PRO).

Local Real-Time Kinematic (RTK) network access (retrieved using a Leica GS15 GNSS nRTK unit) established x, y, z coordinates of each geographic position in real time to cm precision. The Drone Deploy app for iOS and its web equivalent were used to plan and conduct each survey as autonomous flights (area per survey: *c.* 35 ha). The drone returned home for battery change and resumed its mission at the last recorded waypoint. Photoscan Pro was used to create preliminary models to ensure that image quality and overlap were sufficient for model generation. Ground Control Points (GCPs) aided this process.

Over the course of the four field visits during Year 2 1518/6156 hectares (ha), representing 24.56% of Tràng An’s core zone, and the full extent of the principal research corridor was mapped. Taken together with a section of existing raw terrestrial LiDAR data covering the southern and eastern edges of the core zone (a further 1797/6156 ha, 29.19%), SUNDASIA’s total coverage is 3315/6156 ha (53.75%) (Figure 1). With a diverse range of topographic elements incorporated into the DEM from the centre and margins of the massif and principal tourist entry routes, as well as providing a critical component of the research programme for assessing changing settlement patterns in prehistory, the model has potential utility in heritage management (Kahlert *et al.* 2018; see **Section 4.3.4**).

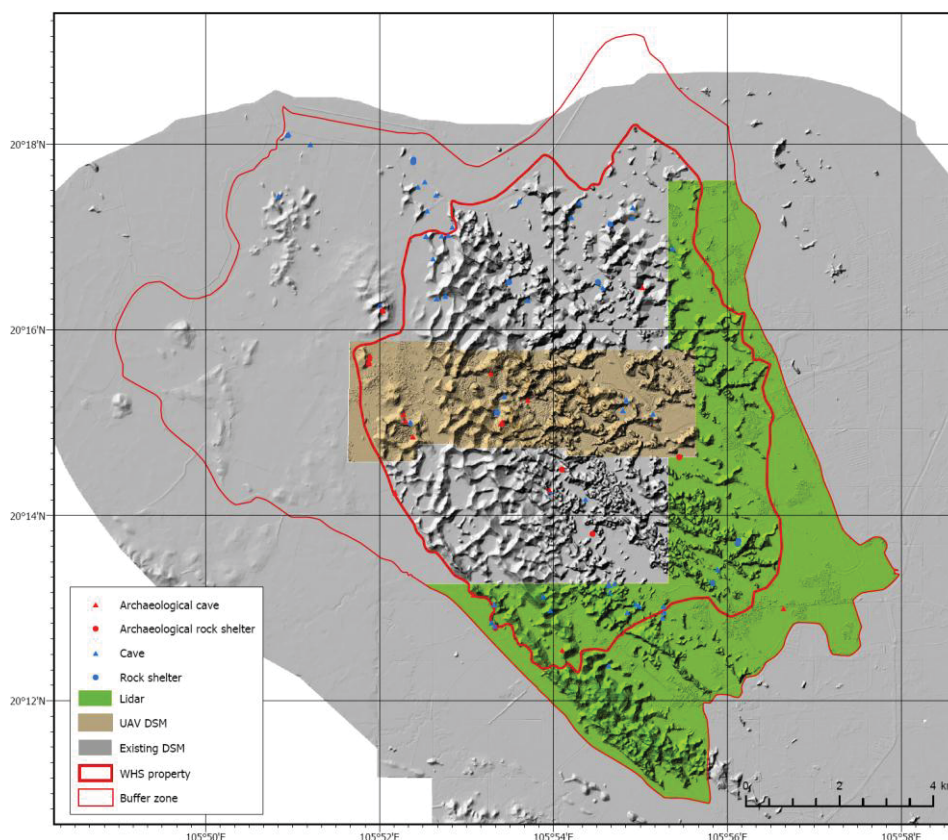


Figure 1. Map showing full extent of SUAV and LiDAR coverage in the Tràng An
(Map: T. Kahlert)

2.2.2. Erosional notch survey

In order to refine the existing model of past sea transgressions affecting Tràng An, survey work during this year of the project also included expanding the catalogue of sea-notches observed along the flanks of the massif, for which we utilised a Leica GS15 NRTK GNSS and Leica TS06 total station. Several control stations were surveyed with the GNSS to orient the total station (TS). Elevations were recorded against an ellipsoid datum, which were reduced to asl elevations using the 140411 local Benchmark as a reference. Measurements were taken at three points on each notch feature: ¹⁾ the top of the notch, which marks the highest point of water level; ²⁾ the deepest penetration into the limestone, which marks the average water level; and ³⁾ the base of the notch, where present. Wherever possible, several measurements were taken along more extensive erosional notches to detect possible vertical displacement of the feature. Limiting factors to data collection included reception to RTK and NTRIP during some notch observations and time investment. In some instances 15-20mins. of observation time per GNSS coordinate was required for post processing purposes. Erosional notches were initially surveyed at six locations in sectors 3B, 4B, 2C and 4C. The majority of these represented locations already included in the 2012 VIGMR survey, such as Thien Ha cave and the notch sites at Tam Coc. These serve as references to calibrate our survey to the 2012 VIGMR survey.

2.2.3. 3D photogrammetry and reconstruction

To augment site archiving of stratigraphy and trench characteristics, for presentation purposes (including integration into the DEM) and, in particular, to produce a highly resolved record of excavations involving human remains at TB1 and Hang Moi, SFM surveys were carried out at both caves. 12 bit encoded targets were used as control points and surveyed in with the TS06 total station. During the project's Sept. 2017 season all three of the trenches (two from SUNDASIA and one from VIA 2012) in TB1 were systematically mass-photographed (i.e. >360 photos per trench) from multiple angles using a full frame Canon 6D and speedlite to create 3D models. This ensured that every part of each trench was recorded and evenly lit. Further photogrammetric surveys were undertaken in Trench 2 at TB1 and in Trench 1 at Hang Moi, following the discovery of human remains. A programme of modelling of the bones themselves was also initiated.

