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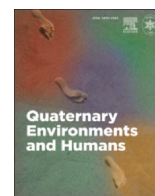
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An integrative study of new environmental and cultural data from the Hoabinhian of Laang Spean Cave (Cambodia) including modern human remains



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ABSTRACT

Although the Hoabinhian culture is renowned for its unifacial pebble tools and its discovery dates back more than a century, only a handful of sites provide complete information on this period. The site of Laang Spean, in Cambodia, has recently been described as a burial cave for the Neolithic period, but it was previously known as an emblematic Hoabinhian site for Cambodia. More comprehensive studies indicate that it offers a wide window onto the settlement of the Hoabinhian between 12900 and 5000 cal BP. The archaeological layer of the Hoabinhian culture at Laang Spean include faunal, human and lithic remains that enrich our understanding of the environment and way of life of this ancient culture. The faunal assemblage, dominated by bovines, tortoises, molluscs, and cervids, reflects a diverse ecosystem and the adaptability of the Hoabinhian people. The presence of both humid and dry forest indicators, alongside significant wetland areas, suggests their ability to exploit a variety of habitats. The lithic assemblage, characterized by a lower representation of unifaces and greater use of split cobbles, reflects a continuity in basic lithic reduction strategies with minor diachronic changes in raw material selection and tool production, possibly reflecting technological adaptations and increased intensity of occupation. The discovery of human remains, though challenging to contextualize precisely, contributes to understanding settlement patterns and cultural links in prehistoric Southeast Asia. The new data allow for a deeper interpretation of the environmental adaptations and hunting strategies of the Hoabinhian people, including their responses to climatic changes, such as the end of the Younger Dryas. This enhanced knowledge significantly contributes to our comprehension of the environmental dynamics and subsistence practices in prehistoric Southeast Asia and underscores the necessity of reassessing key Hoabinhian sites with modern excavation and dating techniques.

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1. Introduction

The Hoabinhian culture, recognized primarily for its unifacial pebble lithic industries, has been known for over a century. Originating from the pioneering work of Madeleine Colani in Northern Vietnam, the term "Hoabinhian" was introduced and defined during the First Congress of Prehistorians of the Far East in 1932 as follows: "a culture composed of implements that are in general flaked with somewhat varied types of primitive workmanship. It is characterized by tools often worked only on one face, by hammerstones of sub-triangular section, by discs, short axes and almond-shaped artifacts, with an appreciable number of bone tools." (Matthews, 1966, p. 86). Contrary to its appearance based on these tools, Saurin (1969) suggested that the Hoabinhian is more recent and leans towards the Mesolithic rather than the Upper Paleolithic due to the associated fauna.

Although Hoabinhian now appears to have originated in southern China at around 43.5 ka (Ji et al., 2016) and its presence spans from MIS-3 to MIS-1 in Southeast Asia, only a few sites predate the Last Glacial Maximum (LGM) and provide a complete stratigraphical sequence such as Tham Lod in Northern Thailand (Shoocongdej, 2006), Lang Rongrien (Mudar and Anderson, 2007) in Southern Thailand or Hang Cho, Hang Trong, and Tham Khuong in Northern Vietnam, the last of which records dates between 30000 and 28000 BP (Nguyen, 1991).

The substantial migration of groups occurred post-LGM, around 20000 BP, as evidenced by various sites across the Indochina peninsula. The majority of Hoabinhian settlements thus emerged during the Pleistocene/Holocene transition, with many dating to the early Holocene, such as the Laang Spean cave in Cambodia and the Hiem cave site in Vietnam (Masojć et al., 2023). The late hunters-gatherers of this period, referred to as forest populations, primarily inhabited caves and rock shelters in Northern Vietnam from 18000 to 7000 BP, showing a significant spike in human activity mainly during the mid-Holocene (Rabett, 2012; Ván Tân, 1980; Yi et al., 2008). The Hoabinhian persisted until 3700 BP (Forestier et al., 2013) on the Burmese borders with Thailand similarly to the case of Gua Cha in Malaysia (Adi, 1985) or others in Central Thailand (Bronson and White, 1992). Hoabinhian was considered a transitional industry until the Neolithic, or even associated with the first horticulture activities (Glover, 1977; Gorman, 1971; Reynolds, 1989).

In this paper, we will explore the complex tapestry of the Hoabinhian culture by integrating modern analytical techniques and interdisciplinary research, in the goal to deepen our comprehension of the Hoabinhian people, their tools, and their adaptability, thereby contributing a crucial chapter to the narrative of human prehistory. Our data will come from the Laang Spean cave site, which has been systematically excavated since 2009.

2. Archeological context of Laang Spean cave site, Battambang province

The geomorphology of the Battambang plain features a series of raised limestone collinear reliefs, termed "*phnom*". These are remnants of a Permian marine limestone formation (Fig. 1). The regional karstification history, as documented by Carbonnel (1972) and Demangeot and Schneider (1973), can be traced back to the Jurassic period following the emergence of these limestone structures. In the Permian period, these *phnoms* became enveloped by the Upper sandstone formation. The subsequent exposure led to karstic flows during the Pleistocene epoch.

Historically, the cavities of these *phnoms* structures have been populated by humans, with evidence suggesting habitation during prehistoric periods by the Hoabinhian groups, as demonstrated by findings at the Laang Spean site (Fig. 2, 3). This cave represents one of the many cavernous formations and shelters scattered across the Battambang plain in Northwest Cambodia.

The cave is perched atop a limestone hill named "Phnom Teak Treang" (coordinates E 102°55'; N 12°51'), at an elevation of approximately 150 m (Fig. 1).

Geomorphological developments, including the lowering of the base level, have resulted in the disconnection of the karstic system from the alluvial plain, promoting the fossilization of the cave's foundational sedimentary infilling. The subsequent strata were formed due to runoff following the roof's collapse. The current ground area of the cave encompasses approximately 1000 m². It was initially explored and excavated on multiple occasions between 1965 and 1970 by Roland and Cécile Mourer. Their investigations unveiled the pioneering evidence of significant Hoabinhian settlements in Cambodia (Mourer and Mourer, 1970, 1971; Mourer, 1977, 1994). The excavations pertinent to this work were conducted as part of the 'French-Cambodian Prehistoric Project' led by H. Forestier and H. Sophady since 2009. Considering the extension of Mourer's trenches, the total area excavated at Laang Spean by our team amounts to approximately 98 m², of which around 70 m² (71.43 %) pertain to Unit I, 8 m² (8.16 %) to Unit II, and about 20 m² (20.41 %) to Unit III. All units exhibit Neolithic occupation, while only Unit I shows evidence of Hoabinhian occupation. The Hoabinhian presence spans across 30 m² of Unit I's 70 m², making up 42.86 % of the area. It is comprised of a single archaeological layer, The pre-Hoabinhian occupation is represented by a few lithic tools, with a lower dating limit that is not yet well-defined and will be the subject of further research. The archaeological record and remains that are the focus of this study all originate from Unit I, which represents the sole Hoabinhian component of Laang Spean.

3. Material and methods

This paper focuses on the Hoabinhian component found exclusively in Unit I of Laang Spean as a balance between the preservation and the natural erosion of the cave's sedimentary fill and the excavation of Neolithic burials. This component consists of a single layer composed of four sedimentological facies, namely facies 9, 10, 11a, and 11b₁ (Fig. 4a). In all facies, animal bones, shells, and lithic remains were recorded (Table 1). However, the sedimentological facies 9 alone yielded 67 human bones. This facies also contains the highest number of remains (N = 10421), accounting for 60.5% of the total remains recorded in Unit I.

3.1. Stratigraphy and sedimentology

For the comprehensive study of the stratigraphy and sedimentology of the Hoabinhian sequence in the Laang Spean cave, we employed a multi-pronged approach. The excavation area was delineated in Unit I. In this zone, we meticulously excavated to a depth between approximately 60 cm and 190 cm revealing and categorizing distinct stratigraphic facies. From the bottom to the top, each facies—11b₁, 11a, 10, and 9—was separately sampled according to its sedimentological properties.

Macroscale analysis involved observing the texture, structure, and color of the sediments. A closer microscopic inspection was conducted to discern the presence of micro-charcoal fragments, burnt bone remains, secondary carbonations, and raw material fragments that might hint at tool-making activities. Furthermore, for a precise chronological placement, samples from each layer underwent Radiocarbon and Optically Stimulated Luminescence (OSL) dating techniques.

To comprehend the composition of the sediments, particularly the calcium carbonate content, we employed various geochemical analyses. This helped in understanding the potential origins, be it from the Permian limestone substrate, secondary micrite, or bioclasts. Furthermore, to grasp the anthropogenic influence on each layer, we quantitatively and qualitatively evaluated the presence of artifacts, lithics, osteological materials, and other signs of human activity.

Lastly, the conservation conditions and unique characteristics of the karstic context were assessed to understand the preservation and



Fig. 1. Laang Spean site location, Battambang province, among the limestone areas in Cambodia (Source: S. Puaud). The location of the sites mentioned throughout the text is also indicated.

deposition dynamics in the cave. This involved studying natural dynamic agents such as wind and water runoff patterns, combined with observable human activity imprints.

3.2. Dating and chronological model

After carrying out an initial conventional radiocarbon dating, which showed extremely low levels of residual collagen in the bones of the individual from first discovered burial, we opted for an effective bone apatite protocol for both the individuals from the Neolithic tombs and the isolated Hoabinhian skull. Indeed, as post-mortem chemical exchanges between bone and the surrounding sediment can be limited under certain environmental conditions, the structural carbonate present in the mineral fraction of the bone (bioapatite) can be dated (Zazzo and Saliège, 2011). The humid tropics are a priori sub-optimal environments for this type of dating because water is likely to promote carbon exchange by dissolution of bicarbonates between the bone and the surrounding sediment. The

preparation of the samples was performed at the MNHN Radiocarbon Laboratory, according to the protocols described in Zazzo (2014). Pretreatment and CO₂ extraction lines were used to remove contaminants and to produce purified carbon dioxide from the hydrolysis of the samples. After quantification, the CO₂ were sealed in glass tubes, and next sent to the Artemis AMS facility in Saclay for graphitisation and radiocarbon measurement.