2.3. Reconstructing past environmental & climatic conditions

This section focuses on flora and vertebrate fauna; invertebrate (molluscan) fauna and climate are covered in **Section 3**. The vegetation history of Trảng An is being reconstructed by integrating data obtained via cave sediment analysis, pollen trapping, herbarium creation, and sediment coring. Comprehensive information obtained about the floristic structure, composition and taphonomic pathways of modern limestone karst forest is being used to guide accurate interpretation of data recovered from the landscape's more limited palaeoenvironmental repositories.

2.3.1. Pollen analysis from cave sediments

A total of 16 sediment samples from two caves, TB1 and Hang Trong (HTC) (collected and recorded during previous excavations), have so far been processed for the recovery of pollen and other microfossils. In the laboratory, five cubic centimetres (cc) of sediment were volumetrically sub-sampled. This enabled the quantification of microfossil concentrations, improves assessments of preservation, and enables comparisons between assemblages. Pollen extraction followed Campbell *et al.* (2016), excluding acetolysis as marginal preservation was anticipated.

Microfossils encountered and quantified under high-magnification light microscopy (400x) included pollen and fern spores (collectively termed 'palynomorphs'), phytoliths, fungal spores and other non-pollen palynomorphs (NPP). Selected preliminary data are presented in Table 2. As anticipated, microfossil preservation proved poor-to-marginal in all samples. None of the nine samples from TB1 produced countable assemblages. Across the seven samples from HTC, palynomorph concentrations ranged from 1740 to 14,726 per cc of sediment. Within these palynomorph assemblages, only one sample (that from sample no. 3096, representing surface deposits) contained more pollen than fern spores. To put these data into context, well-preserved assemblages from continuously accumulating deposits typically yield palynomorph concentrations of 50,000-300,000 per cc of sediment; those from open landscape settings usually display a pollen to fern spore ratio of near three to one, with this

ratio decreasing as diagenesis alters assemblages in favour of the typically more robust and heavily ornamented fern spores (Havinga 1964). The low pollen-fern spore ratios identified could represent diagenetic bias or taphonomic filtering (Burney & Burney 1993). Pollen trap data will clarify the relative importance of these processes.

The pollen that was recovered from the HTC sediments consisted primarily of that from montane conifers, e.g. pines (*Pinus* spp.), firs (*Abies* spp.), hemlocks (*Tsuga* spp.), cypresses (Cupressaceae spp.) and podocarps (Podocarpaceae spp.). Pollen trap data will clarify whether these are more likely representative of local or regional presence of these wind pollinated trees. Occasional broadleaf elements, such as members of the dogbane (Apocynaceae), ivy (Araliaceae), evening primrose (Onagraceae) and citrus (Rutaceae) families, were also encountered, though never more than one or two grains per sample. Also of note was a very high concentration of 'darkened' silicates recovered from HTC sample 3099 (28,246 per cc of sediment). These might represent burnt phytoliths or silicates that have trapped locally mobile humic residues. This finds support in the fact that the sample was taken from context (8006), which lies immediately above a series of undated ashy and charcoal-rich layers (*see Rabett et al.* 2017a, fig. 3).

Table 2. Selected preliminary microfossil data from Thung Binh 1 and Hang Trong sediments

Site	Sample no.	Context	Palynomorph concentration (per cc of sed.)	Pollen : Fern	Darkened silicates (per cc of sed.)
HTC	3096	8000/8001 interfaced	1740	1.37	773
HTC	3097	8003	11,441	0.31	2091
HTC	3098	8005	14,726	0.69	3241
HTC	3099	8006	10,633	0.11	28,246
HTC	3100	8007	6338	0.13	2765
HTC	3101	8009.1	8404	0.00	6786
HTC	3102	8009.2	2130	0.44	498
TB1	V1926	E905	nd	nd	nd
TB1	V1929	E906	nd	nd	nd
TB1	V1985	E907.1	nd	nd	nd
TB1	V1989	E907.2	nd	nd	nd
TB1	V2001	E907.3	nd	nd	nd
TB1	V2004	E908.1	nd	nd	nd
TB1	V2007	E907.4	nd	nd	nd
TB1	V2012	E908.2	nd	nd	nd
TB1	V2016	E909	nd	nd	nd

2.3.2. Pollen traps

A network of 24 pollen traps (1) were deployed in open-air and cave settings with the objective of catching the 'pollen rain' from modern vegetation surrounding sites from which subfossil pollen assemblages would be extracted (*Table 3, Figure 2*). Trap placement was guided by the aim of clarifying and quantifying taphonomic relationships between modern vegetation and its pollen rain that falls onto, and is incorporated into, sedimentary deposits. Such sedimentary deposits that may potentially bear preserved pollen assemblages come from caves and rock-shelters that are foci of present and past archaeological excavations, as well as from depositional points within the surrounding open landscape. The traps are due to be collected in late 2018.

Table 3. Sites, trap numbers and positions within sites of the 24 pollen traps deployed

Site	Trap #	Position
Hang Ang Noi	R2200	Back of chamber, beneath bat roost
	R2201	Front-centre of cave mouth, just inside drip-line, affixed to fence post
Hang Moi	R2202	Back of chamber, next to TAP 2011 & Vietnamese Team trenches
	R2203	Corner of cave mouth, inside drip-line, adjacent to trench dug into ashy midden
Hang Hanh	R2204	Hung from overhang c. 2.5m above rock-shelter floor
Thung Binh	R2205	Back of main chamber
	R2206	Upper (small) chamber, beyond northern wall of trench
	R2207	South corner of cave mouth, in front of main trench, affixed to fence post
Mai da Ong Hay	R2208	Hanging within a vertical crevice above flooded cave floor
	R2209	Affixed to young <i>Ficus</i> tree in open landscape ~ 50m in front of cave (near TAK2)
Mai da Vang	R2210	Hanging from rock ledge c. 2.5m above rock-shelter floor
	R2211	Affixed to leg of large metal sign at bridge over river, in open landscape c. 250m in front of rock-shelter (near TAK1)
Den Thai Vi	R2212	Affixed to limestone outcrop in paddy south of Den Thai Vi (near TAK9)
Hang Boi	R2213	Back of chamber, affixed to fence enclosing open trench
	R2214	Front-centre of cave mouth, just inside drip-line, affixed to fence post
Thung Chua	R2215	Affixed to <i>Mallotus</i> tree on forested floor of doline
Vung Chay	R2216	Levelled, developed southern half of valley floor, c.10 m south of central channel
	R2217	Levelled, developed southern half Vung Chay valley floor, but closer to perimeter limestone walls (and hence also closer to limestone vegetation) than R2216
	R2218	On marshy valley floor of northern half of Vung Chay
Vung Tham	R2219	Adjacent to augering locale TVA2, between rest house and Hang Moi
	R2220	Near to TVA4, the furthest augering locale west, and hence the closest augering locale and open landscape pollen trap to Hang Moi
	R2221	Adjacent to TVA3 augering locale in centre of Vung Tham. The vegetation here is comprised of disturbance regeneration taxa
Hang Trong	R2222	Inside northern mouth of Hang Trong, closer to eastern wall
	R2223	Inside southern mouth of Hang Trong, behind main trench, closer to western wall