A hierarchical Bayesian chronological model was developed using ¹⁴C ages, Optically Stimulated Luminescence (OSL) ages, and stratigraphic data. The ChronoModel software package (v.2.0.18; Lanos, 2017; Lanos and Dufresne, 2019) facilitated this development. Calibration of ¹⁴C data employed the IntCal20 curve (Reimer et al., 2020). The model's Markov Chain Monte Carlo (MCMC) parameters included a study period from 20,000 to 1000 BP, with settings of three chains, 1000 burn-in iterations, and adaptation over a maximum of 20 batches with 2000 iterations each. Data acquisition proceeded over 100,000 iterations with a thinning factor of 10. Table 2 and Fig. 5 present the model's results, displaying phase ages at a 95% confidence level.



Fig. 2. Environment and excavations at Laang Spean cave, Cambodia: a) 3D perspective view of Phnom Teak Treang. The Laang Spean cave is located at the top of the hill; b) Frontal view from the south of Phnom Teak Treang; c) Main excavation area inside the Laang Spean cave; d) Excavated surface in 2016 from squares where skull remains associated with a large lithic artifact were found; e) Excavation and cleaning of grids (Source: H. Forestier).

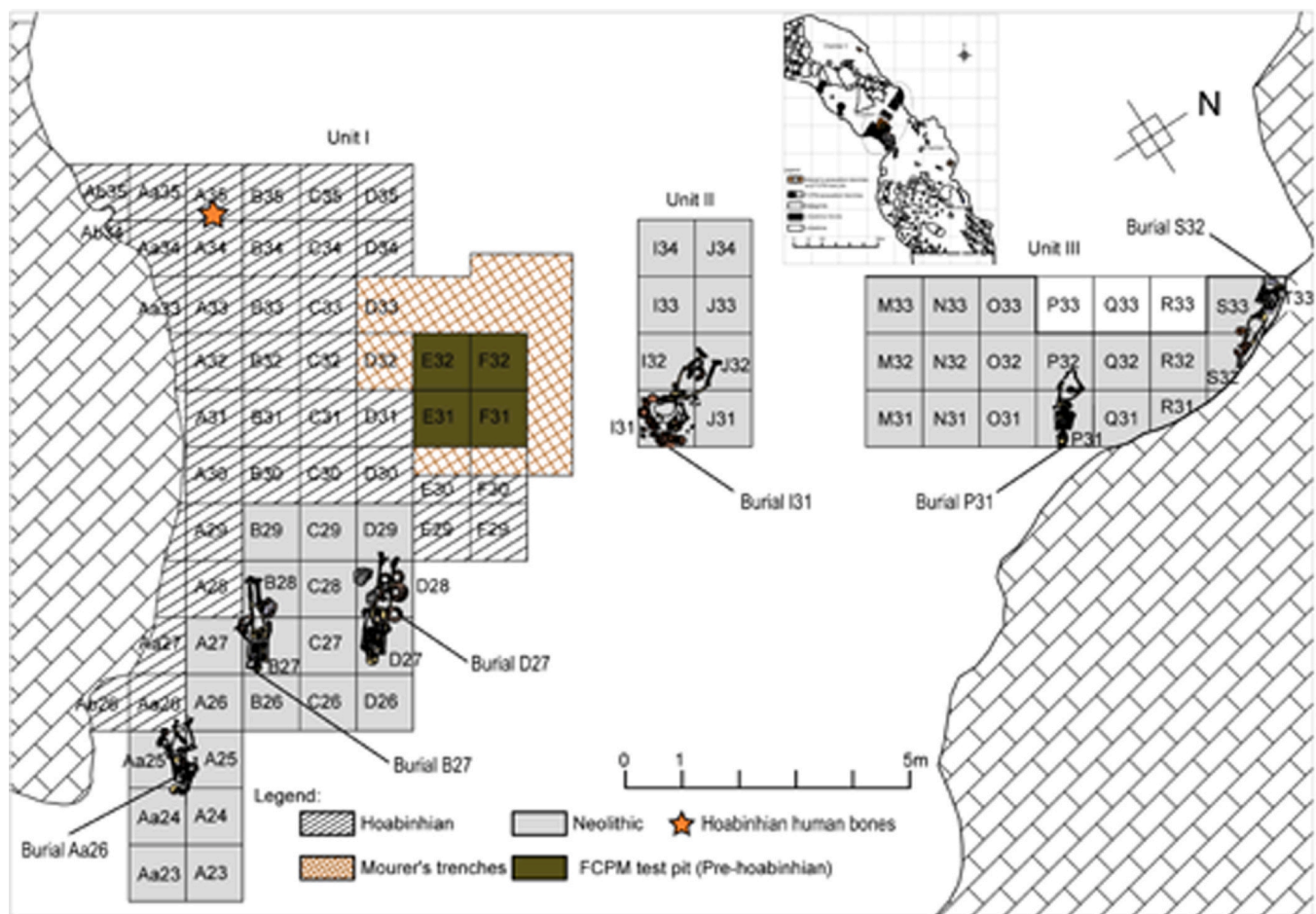


Fig. 3. Map of the excavation zones in Laang Spean cave. (Source: French Cambodian Prehistoric Project).

3.3. Archeoanthropology

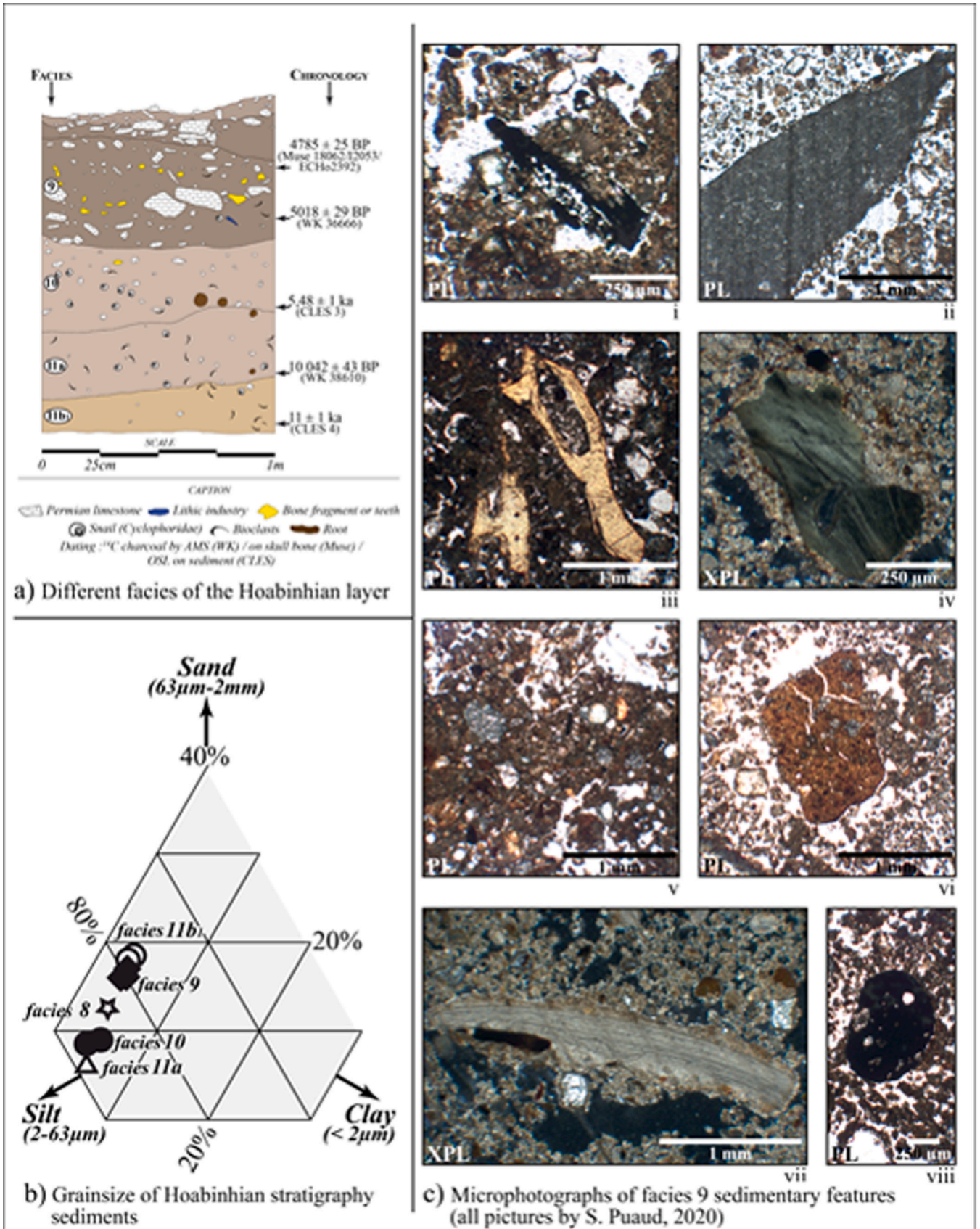
A systematic archaeological dig was carried out in the Laang Spean cave following the initial discovery of human isolated teeth and bones in the 1970s, but which did not reveal the presence of any burials (Mourer, 1994). Since 2009, we have been able to unearth six burials (Zeitoun et al., 2021) and the isolated bones of five individuals belonging to the Neolithic period (Zeitoun et al., 2012). We are providing here the whole direct dates of these burials. From the Hoabinhian archaeological layer, we identified 57 isolated skull cap fragments and 10 scattered isolated post-cranial fragments belonging to the sedimentary facies 9. A LMI HDI Advance R3x 3D surface scanner was used to digitally assemble the Hoabinhian cranial fragments using FlexScan3D and MeshLab software, culminating in the reconstruction of a single individual's skull.

3.4. Zooarchaeological analysis

The complete assemblage of both shells and animal bone remains collected in the Hoabinhian layer of the Unit I have been exhaustively studied. Among the faunal assemblage 13644 osteological remains and 1147 mollusc shells or shell fragments were taxonomically determined. Bone identifications were carried out using comparative specimens stored in several museum collections as well as relevant literature when available (Bochaton et al., 2019b; Claude et al., 2019). The quantification of the remains follows usual zooarchaeological (Bochaton et al., 2023) counting practices (Lyman, 2008).

3.5. Lithic analysis

Our comprehensive lithic analysis at the Laang Spean cave was anchored in a multi-dimensional approach, mainly based on identifying the reduction sequences (*chaîne opératoire*) (Audouze and Karlin, 2017; Inizan et al., 1995; Leroi-Gourhan, 1964) and the corresponding target tools. Initially, all artifacts from the Unit I squares were meticulously enumerated, with 1044 pieces identified and classified based on their typological and technological characteristics. A comprehensive analysis of the raw materials was conducted, revealing a dominant use of hornfels pebbles. These were primarily sourced from the adjacent Chanob River, situated at the base of Phnom Teak Treang, and from the major Stung Sangke River that runs through the Battambang plain. Tools, both cutting and non-cutting, were systematically categorized and their frequencies discerned, while distinct morpho-structural configurations were examined to understand tool formation based on natural pebble shapes. Macro-tools underwent a detailed metric evaluation, encompassing dimensional measurements and mass considerations. A Principal Component Analysis illuminated morphometric groupings based on blank and tool production over time. Lastly, patterns in raw material utilization for different tool types elucidated the prehistoric inhabitants' preferences in tool crafting. These methodologies, employed in tandem, provided an enriched understanding of the Hoabinhian lithic tradition at Laang Spean, validating and building upon findings from Forestier et al. (2021), (2022), (2023).



(caption on next page)

Fig. 4. Hoabinhian sequence of the Laang Spean Cave site (Cambodia): stratigraphy, grain-size and anthropized sediments. a) Laang Spean Cave, stratigraphy of the Hoabinhian sequence: 4 facies (11b₁, 11a, 10, 9). There is sealed by a stone facies (8) disturbed on the surface (2). Sedimentary facies are silty and bioclasts-rich. Features of anthropization are most-developed in facies 9: micro-charcoal (dark colour), faunal remains and lithic artefacts. b) Textures triangular diagram, grainsize analyse of the crude fine fraction (size particle under 2 mm) by laser diffraction. Sediments are mainly silty texture (80–90 % silt) with few sand (10–20 %). The high percentage of sand characterize here high anthropization of the layer 9 sediments. This fraction is composed by human activity micro-remains. Others sandy remains (20 % in 11b₁ facies) like siliceous debris and laterite are naturals. c) Microphotographs of thin sections of micromorphological samples from facies 9: microfacies details and sediment anthropization main features. i. Infra-millimetric fragment of charcoal. Cellular tissue with porous structure (section of ligneous vessels) is visible. ii. Plurimillimetric fragment of « hornfels »: a fine grain siliceous rock and sub-conchoidal break. This raw material has been mainly used by Hoabinhians to knapping stone tools. iii. Millimetric bone remains. These debris result of the human activity on the site and on his environment. These are remains of his meals. A high rate of breaking and an almost connected position of bone fragments result of substrate trampling. This is on other clue of the sediment anthropization. iv. Inframillimetric bone fragment. In cross polarized light, bone microstructure and micritic deposit around the bone remain are visible. This coating may be results of the leaching calcium carbonate in the soil from ashes. v. Sedimentary facies 9. The dark brown microaggregated matrix contains rounded elements: quartz, limestone, burnt bone fragments or calcium phosphate material, opaques (iron oxides). Biological porosity is well-developed. Bioturbation is related with the substrate organic matter richness (related with human activity). vi. Soil fragment (papule) integrated to the facies 9 matrix. It comes from pedological formations outcropping outside the site. Wind (deflation), water (run-off after the cave roof was collapsed) or Hoabinhian people (when they come in the cave) may be at the origin of this kind of material in the sediments. vii. Fragment of terrestrial gastropod shell showing its lamellar microstructure. Land snail shells become very abundant in the infilling after the cave roof collapsing. These land snails are Cyclophoridae, they found in the cave good living conditions. viii. Nodule of lateritic material. It composes by iron oxides and subrounded quartz grain. It's inherited of oxisol developed on the top of the phnom (palaeosurface). With the roof collapsing this pedological formation has been eroded.

Table 1

Number of identified specimens and lithic pieces recorded in the Hoabinhian component of Unit I.

| Sedimentological facies remains | Facies 9 | | facies 10 | | facies 11a | | facies 11b ₁ | | TOTAL |
|---------------------------------|----------|--------|-----------|--------|------------|--------|-------------------------|--------|-------|
| | N | % | N | % | N | % | N | % | |
| Animal bones | 8985 | 86.2 | 4030 | 89.0 | 1770 | 87.1 | 172 | 72.9 | 14957 |
| Shell | 815 | 7.8 | 191 | 4.2 | 118 | 5.8 | 23 | 9.7 | 1147 |
| Human bones | 67 | 0.6 | 0 | 0.0 | 0 | 0.00 | 0 | 0.00 | 67 |
| Lithic | 554 | 5.3 | 305 | 6.7 | 144 | 7.1 | 41 | 17.4 | 1044 |
| TOTAL | 10421 | 100.00 | 4526 | 100.00 | 2032 | 100.00 | 236 | 100.00 | 17215 |

4. Results

4.1. Chronostratigraphy and sedimentological analysis

The Hoabinhian sedimentary deposits exhibit their development in Unit I, located on the western side of the main room of the cave. Within this sector, and up to a depth between approximately 60 and 190 cm, we identified a single archaeological layer which can be divided in four distinct sedimentary facies: 11b₁, 11a, 10, and 9 which will be considered as assemblages of anthropogenic remains to evaluate if there is any change of the environment or to the anthropological practices within the Hoabinhian archaeological layer (Fig. 4a). The timeline for this layer ranges from 11000 ± 1000 BP (CLES 4) to 4785 ± 25 BP (Muse 18062/I2053/ECHo2392). The Neolithic occupation is dated between 3310 ± 29 BP (WK30118) and 3370 ± 25 BP (Muse18061). The chronological model carried out indicates a range between 16361 and 5358 cal BP. (Table 2, Fig. 5).

Macroscopically, these deposits showcase consistent characteristics. Predominantly, they exhibit a loamy texture (Fig. 4b) with a relatively loose structural quality, rendering the sediment powdery in nature. Calcium carbonate makes up almost a third of the sediment's content, originating from sources like the Permian limestone substrate, secondary micrites, or bioclasts (Fig. 4c iv and vii). Moreover, remnants of malacofauna have also been detected (as per Forestier et al., 2015). Notable variations in the sediment's color include shades such as pale brown (for 11b₁), a pink-tinged gray (observable in 11a and 10), and a richer dark gray-brown (specific to facies 9). This coloration is intricately linked to the presence of charcoal fragments (Fig. 4c i) and the inherited clayey or lateritic components, which result from the degradation of external soil structures (Fig. 4c v and vi).

Interestingly, the coarseness of the sediment, specifically elements that are larger than 2 mm, varies across the sedimentary facies, mirroring the extent of human influence or anthropization. It is within the confines of facies 9 that we observe the most evident signs of anthropization. From a macro perspective, it yielded a significant portion of

the archaeological findings, be it lithic or osteological. Human cranial remnants were also sourced from this facies. On a more microscopic level, traces of human influence or anthropization became evident (as seen in Fig. 4c). For instance, the sediment contained micro-charcoal fragments (Fig. 4c i) that were indicative of combustion activities. This observation is further bolstered by the prevalent discovery of burnt bone remains (Fig. 4c iii and iv) and the potential presence of secondary carbonates (as micritic coatings, detailed in Fig. 4c iv and vii). Additionally, under microscopic examination, fragments of materials used for crafting tools became evident (Fig. 4c ii) and such fragments were notably present in facies 11b₁.

A final point to highlight is the exceptional preservation conditions of the Hoabinhian sequence deposits in the Unit I. This can be attributed to the cave's protective karstic environment. This very setting enabled the deposition of sediments, influenced both by natural processes like aeolian dynamics and runoff, as well as evident human interventions. Indicators of such anthropogenic activities are diverse and abundant within the sedimentary layers including some perturbations due to the excavation and filling of Neolithic burials at the top of the sequence.

4.2. Archaeoanthropology

During the 1970s excavations, numerous isolated teeth and fragments of human bones were unearthed from the upper level in Laang Spean Cave but at that time no burial was discovered (Mourer, 1994). Our subsequent digs supported the findings of human occupancy identifying remains belonging to at least five distinct individuals (Zeitoun et al., 2012) and further, six Neolithic tombs were discovered. Using the principles of archaeoanthropology (Duday, 2009; Duday et al., 1990; Duday and Guillon, 2006), we can deduce the original positioning of the body before post-burial disturbances occurred (Zeitoun et al., 2021) (Table 1). We will provide here all their unpublished dates (Fig. 5).