2.3.3. Herbarium

Botanical collecting focused almost entirely on valley bottom habitats, which, at present, are often dominated by disturbed, edge-adapted and re-growth communities. Only fertile plants were collected. In addition to providing the potential to extract pollen for reference collections, this was to aid in identification and in light of the fact that many herbaria are unwilling to accession sterile material. A total of 54 plants were collected over a three day period (Figure 2). Five replicates were made of each of these collections: three to remain in-country, distributed to local herbaria by NTMH (Hanoi University of Pharmacy; Institute of Investigation and Forest Planning; and University of Sciences, VNU); the remaining two replicates of each collection were shipped to the UK under licence for accessioning within the Herbarium at the Royal Botanic Gardens, Kew, and

into the SUNDASIA Project reference herbarium; full data are tabulated in an Excel spread-sheet curated within project digital archives. To facilitate identification and further sharing of data, a project page was created on the citizen science platform, 'iNaturalist' (information accessible at: <https://www.inaturalist.org/projects/sundasia>).

2.3.4. Auger survey

Exploratory augering for potential pollen-bearing sedimentary sequences was carried out in the vicinity of Thung Binh and in Thung Chua in Sept. 2017, and at a further three sites in Dec. 2017 (Vung Tham, Vung Chay & Thung Ui) (Figure 2). Full descriptions of the sedimentary units are presented in Rabett *et al.* (2017c, d).

Within the cultivated alluvial landscape to the east of Thung Binh, sediments were augered at three points (TB1a, TB1b & TB1c) along an east-west transect perpendicular to a southward flowing stream. These sequences are interpreted as colluvial (TB1a), floodplain and channel deposits (TB1b and TB1c) of a low-energy meandering stream east of the foot of the isolated limestone hill that houses the TB1 cave. Based upon the nature of the notional mangrove and marine deposits at the base of TB1c, these deposits probably date to after 4000 cal. BP, when the sea regressed following the Dong Da transgression (*c.* 7000-4000 cal. BP). Whilst evidence of redox did not bode well for pollen preservation, the more reduced sediments from *c.* 1m depth and below, which also include the notional mangrove and marine sediments at the base, may contain palynological signatures of littoral, mangrove and estuarine vegetation that likely occurred in the area during the hundreds of years to millennia as the sea regressed following the Dong Da transgression.

Based upon the sediments encountered in Thung Chua, this doline appears to contain deposits of oxidised colluvium from the weathered limestone walls that enclose this circular doline, combined with organic matter from the vegetation growing atop the valley floor. The degree of oxidation of the sediments suggests that the valley floor has remained well above the local water table. It was deemed unlikely that such conditions will have promoted the preservation of sedimentary pollen assemblages.

Vung Tham is a triangular-shaped doline immediately to the southeast of the Hang Moi archaeological site. Augering was undertaken at six locations in this doline (TVA1-6) covering the centre and periphery of the valley (*see* Rabett *et al.* 2017d). Two further exploratory survey points were taken in the vicinity of the park Rest House and in a marshy depression close to the junction between pathways leading to HTC and Hang Boi, an area known to be seasonally flooded.

The profiles at sites located toward the edges of the valley (TVA1 & TVA2) consist of moderately organic silts and clays, with evidence of reduction-oxidation, decaying plant fragments and angular limestone grit towards the base. The profiles at the remaining four sites, which are located more towards the centre of the valley, comprise fine-grained silts and clays with higher organic content and visible indication of reducing settings throughout. We interpret these as representing deposition beneath and along the margins of a perennial water body within a very low-energy environment, with minor colluvial input from valley sides.

Peripheral sites and the upper most layers of more central sites show evidence of oxidation, possibly the result of their positions as marginal to the inferred water body, and perhaps just above a fluctuating local water table. The estuarine faunal remains from Hang Moi, taken together with preliminary findings from the Vung Tham core of microfossils of mangrove and aquatic taxa, suggest that at times of higher sea level than that of today Vung Tham was flooded with brackish water and inhabited by estuarine and back-mangrove ecosystems within a lagoonal setting sheltered from wave energy. Determining if this was indeed the case will not only further clarify the picture of past marine intrusion into massif interior, it will also provide a valuable tie-in to other local dated sedimentary records from the Song Hong Delta (e.g. Hori *et al.* 2004; Tanabe *et al.* 2003).

Four auger survey holes were made in Thung Ui (TUA1-4) at points around the margins of an artificial lake that fills the eastern end of this horseshoe-shaped valley as well as in the western and central parts of the valley (*see Rabett et al.* 2017d). Augering at all four locales halted short of reaching two metres' depth due to the stiff oxidised laterites encountered. These clays also constitute deposits deemed unlikely to preserve microfossil assemblages. On the evidence of the auger survey, it was difficult to say much about the Thung Ui deposits other than that the upper two metres of the valley fill appears to have remained in an oxidising setting above the local water table, receiving its constituent sediment from weathering and colluvial transport of material derived from the encasing limestone walls. An exception to this generalisation is the portion of the TUA1 auger hole corresponding to depths 42-96cm, which comprised dark greyish silts with higher organic content than that of the laterites across the rest of the valley floor. The TUA1 site is located near to a small stream that feeds the lake from the NE. Anecdotal evidence suggests this may be a persistent natural feature predating the lake. For this reason, and more organic less oxidised local deposits, TUA1 was selected for mechanised core extraction.

2.3.5. Mechanised coring

In response to challenges posed by the terrain and remoteness of the central part of the massif, a sampling programme was drawn up that would tie manual coring, using a Livingstone corer (1m chamber), in the central dolines to a deep mechanised core extracted from the western side of the massif and one already extracted from the eastern margin. This latter core was drilled in the immediate vicinity of the 2012 VIGMR TAK10 core (20.285281N, 105.905997E), close to the Hoa Lu ancient capital just outside the massif to the north east. The western margin core was drilled in Thung Ui, the only interior eastern doline accessible by road. Although the lake that now occupies the eastern section of the valley is artificial, its spring-fed origin left the possibility that organic deposits may exist beneath or within the sandy, silty clays which characterised the profile to a depth of 180cm during our auger survey of TUA1 (20.25599N, 105.88761E). Using a large mechanised coring rig, 13 m of deposit were drilled at this location under adequately controlled conditions. The upper nine metres consisted of laterites with almost no organic content. It was deemed upon inspection (by NTMH and SAO) that this portion of the sequence contained little palynological potential the upper five metres were photographed and described, but not retained. Core recovery therefore began from a depth of five metres, with organic content beginning to increase after nine metres. The tentative hypothesis is that the 9-13m depth portion of the sequence corresponds to the Early-Mid Holocene when sea-level and water tables were higher and climate wetter.

2.3.6. Manual coring

Three cores were made using the operated Livingstone corer. As at Thung Ui, site selection in two cases (Vung Tham & Vung Chay) was driven by exploratory augering carried out in Nov./Dec. 2017. The third core (Dong Trong) was obtained within Bich Dong, a site identified from VIGMR's 'Landscape Map' in Annex 3 of the UNESCO Nomination Document, and visual inspection of surface sediments and vegetation during a previous visit to the site. All three yielded productive cores with sediment sequences in which organic units predominated, indicating pollen preservation should be sufficient to produce proxy vegetation histories. Laboratory analysis thus far on the Vung Tham core, supports this contention. Three ^{14}C dates obtained (on wood) from this profile, at core depths 54 cm (1229 - 1358 cal. BP, UBA - 38672), 84 cm (1280 - 1352 cal. BP, UBA - 38673) and 223 cm (7692 - 7872 cal. BP, UBA - 38674) establish the depositional sequence and demonstrate that the record will help track changes around the Mid-Holocene incursion.

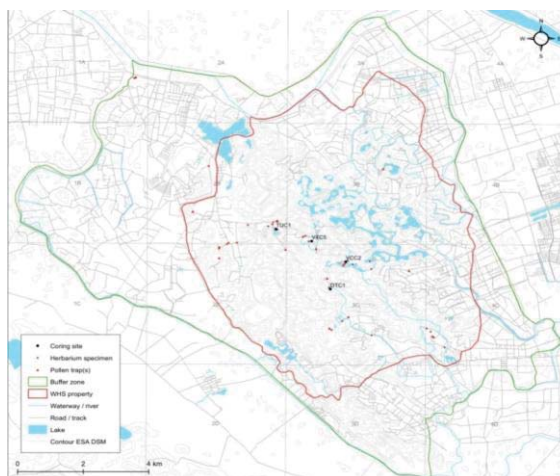


Figure 2. Map showing the distribution of the pollen trap locations (red triangles), herbarium collection points (red dots) and the four cores (black dots) discussed in text (Map: T.Kahlert)

2.3.7. Faunal record

Archaeological excavations at five cave sites (Hang Trong, Hang Boi, Hang Moi, Thung Binh 1 and Hang Hanh) have yielded faunal remains. Assemblages from these sites are, overwhelmingly, the product of human subsistence activities and are generally highly fragmented. These materials, however, do include taxonomically diagnostic elements (*Figure 3*) and represent records of human subsistence activities and animal life in Tràng An, during the period between 23,000 and 3000 cal. BP. Identification of animal bone remains is being achieved through the use of comparative collections in museums (Oxford University Museum of Natural



Figure 3. A selection of diagnostic faunal remains, incl. mammals (porcupine), birds (owl) and reptiles (monitor), recovered from archaeological sites in Tràng An (Photographs: C. Stimpson).

History, University of Cambridge Museum of Zoology, Natural History Museum, UK, and American Museum of Natural History). The animal bones are being used to investigate spatial and temporal trends in taxonomic representation and human exploitation of vertebrates in the Tràng An World Heritage Area. A detailed analysis and comparison of

regional evidence for the exploitation of deer (Cervidae) in the ‘Hoabinhian’ is underway: preliminary results were presented at the XVIII Congres UISSP in Paris in June 2018. Furthermore, targeted studies (e.g. Kelly 2018; Stimpson *et al.*2019) are examining individual taxa which are either poorly represented or understood in archaeological and palaeontological records.

2.3.8. Trail camera survey

A trail camera survey was initiated in Sept. 2017, with a view to improving our understanding of the current community of medium/large mammals. The survey was concluded in Apr. 2018 and comprised 1013 camera days in the core zone (Figure 4, Table 4). Triggers recording wild animal activity were very rare with a total of 7 incidences out of a total of 114 events (an ‘event’ represents a series of images pertaining to the same trigger). Two taxa could be identified from the resulting images: tree shrew (*Tupaia* sp.) and hog badger, (*Arctonyx collaris*). Unidentified taxa in the remainder of the images are likely civets or treeshrews.

Domestic animals were a more common occurrence (12 out of 114 events), with regular incursions of grazing goats into the core of the park being indicated. The most common events recorded (71 out of 114) were activities by people. The results from the trail camera survey suggest that it is highly unlikely that larger mammals (certainly ungulates or carnivores) remain in the core area, although the confirmation of the presence of hog badger is encouraging given the long standing presence of this species indicated by archaeological investigations in Trảng An. On this evidence the medium/large mammal community is likely to be severely impoverished.