Within the ninth sedimentary facies of the Hoabinhian archaeological layer, 57 human cranial bone fragments and 10 scattered post-

Table 2
 Phases time range from ^{14}C and OSL modeling in the Hoabinhian cultural sequence of Laang Spean Cave. See stratigraphic sketch for the location of dating. Data was calibrated and modeled in ChronoModel 3.1.8 (Lanos and Duffresne, 2019), using IntCal20 calibration curve (Reimer et al., 2020). The starting and ending points of the posterior distribution are defined as the MAP (Maximum A Posteriori) of the phase distribution, in each case (fourth and fifth columns), at 95% confidence level. The phase time range (sixth column) is also given for a 95% confidence level.

| Phase | ^{14}C | OSL | Code | Posterior distribution Begin MAP (cal BP) (95%) | Posterior distribution End MAP (cal BP) (95%) | Phase Time Range (95%) (Age cal BP) |
|---------------|-----------------|--------------|---------------------------|---|---|-------------------------------------|
| Burial_I31 | 3310 ± 29 | | WK30118 | 3524 | 3524 | 3698–3366 |
| Burial_D27 | 3370 ± 30 | | SacA42307 | 3602 | 3602 | 3822–3384 |
| Burial_P31 | 3360 ± 35 | | SacA41292 | 3593 | 3593 | 3840–3356 |
| Burial_B27 | 3335 ± 30 | | SacA42308 | 3537 | 3537 | 3780–3358 |
| Burial_S32 | 3360 ± 30 | | Muse615/SacA44398 | 3595 | 3595 | 3816–3349 |
| Burial_Aa26 | 3370 ± 25 | | Muse18061 | 3603 | 3603 | 3797–3408 |
| Layer 9_sup | 4785 ± 25 | | Muse 18062/12053/ECHo2392 | 5512 | 5512 | 5675–5358 |
| Layer 9_cent | 5304 ± 25 | | WK 33631 | 6026 | 6026 | 6208–5582 |
| Layer 9_inf | 5018 ± 29 | | WK 36666 | 6077 | 6077 | 6674–5633 |
| Layer 10_inf | | 5480 ± 1000 | CLES 3 | 7455 | 7455 | 10209–5957 |
| Layer 11a_inf | 10042 ± 43 | | WK 38610 | 11535 | 11535 | 12026–11018 |
| Layer 11b_inf | | 11000 ± 1000 | CLES 4 | 12874 | 12874 | 16361–11366 |

cranial pieces were categorized and lateralized. The cranial bones bore micritic coatings; some showed pronounced porosity and superficial carbonization, especially the right frontal bone, likely due to taphonomic processes and chemical interactions near hearths or fireplaces. There was no evidence of intentional modification, unlike the associated fauna which bore cut marks.

This incomplete skull consists of a frontal bone, a right parietal bone, fragments of the left parietal bone, the mastoid process of the right temporal bone, the left zygomatic arch, several fragments of maxillary bone, the nasal walls and 10 teeth (M³, M2, M1, P4, P3, C1 on the right and M3, M2, P4, P3 on the left). We successfully reconstructed a single individual's skull (Gollette, 2017) (Fig. 6). In *norma verticalis*, the skull cap displays an ovoid contour with an almost complete right parietal. The arachnoid fossae are clearly visible on the posterior part of the parietals. The sagittal, coronal and lambdoid sutures are visible. The sagittal suture is complete and the coronal suture is almost entirely present. In *norma facialis*, the frontal scale is abnormally straight because of taphonomical distortion, with a metopic suture visible all along the preserved portion. The differentiation between the ciliary and supraciliary arches. The muscular insertions of the temporal lines are pronounced. In *norma lateralis*, a fairly poorly developed right mastoid process and a piece of left parietal bone can be seen. In *norma basilaris*, the shape of the alveolar arch appears to continue in a parabolic form. The zygomatic arches are represented by two fragments, one at the level of the left arch itself and the other forming the lower right base.

The presence of the upper third molars, albeit with incomplete roots which is coherent with the rather moderate occlusal wear of the dentition (equivalent to category 4–5 of Molnar, 1971) and could suggest a young adult age for this individual. Finally, the prominence of the temporal lines and the overall size of the bones found suggest that this individual was muscularly robust. As for the 10 isolated post-cranial fragments (a fragment of the body of a cervical vertebra, a fragment of the body of a thoracic vertebra, a fragment of the neuronal arch of a thoracic vertebra, a fragment of the diaphysis of a left femur, a fragment of the right patella, a left navicular, a left fourth metatarsal, a fragment of the distal phalanx of a left first metatarsal, a fragment of the median phalanx of a third or fourth metatarsal, a proximal phalanx of a right first metatarsal) according to their nature, size, and anatomical lateralization they may belong to a single adult individual. All morphological characteristics correspond to *Homo sapiens*. Nevertheless because of the taphonomical distortion and due to the lack of anthropological landmark it is not possible to make data available that would be useful for morphometrical comparisons.

Later Holocene groups often dug burial by into earlier hunter-gatherer deposits in cave and rockshelter sites in Mainland Southeast Asia (D. Anderson, 2005; Bulbeck, 2014; Lewis et al., 2015; Lloyd-Smith, 2014; Treerayapiwat, 2005). Consequently, the dating of the oldest remains could cast doubts and may be re-evaluated (Conrad et al., 2022). For instance, Treerayapiwat (2005) specified that the dating of the Hoabinhian burial of Ban Rai is provided by a charcoal sample taken near the left humerus of the skeleton when he assessed that the Log coffin culture caused major disturbance to the Hoabinhian levels. At least, older elements can be excavated when digging the burial and refilled in the tomb. As at Laang Spean we have shown that the tomb of the Neolithic burial I31 was opened, disturbed and then closed again, but without the skull cap being deposited (cf. Zeitoun et al., 2012), it was legitimate to wonder whether the isolated human skull that was found in the Hoabinhian layer was the one that was missing. Thus, similarly to the skeletons of the Neolithic burials, due to the lack of collagen, we carried out a radiocarbon analysis on the apatite of the skull to confirm that it was not intrusive in the Hoabinhian layer. The radiocarbon analysis carried out on the apatite indicates an age of 4785 ± 25 BP (Muse 18062, 5675 – 5358 cal BP) for the individual and approximately 2000 years between the end of the Hoabinhian occupation and the beginning of the Neolithic period (Fig. 5). Finally, the extremely low percentage of endogenous human

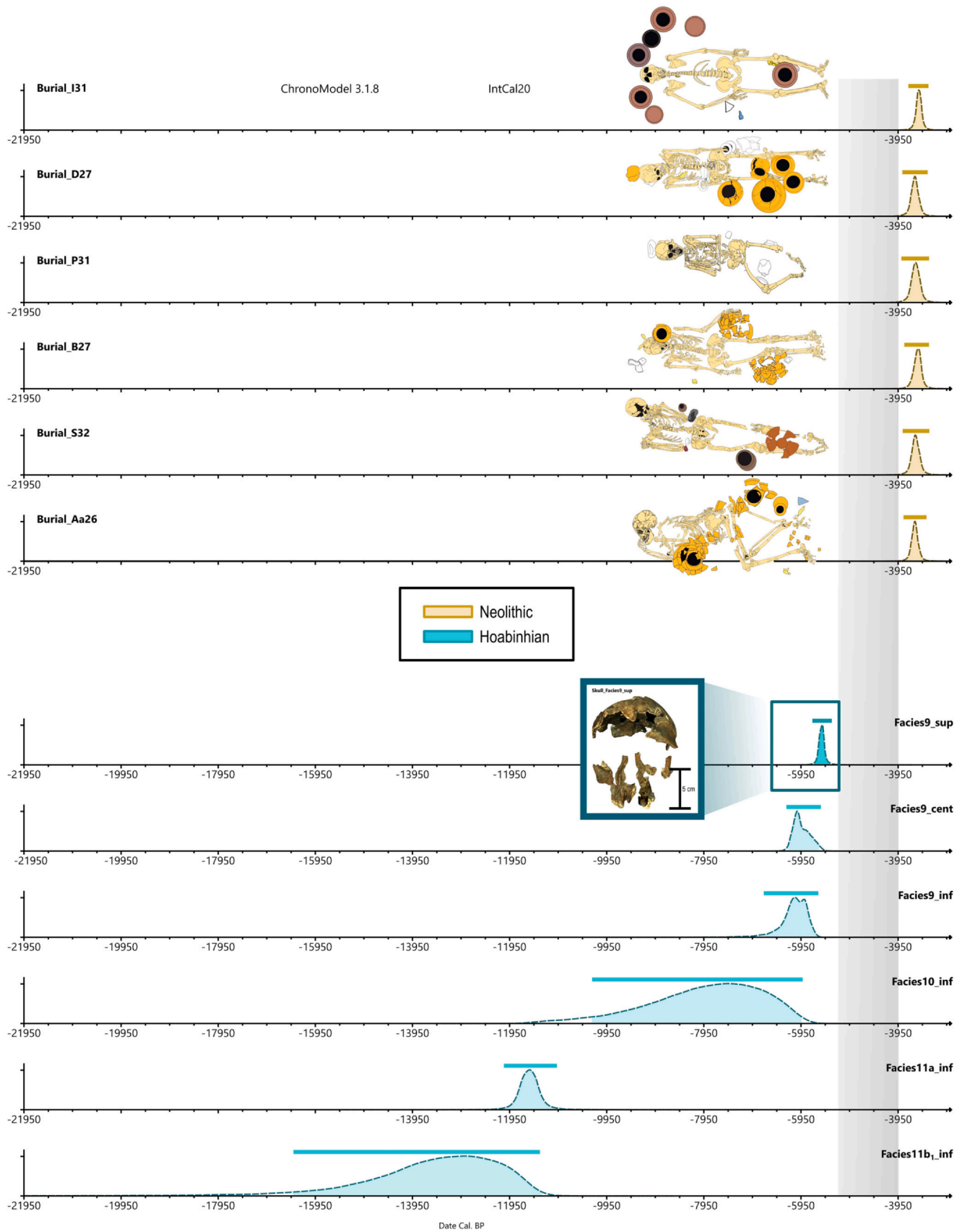


Fig. 5. Posterior distributions of the six defined phases. Confidence bars are given with a 95% confidence level. Hierarchical Bayesian modeling realized in ChronoModel 3.1.8 software package (Lanos and Dufresne, 2019). The phase duration is symbolized by a bar. The vertical gray bar indicates a gap in occupation of approximately 2000 years between the end of the Hoabinhian occupation and the beginning of the Neolithic period.