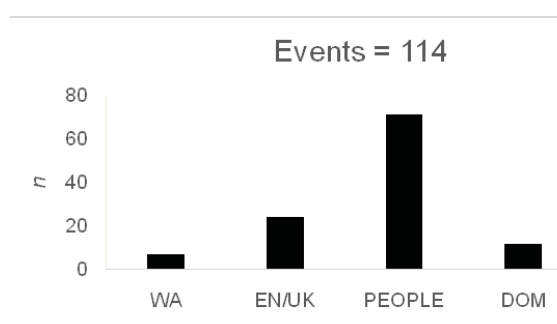


Figure 4. Total nos. events (114) 11/09/2017 to 22/11/2017 ($n = 105$) and 10/12/2017 and 23/04/2018 ($n = 9$). Key: WA = wild animals; EN/UK = environmental/unknown; PEOPLE = visitors; DOM = domestic animals (Chart: C. Stimpson)

Table 4. Trail camera data from September deployment

UNIT	DEPLOYED	RECOVERE D	DAYS	LAT	LONG	ASL	ORIE N.
1	11/09/2017	22/11/2017	73	20 15 13.3	105 53 54.7	15	220
3	11/09/2017	22/11/2017	73	20 15 13.3	105 53 38.6	3	330
4	11/09/2017	22/11/2017	73	20 15 16.9	105 53 35.2	12	270
5	22/09/2017	22/11/2017	62	20 15 24.8	105 53 21.7	9	360
6	22/09/2017	22/11/2017	62	20 15 28.7	105 53 20.1	18	130
1B	10/12/2017	23/04/2018	134	20 15 16.3	105 53 29.5	44	280
3B	10/12/2017	23/04/2018	134	20 15 16.7	105 53 25.8	70	360
5B	10/12/2017	23/04/2018	134	20 14 59.4	105 53 24	140	42
7B	10/12/2017	23/04/2018	134	20 14 58.9	105 53 25	132	180
8B	10/12/2017	23/04/2018	134	20 15 12.4	105 53 22.8	28	180

2.3.9. Biodiversity monitoring

Archaeological investigations at Hang Ang Noi (20.275000N, 105.916667E) revealed an abundance of recent skeletal remains of small vertebrate taxa in surface deposits. These assemblages comprise skeletal remains from naturally-occurring cave vertebrates (chiefly, bats - Chiroptera) along with the bones deposited as regurgitated material by owls (likely fish owls: *Bubo* sp.) using the cave as a roosting site and incorporated into the cave deposits. The study of cave-roosting species, like bats and owls, provides a ready and inexpensive way to assess trends in the character of local small vertebrate communities. Hang Ang Noi occupies a position within the Trảng An core zone that is *c.* 0.5 km from an arterial route, making the record from here potentially sensitive to external disturbance and a good marker for the health of the local environment.

Samples of this material have been collected systematically on four occasions since Sept. 2016. Identification of small vertebrate taxa is being undertaken at the Oxford University Museum of Natural History (CS) and QUB (AR). Analysis is in its early stages; however, indications are that the assemblages include skeletal elements from fruit bats (*Rousettus*, *Cynopterus*), insectivorous bats (*Hipposideros*, *Taphozous*, *Scotophilus*) shrews (Soricidae), murid rodents (Muridae), tree shrews (*Tupaia belangeri*), voles (Microtinae), frogs (Anura) and birds (Aves). While the focus will be necessarily on cave-dwelling vertebrates and be biased by the hunting preferences of owls, this material will yield basic biodiversity data, where none exists currently.

2.3.10. Tephrochronology

Tephrochronology uses volcanic ash layers (tephras) to link, date, and synchronise geological, palaeoenvironmental, or archaeological sequences or events (Lowe 2011). The primary analytical method is by geochemical characterisation or 'fingerprinting'. A securely characterised tephra layer can then be used as a precise age-equivalent horizon between sedimentary sequences, whether in visible layer form or as distal cryptotephra (deposited thousands of kilometres from source) with ash shard particles <100 µm which are not visible in the stratigraphy. The precision derives from the rapidity of atmospheric particle deposition following eruption (days - weeks). The greatest chronological value of the technique is when a numerical age obtained for a correlated tephra is transferred from one site to another. There are three major volcanic regions in close proximity to Northern Vietnam: Indonesia, the Philippines and Japan. All have a number of highly explosive volcanoes known to have been frequently active throughout the Late Quaternary. Any tephra present are expected to be in cryptotephra form.

The cores Vung Tham, Dong Trong, Vung Chay and Thung Ui were subsampled at 5cm contiguous intervals (*c.* 2-3 cm³). These initial rangefinders were used to locate stratigraphic regions for glass shard presence indicative of a possibly volcanic tephra layer. Sediments were sieved between 80 and 25 µm to remove coarse particles >80 µm and obscuring silts and clays <25 µm. Each >25 µm fraction was then subjected to the centrifuge density floatation method of Blockley *et al.* (2005) using SPT (sodium polytungstate) to float out rhyolitic volcanic glass shards from the relatively heavier background mineral assemblage. Floated residues were then mounted onto slides and inspected by light microscope for the presence of glass shards.

Single clear glass shards were found in each of the 5-10 cm and 10-15 cm rangefinder intervals in Vung Tham core section R2413 (0-100 cm); however no inference about a cryptotephra ash layer could be made as these are likely only random background atmospheric deposition. No further tephra shard presence was detected in any of the other core rangefinder intervals. This was surprising, as one would expect to see more shards from background deposition or reworking. More will need to be determined about the respective depositional environments before these results can be put into context.

3. How does coastal evolution impact upon tropical settlement systems?

3.1. Radiocarbon dating of molluscs in tropical contexts

This research aims to create a reliable tropical carbon off-set that can be applied in the ^{14}C dating of archaeological shell from sites that are geographically separated, using the tower karst landscape of Trảng An as a test study, as spatial variability here is likely to be accentuated. It also examines variation in carbon up-take across a wide temporal range covering the Late Pleistocene to Mid-Holocene to assess the impact of changing habitat conditions that are linked to transgression phases and that were caused by deliberate selection in the gathering strategies of early foragers. The impact to carbon up-take into shell through fluctuations in the palaeomonsoon is also being studied (*see* Section 3.2.)

3.1.1. The impact of geographic variability and species diversity on modern carbon off-sets within the mollusc genus Cyclophorus

The field sampling strategy adopted ensured maximum geographic coverage was achieved within the confines of the massif (tempered by access practicalities) and structured using the 4 x 4 km grid system for ready incorporation into the project's GIS database. The collection of molluscs proceeded in a 10 x 10 m area around the initial find spots (with supplementary collection of associated foliage, particularly if this was in the process of being consumed), and small limestone and sedimentary samples for geochemical analysis. Each initial find spot was GPS-tagged. Where-ever possible a range of different micro-habitats was included in the sampling protocol, which was adapted from Vermeulen and Maassen (2003). Over two field seasons in 2017/18 *Cyclophorus* specimens were collected live from 10 locations across the massif. Basic biometrics were taken (width of shell, height of aperture, width of aperture) to determine the average size of shell and standard deviations, so that size variability could be controlled for.

F^{14}C age determinations have been obtained from these samples. Laboratory sampling for the ^{14}C dates was carried out at the 14 CHRONO Centre, Queens University Belfast using the framework developed in Hill *et al.* (2017). Sampling for the F^{14}C determinations focused on apertures (outer lip) only. Atmospheric, dietary and background F^{14}C values were calculated as $1.0153 \pm 0.0033 \text{ F}^{14}\text{C}$, based on seven samples of vegetation. The average F^{14}C diet value for *Cyclophorus* spp. across the sampled sites was calculated to be $1.0080 \pm 0.0051 \text{ F}^{14}\text{C}$. A preliminary age offset for *Cyclophorus* spp., based on the equations published in Hill *et al.* (2017), has been therefore calculated as $417 \pm 57 \text{ }^{14}\text{C}$ yrs, though further work by IBS will refine this. Average old carbon uptake in the sampled specimens varies 0-11% as an estimated fraction of diet, based on the method of estimation in

Hill *et al.* (2017). The data obtained so far suggest that while *Cyclophorus* appears to be suitable for ^{14}C dating, there are some significant variations in $F^{14}\text{C}$ values between specimens at some of the sample sites. At least three possible reasons for this can be considered higher than expected species diversity at some sample sites. This is being particularly explored with the aid of recent findings on the genetic community character of modern Cyclophoridae in coastal settings (vonOheimb *et al.* 2018). Some sample sites may be adversely affected by anthropogenic pollution leading to increased noise in the ^{14}C ages of specimens from those sites (*see* Pigati *et al.* 2010). Unexpected or unusual behaviour in individuals, exacerbated by small sample sizes at some sites.

3.1.2. *Assessing the impact of long-term environmental, climatic and anthropogenic factors on carbon uptake and the dating of archaeological shell-bearing midden sites*

A clear understanding of the effect of coastal proximity on species representation and its effect on carbon uptake profiles, as well as the impact of tower karst insularity in general, are critical to the formulation of a robust radiocarbon off-set curve. This is because prehistoric occupation of the shell-bearing midden sites being investigated by SUNDASIA occurred during periods when the sea was comparatively distant (as today) and also when it was much closer to the massif. This raises further questions about the rate of change between a coastal and sub-coastal state for molluscan communities. Bearing in mind that sea-level rise since the end of the Last Glacial Maximum (*c.* 19,000 cal. BP) has not been uniform (Haneburth *et al.* 2000), the rate of adaptive change may have been out of step with landscape change to a varying degree. Each of these considerations will need to be built into carbon off-sets for archaeological datasets of *Cyclophorus* spp. In order to accurately reconstruct trends in site use and resource acquisition; with the latter having been potentially affected as communities of this dominant genus adjusted to changing conditions.

An additional factor to be considered is the effect of the deliberate selection strategies of early foragers in mollusc collection on the archaeological data. Most shells from archaeological middens will have been purposefully selected during gathering activities. This will have led to an over-representation of some taxa compared to others in the local snail community (*e.g. see* Rabett *et al.* 2009), and also affected by the time of year during which they were most active and collected. The proportion of snail shells entering an archaeological midden naturally within a limestone karst setting (*i.e.* by non-anthropogenic means) is unknown, though natural accumulations of significant volumes can occur (F. Naggs *pers. comm.* 2008) and will need to be considered.

3.2. *Reconstructing the palaeomonsoon*

Tracking changes in palaeomonsoon strength and receipt of precipitation, and the potential effects of such variability on carbon up-take by terrestrial snails forms an additional line of enquiry in the chronological component of the project's molluscan analysis. If a strong relationship can be identified between the environmental $\delta^{18}\text{O}$ values related to rainfall and the stable isotope values obtained within individual *Cyclophorus* shells, such a proxy can then be further utilised to provide a more detailed view of how the summermonsoon has changed over time. There are additional considerations relating to the impact of the palaeomonsoon. These include, how the intensity of precipitation associated with a stronger monsoon might have mobilized increased levels

of calcium carbonate in the environment; or the effect that a changing receipt of precipitation might have had on species abundance and representation. Shell recrystallization rates (and hence utility in ^{14}C dating) could also vary chronologically.

3.2.1. Investigating the palaeomonsoon using archaeomalacology, stable isotopes and ^{14}C dating on shell material from archaeological contexts

Investigation of the palaeomonsoon using shell assemblages will combine three inter-related aspects of research:¹The archaeomalacological taxonomic and taphonomic climate story in shell assemblages from the excavated sites in Trảng An; ²stable isotope analysis on selected samples of the genus *Cyclophorus* from archaeological assemblages to reconstruct humidity and aridity through time; ³ ^{14}C dating of selected specimens of the genus *Cyclophorus* spp. to provide an absolute chronology for these climatic records.

Archaeological shell material from Thung Binh 1 will provide the basis for this research. Similar, smaller, partial sequences of shell assemblage material have been previously analysed in a previously (Rabett *et al.* 2017a) have already demonstrated the potential for tracking significant climatic trends in this fashion at archaeological sites in this region. Furthermore, recent work on the patterning and distribution of cyclophorids (von Oheimb *et al.* 2018) in Vietnam suggests that proximity to the coast results in distinct distributions of this taxon. From their genetic study we infer that the general taxonomic distribution of mollusc species within Trảng An today should be very similar to that recovered during the timeframe of our archaeological material.