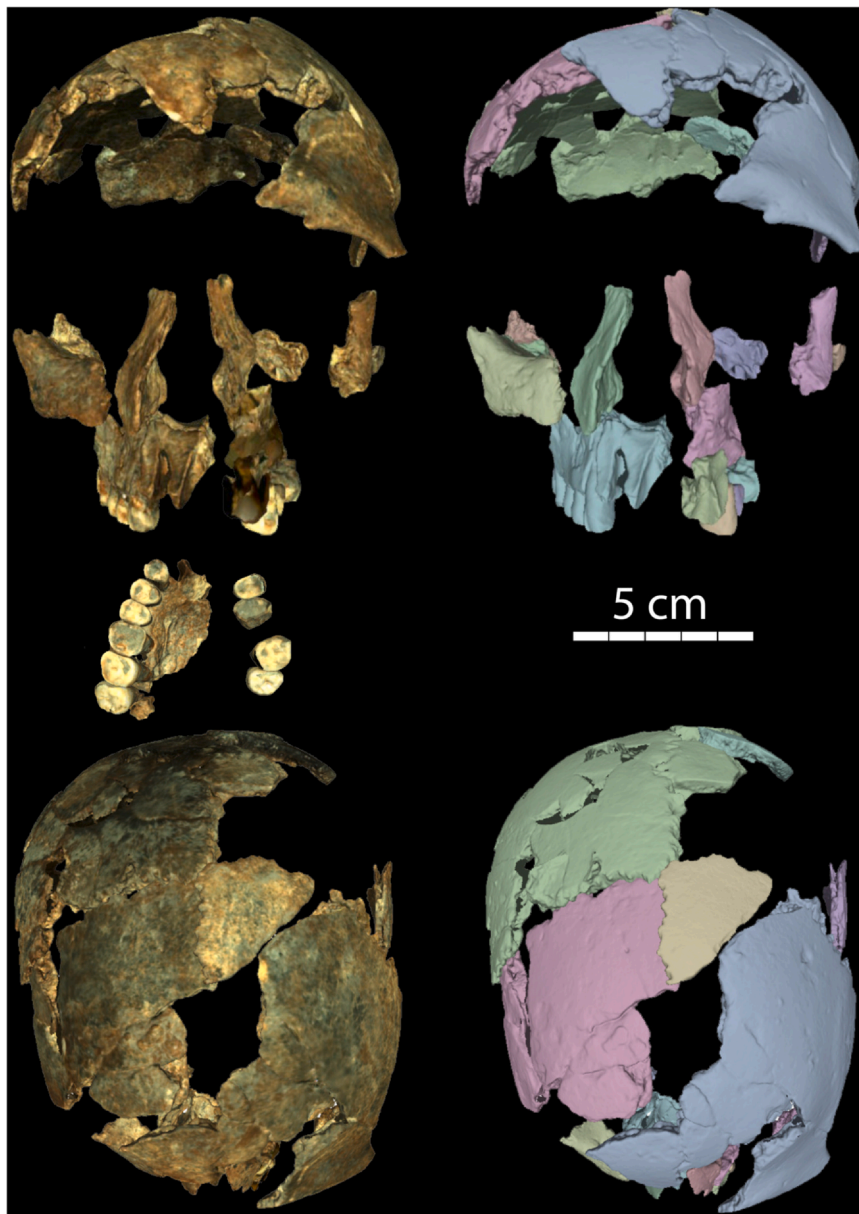


Fig. 6. 3D reconstruction of the Hoabinhian skull of Laang Spean cave, Facies 9. Source: after Gollette (2017).

DNA preserved in these bones did not allow us to obtain sufficient DNA reads for statistical analysis.

4.3. Dating and chronological model

The dates obtained from the biapatite of the human bones from the burials (Aa26, B27, D27, P31, S32) are consistent with the classic radiocarbon dates (burial I31) and, the age of the skull cap (4785 ± 25 BP Muse 18062; $5675 - 5358$ cal BP see Table 2) is consistent for the age of the Hoabinhian layer containing this skull cap (Fig. 5). It is nevertheless likely that the slightly older values obtained from the biapatite are related to the influence of diagenesis; the age estimates should therefore be considered as minimum values.

4.4. Archeozoology and fauna remains

Among the faunal remains found in the Laang Spean cave, the shell remains (NISP = 1147) are mainly bivalves (mussels) and freshwater gastropods (paludina). These taxa were almost certainly consumed by the Hoabinhians. The presence of land snails (*Cyclophorus* and *Rhiostoma*),

which are rarer, is natural. Regarding vertebrates, mammals (Fig. 7 d, e) are largely dominated by Bovines, especially represented by the Banteng (*Bos javanicus*). A very few bones are related to large Bovines such as the Gaur (*Bos frontalis*) or the Kouprey (*Bos sauveli*) and the Water Buffalo (*Bubalus bubalis*). Cervids are the second best represented mammalian taxon. Among them, the Sambar (*Rusa unicolor*) yielded the greatest number of remains, followed by the Thamin, *Rucervus eldii* and the Muntjac (*Muntiacus* sp.). The list of herbivorous mammals also includes rare Javan Rhinoceros (*Rhinoceros sondaicus*), the Wild Boar (*Sus scrofa*) and the Serow (*Capricornis* sp.). Among the carnivores: the Tiger (*Panthera tigris*), the Panther (*Panthera pardus*), the Bengal Cat (*Prionailurus bengalensis*), and among the monkeys: the Macaque (*Macaca* sp.), the Gibbon (*Hylobates* sp.) and the Langur (*Trachypithecus* sp.) are represented by only a few remains. These animals appeared to be rarely hunted by the Hoabinhians of Laang Spean. Reptiles are clearly dominated by Turtles (Fig. 7 a, b), and in particular by *Indotestudo elongata*. Freshwater turtles, in smaller numbers, belong to the Geoemydidae family. Squamates, are represented mainly by Varans (*Varanus bengalensis* and *Varanus salvator*) (Fig. 7c) and to a lesser extent by Pythons and *Ophiophagus hannah*.

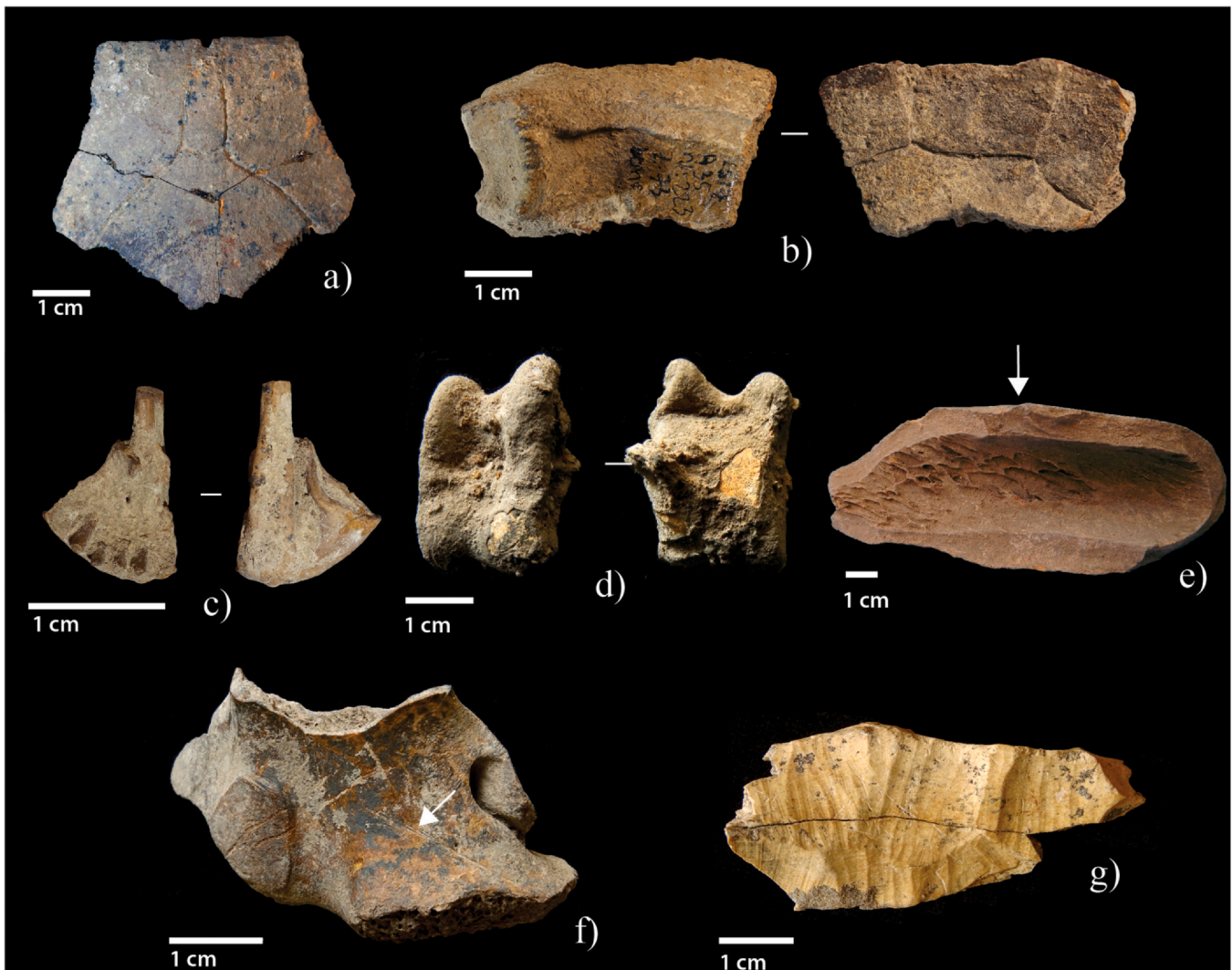


Fig. 7. Some examples of faunal remains from the studied archaeological contexts. A) Nuchal plate of *Indotestudo elongata*; B) Left peripheral plates 7 and 8 of Geoemydidae; C) Premaxilla of *Varanus salvator*; D) Left talus of *Muntiacus muntjac* covered by a veil of calcite; E) Fragment of a large bovine femur diaphysis showing marks of breakage on fresh bone associated with a percussion mark (indicated by a white arrow); F) Cut-marks on a fragment of thoracic vertebra of bovine (indicated by a white arrow); G) Fragment of a ungulate long bone diaphysis gnawed by a porcupine. Source: C. Griggo.

Thus the faunal association, very clearly dominated by Bovines, Molluscs, Turtles and Cervids, but also with *Varanus bengalensis*, reflects a tropical rainforest environment, sparsely interspersed with a few areas of wooded grassland. The presence of Water Buffalo, *Varanus salvator*, freshwater turtles and freshwater malacofauna indicate the existence and close to the site, of wetlands that are almost certainly swampy and, the monkeys, including Gibbon and Langur, the presence of forest and rainforest. Taking into account the number of identified specimens, this faunal association is largely dominated by Mammals (57.7%) (Table 3a). Turtles represent 31.3% and Varans only 2.1%. It should be noted that the mean length of the mammal remains is only 3 cm. This fragmentation is not natural as 91% of the breaking marks were made while the bone was still fresh (Villa and Mahieu, 1991) (Fig. 7f). The long bones of the limbs are all broken and only a few phalanges and other small bones of the basipods are complete. Eight percussion marks were also observed on the same remains which confirm the anthropogenic origin of this phenomenon. The fragmentation is less important for reptiles remains as 15% of the assemblage correspond to nearly complete bones (representing more than 80% of the original element) and 44% to highly fragmented remains (representing less than 10% of the original element). More than 90% of all bone remains are covered by a thin veil of calcite making impossible the

observation of surface modification (Fig. 7 b, c, e). Diaphyseal fragments of long bones and phalanges are clearly over-represented. Spongy elements (cranial bones, vertebrae, ribs) and teeth show a marked deficit, suggesting that only the fleshiest anatomical parts (legs) were butchered at an off-site slaughter site and brought back to Laang Spean. Indeed, only 17 butchery striae, including 11 on cattle bones, 2 on deer bones, 3 on an unidentified ungulate and 1 on a rhinoceros metatarsal were observed. Despite the small number of cases, it was possible to identify the main stages in the processing of carcasses with striations from skinning, evisceration, disarticulation, emaciation and tendon removal. Moreover, fire traces were very numerous and have been observed on 45% of mammal, and 29% of reptile remains. Most often it concerns spongy elements of the bones. This may help to explain the significant under-representation of long-bone epiphyses and carpal and tarsal bones. Some very rare traces of the actions of porcupines (N=104, Fig. 7g) and small rodents (N=17) were also observed on the material but the overall role of rodents in the composition of the assemblage appears insignificant. No traces attributable to a carnivore were observed on the bones. The Tiger, the Panther and other small carnivores identified at Laang Spean are therefore among the taxa hunted and introduced to the site by the Hoabinhians.

If four sets can be identified according to the sedimentary facies (11b₁, 11a, 10, 9), from the point of view of the fauna's analysis,

Bovines, Turtles, Molluscs and Cervids are the dominant taxa in all of them but the number of the faunal remains is increasing (respectively 1.1 %, 11.8 %, 26.9 % and 60.1 %) over the time which shows an exponential Hoabinhian occupation of the Laang Spean cave (Table 3a). Gastropods (mostly freshwater) are present throughout the Hoabinhian sequence, but the appearance of Bivalves of the Unionidae family which is anthropogenic in origin began in the facies 11a. Hoabinhians thus began to collect freshwater mussels, thus diversifying the protein content of their diet. Apart from the dominant taxa, the other taxa are very poorly represented and the conclusions we can draw from their analysis will have to be completed when the excavation of the site will be finished. Nevertheless, if we try to detect a trend from a perspective linked to climatic change via large mammals alone, from a quantitative point of view we observe a trend towards openness of the landscape with an increase in the percentage of Bovines throughout the sequence (Table 3b). This is accompanied by a reduction in the number of the hunted carnivores. It may be possible to detect an anomaly with a peak of the contribution of the Cervids in the facies 11a (12026 – 11018 cal BP) (Table 3b), and slight decline in Varans observed in the herpetofauna alone on this same facies 11a (Table 3c).

4.5. Stone tool assemblages

The quantitative and qualitative results obtained from the Hoabinhian layer align with the typotechnological data previously gathered from Laang Spean (Forestier et al., 2021, 2022, 2023). From the layer yielding Hoabinhian human remains, a total of 1044 lithic artifacts were recorded (Table 4), across facies 9–11b₁. Associated with the Hoabinhian human remains were a unifacial cobble, a split tool, a limestone knife, a slab tool and a chopper (Fig. 8). As in the fauna remains, the number of the lithic remains is increasing (respectively 4.0 %, 13.8 %, 29.2 % and 53 %) over time which shows also an exponential Hoabinhian occupation of the Laang Spean cave.

4.5.1. Raw material selection

In total, 11 raw materials were identified (Table 4). All of these were present in all the facies, except for silicified limestone only present in facies 11a, silicified sandstone only present in facies 9 and 11a, ochre only present in facies 9 and 10, phtanite absent only in facies 11b₁, and volcanic rock only present in facies 9. The two most significant raw materials are hornfels, followed by limestone. The former reaches nearly 80 % in facies 9 and 10, while the latter reaches approximately 40 % in facies 11b₁. Sandstone is also an important material across all facies, averaging about 10 % in each. Hornfels, a distinctive and easily identifiable material, was selected and transported back to the cave by prehistoric hunter-gatherers as pebbles from the Chanob River, located just a few hundred meters from the cave entrance. These pebbles, often oblong or oval-shaped, were chosen based on specific criteria and exhibit various natural morpho-structural configurations, such as plano-convex or oval sections, some being notably thick. Typically, different operational schemes were applied depending on their morpho-structure; for instance, pebbles with a plano-convex section were generally used to produce uniface, while those with an oval section were used for splits. Diachronically, facies 9 and 10 consistently feature the greatest quantity and diversity of selected raw materials, whereas facies 11a and 11b₁ have lesser amounts and diversity. Siliceous, on the other hand, is anecdotal in the Hoabinhian sequence of Laang Spean, averaging about 1.5 % in each facies and remaining relatively stable throughout, with only a slight increase in facies 10 and 11a.

Hornfels was primarily exploited for flake production across all facies. Specifically, in facies 9 (N = 255; 58.62 %), facies 10 (N = 146; 61.09 %), facies 11a (N = 50; 63.29 %), and facies 11b₁ (N = 9; 64.29 %). Regarding limestone, it was primarily utilized in facies 9 for the production of cobble tools, including choppers and chopping tools, amounting to N = 15 (20.55 %). In facies 10, limestone was mainly used for these cobble tools as well (N = 8; 26.67 %). In facies 11a,

however, limestone was chiefly used for flake production (N = 8; 28.57 %), with choppers being anecdotal (N = 1; 3.57 %). Interestingly, macro-tools (N = 4) and horse hoof scrapers (N = 4) together constitute a significant percentage (44.44 %) of the exploited limestone. Considering now the third most important raw material in the sequence, sandstone, we observe that in facies 9, this material was used both for the production of cobble tools (including choppers; n = 5; 20.83 %), and for flake production (N = 6; 25.00 %). In facies 10, sandstone was preferentially used for flake production (N = 7; 25.00 %) and for tested cobbles (N = 10; 35.71 %). In facies 11a, sandstone was primarily used for cobble tools (including choppers and chopping tools; N = 3; 15.79 %) and tested cobble (N = 5; 26.32 %). Finally, in facies 11b₁, sandstone use is reduced to its minimal expression throughout the sequence, with only debris and tested blanks remaining.

It is also worth noting that the production of limaces (N = 2) was restricted to limestone only in facies 10. Unifaces, the most represented tool type in the site's sequence, are almost exclusively associated with the use of hornfels across all facies (except for facies 11b₁).

4.5.2. Blank production

Cores are almost nonexistent in the Hoabinhian sequence of Laang Spean, with only one found in facies 11a and another in facies 11b₁ (Table 5). Consequently, we have limited direct information on the methods and techniques of flaking. This information has been indirectly gathered from the various blanks recorded. Out of the total blank production (N = 583), which represents the majority (55.84 %) of the production across the entire sequence, simple unidirectional flakes are overwhelmingly predominant (N = 508; 48.66 %). Splits of various types constitute the second most represented type of blank throughout the sequence, with N = 65 (6.23 %). These flakes and splits are predominantly found in the upper facies 9 and 10. Blade-like, slab, and "salami slices" (specific types of unidirectional flakes) blanks together account for 0.96 % of the entire sequence. Blade-like and salami slices blanks are typically found in the upper facies 9 and 10, virtually disappearing in the lower facies 11a and 11b₁. Meanwhile, slab blanks, although very rare, are recurrently found throughout the sequence.

4.5.3. Tool production

Tool production represents the second most prevalent technical activity throughout the entire Hoabinhian sequence of Laang Spean, accounting for N = 193 (18.49 %). The frequency behavior of tools is similar to that of the raw materials, meaning that facies 9 and 10 are quite alike and differ from the lower facies 11a and 11b₁, which can also be grouped together due to their similarity in diversity and frequency of tool types. Moreover, when considering choppers, chipping tools, and other cobble tools together, we find they constitute 4.5 % of the entire sequence, predominantly appearing in the two upper facies. Used flakes, meaning flakes with macroscopic signs of use, make up 4.98 % of the entire sequence, also predominantly in the upper sequences. However, it is the uniface that forms the principal tool type of the entire sequence, representing 6.03 % and clearly dominating in the upper facies 9 and 10.

In terms of dimensions (length, width, thickness, and in some cases weight), Principal Component Analysis (PCA) of choppers throughout the entire sequence indicates a distinction between the dimensions found in facies 10–11b₁, and those of the choppers in facies 9 (Fig. 9A). Although facies 11a falls within the dimension range of facies 10, it represents a group with its own specific dimensions. Regarding chopping tools, their presence is almost nonexistent in lower facies, limiting solid comparisons; however, it is still observable that facies 9 also has different dimensions from the rest of the facies (Fig. 9B). Unifaces, on the other hand, exhibit almost identical dimensions throughout the sequence, highlighting a slight difference in facies 11a compared to the others (Fig. 9C). Concerning flake tools, dimensions in facies 10 slightly differ from those in facies 9, though with a significant overlap between them (Fig. 9D). Used flakes appear to have facies-specific dimensions,

yet share some similar characteristics as well (Fig. 9E). As for flakes, their dimensions remain relatively stable over time, with dimensions being quite distinct in facies 11b₁ (Fig. 9F), which has the lowest values of length and width. Facies 11a tends to have the highest values in all dimensions. Facies 10 and 9 show similarity in terms of length and width, but differ in thickness (Fig. 9F). Lastly, splits also seem to follow the same dimensional behavior as flakes, albeit less distinctly (Fig. 9G). Facies 11a, in all these mentioned tools and blanks, appears to be a specificity in terms of dimensions throughout the Hoabinhian sequence of Laang Spean.