The assemblage to be analysed will be extracted from sample columns obtained during excavations scheduled for late 2018. These will also provide the basis for the stable isotope analysis and ^{14}C dating of archaeological shell. A type collection and photographic record of common species in archaeological shell sequences has been prepared.

3.2.2. Magnetic susceptibility

In addition to its research into changes in shell $\delta^{18}\text{O}$ and sedimentary biomarkers (Rabett *et al.* 2017a) SUNDASIA is analysing magnetic susceptibility (MS) in cave sediments as another method to track climate change. This approach was pioneered in European cave sequences (e.g. Balsam *et al.* 2011; Ellwood *et al.* 2004). The composition of sediment mineralogy is largely determined by the climate in which it is formed and deposited. Therefore, magnetic readings of sediment columns can provide numerical data which upon further analysis can determine climatic variations of the past.

A key variable in the application of this method rests with the stability of the depositional environment within caves. Significant pedogenic disturbance is likely to adversely affect the preservation of palaeomagnetic stratigraphy within a sediment column. Given the success from using MS from caves in Europe, work by this project is assessing the potential for expanding collection of this line of proxy data to Southeast Asian contexts. Our analysis has focused on comparing the MS curves from two cave sites within Trảng An: HTC and TB1. Both sites contain depositional sequences of sufficient antiquity to incorporate evidence of key climatic swings during the post LGM period. Of particular interest as a point of comparison between the two sites is the regional aridity pulse coincidental with Heinrich 1 Event (17,500-14,700 cal. BP); the effects of this shift in the receipt of precipitation we have already established at HTC through the changes in biomarkers recovered from within the cave sediment.

MS data from the deepest trench at HTC (Trench 1) is already published (Rabett *et al.* 2017a). Two comparable sample series were taken at TB1 in Sept. 2017. The first came from the south-facing section of Trench 1 (14 samples); the second from the south-facing section of the VIA trench (22 samples) - both cases at comparable resolution to the HTC analysis: 5 cm intervals from the ground surface to the base of excavation. Analysis was undertaken using a Bartington MS2 B bench system (McAllister 2018). While offering considerable promise for future work, variations observed in the data obtained from HTC and TB1 qualifies earlier contentions about the uniform suitability and stability of cave settings for MS analysis. Successful application requires a detailed appreciation of how cave formation processes have affected the pathways of sediment accumulation and the level of direct correlation between external conditions and those in the sampling area.

4. Contributions to future responses to sea-level change

4.1. Present a long-term perspective on human responses to coastal flooding

The data collection for SUNDASIA's digital terrain modelling, including its expansion of the existing database of erosional features from past periods of marine transgression, is nearing completion. The data base that has been created within the ArcGis framework will enable creation of a highly resolved virtual landscape within which processes of sea-level change (particularly transgressive) in Trảng An and the effects this had on the geography of the massif can be explored through time slices. Taken in conjunction with archaeological and palaeoenvironmental data generated by the project, human responses to these transformative environmental states will be modelled. Particular focus is placed on not only understanding the progress of incremental change, but also of what happens when environmental (and cultural) 'tipping points' are crossed and incremental change becomes non-linear and transformative.

4.2. Develop understanding of environmental and cultural 'tipping-points'

Profound changes in sea-level have shaped Southeast Asia's geography over tens if not hundreds of millennia, and it is generally accepted that these changes have impacted significantly on the course of human evolution and history in this part of the world though few studies have attempted to address this directly. SUNDASIA is expanding what is known about the impact that changing sea-levels and environmental conditions had on early socio-economic systems. Through more detailed understanding of how communities responded to past change it aims to bolster modern mitigation and adaptive measures in line with the UN 2030 Agenda for Sustainable Development (A/RES/70/1). The full range of variables associated with coastal adaptation, particularly as regards non-linear processes ('tipping-points'), cannot be incorporated effectively by planners until the concept itself is more explicitly addressed and understood (Millner & Dietz 2015).

4.3. Knowledge transfer and the longue durée

Through the course of the project's second year, knowledge transfer and exchange actions, in the context of adopting a long-term perspective to contemporary issues, have been undertaken with local and international outcomes in fields directly associated with the research programme. Collaborations and capacity-building efforts are highlighted in this section, together with spin-out developments, notably, in the fields of biodiversity conservation and digital terrain mapping in heritage management.

4.3.1. Vietnamese authorities and institutions

Close ties are maintained with key authorities and institutions within Vietnam, including the Institute of Archaeology, Hanoi, who authorises and continues to be directly involved in project excavations; and staff from the Vietnamese Institute of Geosciences and Mineral Resources, who have provided advice and also participated in field activities, and whose director (TTV) is a project Co-Investigator. Project nRTK access has been licenced by the Tuong Anh Science Technology Equipment JSC, Ho Chi Minh City. SUNDASIA is also working with the Ninh Binh Provincial Museum, particularly with a view towards the long-term curation and public display of excavated material. A senior member of the Museum's Department of Artefacts joined one of the excavation teams over the course of three seasons to learn archaeological field techniques. Staff members from the Tràng An Management Board have again formed core participants in all aspects of project fieldwork during 2017-18 (including: excavation, surveying, sediment core collection and curation; building experience and competency in drone terrain surveys. The aim is to help build existing experience in archaeological heritage management and dissemination, particularly where this is relatable to changes to current environmental conditions, also though to provide skills that are transferable to managing aWHS. These include helping to monitor and regulate development within the buffer zone and in the tourist-designated corridors through the core zone, and monitor the impact of changes in water level or habitat in all areas of the property.

4.3.2. Student participation

Student involvement continues to be central to the project's activities. Two Vietnamese doctoral students (Senckenberg Research Institute, Germany, and the Institute of History, Hanoi) and seven undergraduates (from three UK universities) participated in fieldwork during the second year of the project, often over more than one season. This has resulted in five undergraduate dissertation projects based on aspects of research in Tràng An (biodiversity monitoring, ceramic residue analysis, magnetic susceptibility, prehistoric subsistence, and phytoliths). Three of these dissertations have received distinctions and university awards. The integration of students into a front-line research is aimed at helping to promote interest in Southeast Asian archaeology among local and international students and to help them develop contacts with those already working in this field.