5. Discussion

5.1. Laang Spean fauna in its regional context

In the Quaternary context of Southeast Asia, the Laang Spean cave's unequivocally suggest human activity, characterized by the presence of non-cave dwelling taxa, marked fragmentation of fresh bones, numerous fire traces, and an absence of non-human predatory activities.

In the faunal assemblage the predominance of Bovines, Turtles, Molluscs and Cervids (Table 3a), along with the evidence of both humid and dry forests (*Bos javanicus*, *Rucervus eldii* and *Indotestudo elongata*), as well as significant wetland areas (Geoemydidae, *Varanus salvator*, etc.) and, some taxa of interest such as Gibbon and Langur for rainforest, reveals a diverse ecosystem exploited by the Hoabinhian peoples. While the fauna shows the duality of the environmental components, the sedimentological analysis of the deposits also shows a duality that reflects the contrasting climate of the period, influenced by the monsoon regime: a wet season, to which the abundance of snails, run-off sediments and the precipitation of secondary calcite respond, followed by a dry season, expressed in the sediments by the silty, powdery nature of part of the sediment.

Thus, the taxonomic composition of the Hoabinhian assemblage of Laang Spean could be globally similar to that of Tham Lod (Amphansri, 2011; Conrad, 2015) in Northwestern Thailand or Moh Khiew (Auetrakulvit, 2004), in Southern Thailand or that of Hiem cave, in Northern Vietnam (Masojć et al., 2023) and among others, but different comparative zooarchaeological data on mainland Hoabinhian deposits preclude further comparisons as the subsistence behaviors of these populations will appear very variable (Auetrakulvit, 2004; Bochaton et al., 2019a; Conrad et al., 2016; Frère et al., 2018; Piper and Rabett, 2009).

There are still many limitations that make it impossible to account for the relationship between global climate changes and cultural evolution or adaptation in the tropics. A number of constraints, errors, lack of data and even bad practices have recently been discussed (Zeitoun et al., 2023), highlighting our inability to answer these questions perfectly.

However, using a sequential sampling of teeth to perform $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ analyses on the tooth enamel of faunal assemblages from the successive archaeological layers of Tham Lod rock shelter, Suraprasit et al. (2021) offer hope. Indeed, they have shown that no significant change in $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values among mammals, nor any major seasonal variation based on the intra-dental profiles of the crowns of the large Bovines, whereas according to their overall interpretation in terms of diet distribution, the various Heinrich events 3, 2 and 1 are already perceptible. The Bølling-Allerød event, on the other hand, is not marked. Thus, they provide evidence for the existence of synchronous mosaic landscapes which is encouraging to go further but, on the other hand, they demonstrated that not all global climatic events are recorded in faunal assemblages. While recent works have finally identified dissociated climatic or ecological phases during the final Pleistocene in the tropics of Southeast Asia (Amano et al., 2016a,b; Suraprasit et al., 2021; Zeitoun et al., 2010), it still seems difficult to perceive such evolution during the Holocene. Nevertheless, Suraprasit et al. (2024) discerned a shift in $\delta^{13}\text{C}$ diet of human at Tham Lod and associated it to the Younger

Dryas event and, according to the analysis of oxygen isotope ratios $\delta^{18}\text{O}$ in the freshwater bivalve *Margaritanopsis laosensis* of Ban Rai rock-shelter, Marwick and Gagan (2011) identified a subtle trend towards increasing dryness during the second cultural phase of Ban Rai (*id est* 9800 BP to 5900 B) assessing that this phenomena also occurs at the same time in China, but does not begin in Malaysian Borneo until around 5000 BP. Laang Spean is at an intermediary latitudinal position between China and Malaysia and, indeed, some regional differences did also exist concerning a monsoon peak which, according to the isotopic record of speleothems is recorded at around 8300 BP at Tham Khao Dang in central Thailand (Jacobson et al., 2024), at 9000 BP at Um-synrang Cave in north-east India (Breitenbach, 2010), but earlier at the neighbouring site of Mawmluh e.g. around 9600 BP (Lechleitner et al., 2017) or even 10240 BP at Tham Klang in southern Thailand (Chawchai et al., 2021).

At Ban Rai, Treerayapiwat (2005) distinguished two cultural phases. The oldest is nearly 12630 cal BP ($10,600 \pm 40$ BP) without faunal remains nor stone tools but only charcoal and ash stains. The second cultural phase is between ~ 10620 cal BP (9400 ± 120 BP) and ~ 4550 BP including abundant faunal remains and lithic artifacts. It is suggested that there was a shift from large mammal to small mammal exploitation during the period of human occupation at Ban Rai rock-shelter (Conrad et al., 2016; Shoocongdej and Wattanapitaksakul, 2020). The faunal assemblage includes Asian black Bear, Eld's Deer, bamboo rat, Goral, and wild water Buffalo matching with a partly open environment to a montane forest and swamps around the valley river. But the mammal fauna of Ban Rai is dominated by Primates and the shifting abundance of their exploitation over time indicates that arboreal fauna became increasingly important (Wattanapitaksakul et al., 2022). Such a result has been confirmed by an isotopic study (Suraprasit et al., 2024, Fig. 6) demonstrating a trend from a mixed faunal assemblage including together C3 browsers, C3-C4 mixed feeders and C4 grazers at the bottom of the sequence of Ban Rai to an exclusive forest/woodland at the top of the sequence. Furthermore, it should be noted that Elephant and Bear are present in northwestern mountainous Thailand but are absent at Laang Spean.

Considering Hiem cave in Northern Vietnam, for a human occupation between 10100 and 10200 cal BP (8970 ± 30 BP and 9140 ± 30 BP, Beta-554963 and Beta-554965 respectively, see Masojć et al., 2023), all the associated faunal remains are connected with the rain-forest habitat. Despite its relatively small size and short chronological span the faunal assemblage of Hiem cave is quite diversified including Elephant, *Bos* sp. (Gaur or Banteng), Deer, Gibbon, marbled Cat, rodents but also birds and fishes. The main taxon is *Sus scrofa* then Tortoise and Muntjak and Macaque. Globally, the contribution of the species inhabiting more open ecosystems such as the Varan, big predators or big ungulates is minimal or even absent. The continuous and abundant occurrence of mollusc shells is composed of terrestrial snails, aquatic snails and mussels but it is not possible to follow any trend or change as-well.

With an abundant and diverse faunal assemblage including crab, fish, birds, squamates, tortoises, rodents, carnivores including *Helarctos malayanus* and *Panthera pardus*, Rhinoceros and Tapir, *Sus scrofa*, *Tragulus*, *Cervus*, *Muntiacus* and Bovines, the analysis of the primary data provided by Auetrakulvit (2004), comparing the Early and Recent Holocene phases for the Moh Khiew site in Peninsular Thailand, reveals no significant qualitative changes in faunal assemblages, with the exception of the disappearance of the Tapir. The quantitative evolution of the assemblages is reflected by an increasing number of Tortoise and a decreasing number of Varan, monkeys and Bovines.

Although dating has since been re-evaluated (cf. Conrad et al., 2022), at Lang Rongrien in Southern Thailand, Mudar and Anderson (2007) identified two modest assemblages from Units 6 and 5 which are dated between 11100 and 8300 cal BP (9655 ± 90 BP and 7575 ± 75 BP; SI-6817 and SI-6213 respectively, see Anderson, 1997). If the list of taxa, not separated between the two layers, is as follows: *Canis* sp. or

Table 3a

Rate of representation of the main taxa identified by sedimentary facies of the Hoabinhian archaeological layer in Laang Spean cave.

| Sedimentological facies | Facies 9 | Facies 10 | Facies 11a | Facies 11b ₁ | Unit I |
|--|---------------------|---------------------|--------------------|-------------------------|--------------|
| Faunal remains | | | | | |
| Bovines (total) | 31.5% | 17.6% | 16.2% | 25.6% | 25.9% |
| <i>Bos javanicus</i> | 12.3% | 6.1% | 7.1% | 9.9% | |
| <i>Bubalus</i> sp. | 0.1% | 0.1% | 0.2% | 0.0% | |
| <i>Bos sauveli</i> or <i>Bos frontalis</i> | 3.8% | 1.6% | 1.9% | 1.2% | |
| Caprins (total) | 0.0% | 0.0% | 0.2% | 2.3% | 0.1% |
| Cervids (total) | 5.6% | 3.9% | 7.9% | 9.3% | 5.5% |
| <i>Muntiacus</i> sp. | 1.5% | 0.8% | 1.5% | 1.7% | |
| <i>Rucervus</i> sp. | 1.5% | 1.3% | 2.9% | 1.7% | |
| <i>Rusa</i> sp. | 1.7% | 1.4% | 2.4% | 2.9% | |
| Ungulate indet (total) | 11.8% | 7.0% | 8.8% | 14.0% | 10.2% |
| Mesofauna indet (total) | 1.1% | 1.1% | 1.2% | 0.0% | 1.1% |
| Tragulids (total) | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Suids (total) | 0.5% | 0.1% | 0.3% | 0.6% | 0.4% |
| Primates (total) | 0.6% | 0.5% | 0.2% | 0.0% | 0.5% |
| Chiroptera | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% |
| Carnivores | 0.4% | 0.3% | 0.7% | 2.9% | 0.5% |
| Rhinoceros | 0.6% | 0.5% | 0.2% | 0.0% | 0.5% |
| Lagomorphs | 0.1% | 0.1% | 0.8% | 0.0% | 0.2% |
| Hystrioids | 0.1% | 0.0% | 0.0% | 0.0% | 0.1% |
| Rodents | 3.9% | 20.3% | 41.8% | 0.0% | 12.8% |
| Mammals (total) | 56.3% | 51.8% | 78.1% | 54.7% | 57.7% |
| Birds (total) | 0.2% | 0.2% | 1.8% | 0.0% | 0.4% |
| Amphibia (total) | 0.1% | 0.2% | 0.2% | 1.2% | 0.2% |
| Turtles (total) | 32.2% | 37.9% | 12.1% | 26.7% | 31.3% |
| Geoemydidae | 1.4% | 0.7% | 0.0% | 0.0% | 1.0% |
| <i>Indotestudo</i> sp. | 10.6% | 14.2% | 4.5% | 12.8% | 10.8% |
| Testudinae indet. | 20.2% | 0.8% | 0.1% | 0.0% | 10.8% |
| Varans (total) | 1.7% | 3.7% | 0.7% | 3.5% | 2.1% |
| Snakes (total) | 0.3% | 1.3% | 0.1% | 0.6% | 0.6% |
| Fishes (total) | 0.2% | 0.0% | 0.3% | 0.0% | 0.1% |
| Molluscs (total) | 9.1% | 4.7% | 6.7% | 13.4% | 7.7% |
| Bivalves (Unio) | 7.2% | 3.2% | 1.0% | 0.0% | 5.3% |
| Gastropods (freshwater) | 1.0% | 0.7% | 2.7% | 12.8% | 1.3% |
| Gastropods (terrestrial) | 0.2% | 0.5% | 2.7% | 0.6% | 0.6% |
| Gastropods indet | 0.7% | 0.2% | 0.3% | 0.0% | 0.5% |
| Total Number of Identified Specimens | 8985 (60.1%) | 4030 (26.9%) | 1770(11.8%) | 172(1.1%) | 14957 |