4.3.3. Biodiversity Conservation

In addition to trail camera surveys and routine sampling of modern cave fauna (*see Sections 2.3.8 & 2.3.9*), SUNDASIA is collaborating with the Vietnam Primate Conservation Program, Endangered Primate Rescue Center, Ninh Binh Dept. of Tourism, Tràng An Management Board, and the Xuan Truong Construction Enterprise to establish a trial population of Delacour's langur (*Trachypithecus delacouri*) in Tràng An (*see [http://whc.unesco.org/en/list/1438/documents/State of Conservation Report 2017 Sub-Annex 1.2](http://whc.unesco.org/en/list/1438/documents/State%20of%20Conservation%20Report%202017%20Sub-Annex%201.2)*). In 2015 the Tràng An World Heritage property was identified as the only viable location for a second release site, following the successful reintroduction into the Van Long Nature Reserve (Ninh Binh province), and marks a crucial step towards safeguarding the survival of this species (Nadler 2015). Study of the Tràng An release group and assessment of a wider, longer-term reintroduction initiative within Tràng An is intended to form the doctoral thesis of a Vietnamese PhD student. Connecting long-term patterns of vegetative and faunal change (using zooarchaeology and palaeoecology) to present conditions forms an essential part of

SUNDASIA's reconstruction programme. In Sept. 2017 within this remit, a vegetation survey of the planned release area was carried out by SO and NTMH. Their survey confirmed the presence of plants that make up the preferred diet of Delacour's Langur, demonstrating that appropriate food resources exist to support a trial reintroduction. This species is a Vietnamese endemic primate categorised as 'Critically Endangered' on the IUCN Red List of Threatened Species (Nadler *et al.* 2008). Its current distribution is restricted to a small number of karstic areas of northern Vietnam. The need to protect existing reserves and instigate new ones has been most recently highlighted in the 'Urgent Conservation Action Plan for Primates in Vietnam to 2025, Vision 2030' (Decision 628 QD-TTg). The success of the programme in Van Long (Dao Nguyen 2008) underscores justification for the initiative in Trảng An. Situating the programme here is also aided by close community involvement in the infrastructure of the Trảng An WHS (Bui Van Manh & Pham Sinh Khanh 2018).

4.3.4. Digital terrain mapping in heritage management

As noted (**Section 2.2.1**), DEMs are being incorporated increasingly into the management programmes of World Heritage sites. The Trảng An Management Board and SUNDASIA are jointly exploring ways to implement this technology effectively within the high relief property of Trảng An in order to help monitor and ensure effective management within heritage conservation, environmental, tourist and developmental spheres (Kahlert *et al.* 2018). Presentations contributing to wider dialogue on this topic were made (by TK) at two colloquia this year: the *International Aerial Archaeology Conference AARG* (Venice, Sept. 2018), and the *International Symposium for the Conservation, Research and Sustainable Development of Pre-Historic Heritage* (Beijing, Oct. 2018).

4.3.5. Contributions to international policy advisory bodies

SUNDASIA and Trảng An featured as a case study within a presentation by the ICOMOS Climate Change Working Group (High Ambition/Communication/Research team) as part of that group's examination of the way heritage management and climate change interact. The presentation (*High Ambition: To push heritage interaction with climate change to places it hasn't been before*) was delivered by Dr William Megarry (QUB) at the 42nd Meeting of the World Heritage Committee, Bahrain. The long-term stability of tropical limestone forest of Trảng An has been presented (by SO) at the Past Global Changes (PAGES)-endorsed conference on *Past Plant Diversity Changes* (Rabat, Oct. 2018) - Session 2: Refugia.

5. Conclusions

In the time since the first year report, primary field data collection has been completed across all proxies. Cave excavations at Thung Binh 1 and Hang Moi have increased the sample size of cultural evidence attributable to the late Pleistocene and Holocene. Zooarchaeological and artefactual analysis of material from these periods has begun and is already yielding significant results that have been presented in conference and are the subject of forthcoming publications. Human skeletal remains have been recovered at two of the archaeological sites studied by the project. Assessment of current vertebrate faunal biodiversity in Trảng An has also been undertaken to better understand the changes through time, including human impact on the ecological communities of this habitat.

Landscape survey of a further 12 caves has contributed data to the spatial distribution of sites with archaeological (and natural) heritage potential, while the mapping of new marine notches has increased the number of data points for coastline reconstruction from that previously available. A high resolution DEM has been completed in a c. 1500 ha corridor across the core zone of the property that also contains the highest concentration of the project's archaeological and palaeoenvironmental site locales. The approach taken using an off-the-shelf SUAV and the challenges overcome to map a tower karst environment have had the additional outcome of demonstrating both the utility and cost-efficiency of this method in heritage monitoring and management with presentations being made accordingly in colloquia. Online publication of collected GIS data has also begun.

The project's palaeoenvironmental reconstruction programme has advanced on four fronts. The setting of pollen traps and herbarium collection to assess modern pathways of pollen accumulation and floral biodiversity will greatly enhance interpretation of subfossil pollen assemblages that have been extracted from cave contexts, and through a successful campaign of landscape coring in dolines across the centre of the core zone, linking two deep mechanised cores on the eastern and western sides of the massif.

Assessment of palaeoclimatic changes expressed through land snail isotopic analysis and sediment magnetic susceptibility, and given chronological resolution through establishment of a reliable shell radiocarbon off-set, is revealing and responding to ecological and taphonomic complexities. The results of this work are greatly enhancing our understanding of these processes and will furnish a considerably refined model of the character, timing and consequences of a changing monsoon and past human responses to it.

A final development for the project over the second year of work has been the emergence of spin-out projects and collaborations, notably fostered through exploring contemporary as well as prehistoric environmental impacts to people and landscape. Each of these is feeding novel information back into the main project programme, aiding and expanding upon its response to the questions it set out to answer.

Notes:

(1) Fabrication of pollen traps followed the design and methods devised by the Open University. Details can be found at: <https://www.youtube.com/watch?v=BgkPROFQvb0&t=81s>

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