Table 3b

Ratio of the Number identified Cervids and Bovines among the Large Mammals by sedimentary facies of the Hoabinhian archaeological layer in Laang Spean cave.

| Facies | Facies 9 | Facies 10 | Facies 11a | Facies 11b ₁ | Unit I |
|--------------------------------|---------------|---------------|---------------|-------------------------|---------------|
| Facies | Facies 9 | Facies 10 | Facies 11a | Facies 11b ₁ | Unit I |
| Number of Identified Specimens | | | | | |
| Bovines (total) | 2834 | 710 | 286 | 44 | 4197 |
| | 61.6 % | 58.3 % | 47.1 % | 46.8 % | 59.5 % |
| Cervids (total) | 503 | 159 | 139 | 16 | 907 |
| | 10.9 % | 13.1 % | 22.9 % | 17.0 % | 12.5 % |
| Carnivores (total) | 40 | 14 | 12 | 5 | 71 |
| | 0.9 % | 1.2 % | 2.0 % | 5.3 % | 1.1 % |
| Large Mammals (total) | 4598 | 1217 | 607 | 94 | 6516 |
| Ratio Cervids/Bovines | 17.7 % | 22.4 % | 48.6 % | 36.4 % | 21.6 % |

Table 3c

Ratio of the Number identified herpetofauna by sedimentary facies of the Hoabinhian archaeological layer in Laang Spean cave.

| Facies | Facies 9 | Facies 10 | Facies 11a | Facies 11b ₁ | Unit I |
|--------------------------------|-------------|-------------|-------------|-------------------------|-------------|
| Number of Identified Specimens | | | | | |
| Snakes (total) | 31 | 53 | 2 | 1 | 87 |
| | 1.0% | 3.1% | 0.9% | 1.9% | 1.7% |
| Turtles (total) | 2889 | 1529 | 215 | 46 | 4679 |
| | 94.1% | 88.3% | 93.5% | 86.8% | 92.0% |
| Geoemydidae | 4.0% | 4.2% | 1.7% | 3.6% | |
| <i>Indotestudo</i> sp. | 30.9% | 32.8% | 34.2% | 40.0% | |
| Testudinae indet. | 59.2% | 50.8% | 56.0% | 40.0% | |
| Varans (total) | 151 | 149 | 13 | 6 | 319 |
| | 4.9% | 8.6% | 5.7% | 11.3% | 6.3% |
| Ratio Varans/Turtles | 5.2% | 9.7% | 6.0% | 13.0% | |

Table 4
Classification of raw materials by facies in the Hoabinhian Component of Laang Spean.

| Facies Raw material | Facies 9 | | Facies 10 | | Facies 11a | | Facies 11b ₁ | | TOTAL | |
|------------------------|----------|--------|-----------|---------|------------|--------|-------------------------|--------|-------|--------|
| | N | % | N | % | N | % | N | % | N | % |
| Hornfels | 435 | 78.52 | 239 | 78.361 | 79 | 54.86 | 14 | 34.15 | 767 | 73.47 |
| Limestone | 73 | 13.18 | 30 | 9.836 | 28 | 19.44 | 18 | 43.90 | 149 | 14.27 |
| Sandstone limestone | 9 | 1.62 | 1 | 0.328 | 6 | 4.17 | 2 | 4.88 | 18 | 1.72 |
| Silicified limestone | 0 | 0.00 | 0 | 0.000 | 3 | 2.08 | 0 | 0.00 | 3 | 0.29 |
| Iron | 5 | 0.90 | 2 | 0.656 | 2 | 1.39 | 0 | 0.00 | 9 | 0.86 |
| Sandstone | 24 | 4.33 | 28 | 9.180 | 19 | 13.19 | 5 | 12.20 | 76 | 7.28 |
| Silicified sandstone | 2 | 0.36 | 0 | 0.000 | 1 | 0.69 | 0 | 0.00 | 3 | 0.29 |
| Ocher | 1 | 0.18 | 1 | 0.328 | 0 | 0.00 | 0 | 0.00 | 2 | 0.19 |
| Phthanite | 1 | 0.18 | 1 | 0.328 | 1 | 0.69 | 0 | 0.00 | 3 | 0.29 |
| Silex | 1 | 0.18 | 2 | 0.656 | 4 | 2.78 | 1 | 2.44 | 8 | 0.77 |
| Volcanic rock | 1 | 0.18 | 0 | 0.000 | 0 | 0.00 | 0 | 0.00 | 1 | 0.10 |
| Ind. | 2 | 0.36 | 1 | 0.328 | 1 | 0.69 | 1 | 2.44 | 5 | 0.48 |
| TOTAL | 554 | 100.00 | 305 | 100.000 | 144 | 100.00 | 41 | 100.00 | 1044 | 100.00 |

Cuon alpinus, *Dicerorhinus* sp, *Sus barbatus* or *Sus scrofa*, *Muntiacus muntjack*, *Cervus unicolor*, Bovines, *Axis porcinus* and, birds, lizards, rodents, small mammals, snakes, and squirrels, it is specified that the bones of Suids constituted a significant proportion of the identified fauna in both units and that a significant number of marine shells were added. In a large meta-analysis, Conrad (2015) suggests that Peninsular Malaysian sites have a higher abundance of Suids in relation to Thailand sites that have a higher abundance of Cervids. Due to the limited chronological extent of the Hoabinhian layer recorded in Laang Spean cave (*id est* 12900 and 5500 cal BP), it remains difficult to distinguish between both hypotheses suggested by Suraprasit et al. (2021). If we consider the fauna as a whole, it seems that there is a mosaic environment reflecting a tropical rainforest environment, sparsely interspersed with a few areas of wooded grassland. If we are using the variations in sedimentary facies as a kind of chronological scale to distinguish some faunal sets, the main conclusion we can draw from this is that, from a stochastic point of view, the oldest facies (11b₁ and 11a) contain very few faunal remains compared with subsequent facies (10 and 9). This is undoubtedly primarily due to the occupancy rate of the site by the Hoabinhian hunter-gatherers.

If we are interested in the variation in the different taxa over time, then we can propose that the environment is evolving towards a more open and diverse environment on the basis of the change in the percentage of Bovines. The appearance of Bivalves of the Unionidae family began in the facies 11a. Hoabinhians thus began to collect freshwater mussels, thus diversifying the protein content of their diet. Such trend has been noticed for the same period at Kaoh Toh Chong (Conrad et al., 2013) but with strong connection with the evolution of the seaside of Thailand and peninsular Malaysia during Holocene. If we read a slight anomaly: the increase of the relative percentage of Cervids within the mammalian fauna, and a relative decrease in Varans within the herpetofauna, we could hypothesise an increase in humidity associated with an episode of increased forest cover restricted in time for the facies 11a (12026 – 11018 cal BP) corresponding to the end of the Younger Dryas and the beginning of a monsoon peak.

5.2. Changes and continuities in technological strategies across the Hoabinhian of Laang Spean

The Hoabinhian lithic assemblage at Laang Spean distinguishes itself from other sites by a lower representation of unifaces and a notable presence of tools made from split cobbles. This typological uniqueness and technical innovation are evident in the efficient use of raw materials for the creation of various tools (Forestier et al., 2023). One of these sequences, made on half-cobbles, stands out reflecting a sophisticated understanding of material economy.

In this paper, we have observed that the Hoabinhian sequence of Laang Spean, encompassing facies 11b₁ to facies 9 (*id est* 12900 and

5500 cal BP), provides a framework for understanding technological changes and continuities. The sequence reveals some minor diachronic changes in some raw materials, blank and tool production, accompanied by variances in artifact size (in terms of metric dimensions and mass), indicative of both an increase in the intensity of occupation over time, and probably technological adaptation and innovation over time. In terms of raw material selection, the presence of silicified limestone, silicified sandstone and volcanic rock in specific facies suggest a selective approach to raw material use. Hornfels and limestone emerge as the primary raw materials, with their use reflecting availability and a clearly techno-cultural choice. The dominant use of hornfels in the upper set (facies 9 and 10) for flake production, and the strategic selection of this material from the Chanob River, indicate a sophisticated understanding of material properties and a deliberate choice aimed at optimizing tool production. The morpho-structural criteria used for selecting pebbles and cobbles for different reduction schemes further highlight the technical knowledge and planning involved in tool production.

The variation in limestone usage across the facies, from the production of cobble tools in the upper facies to a more pronounced use for flake production and specific tool types in the lower facies, reflects a flexible adaptation to possible changing technological need or environmental constraints. The fact that limestone was chosen for the production of macro-tools and horse hoof scrapers in specific contexts suggest an understanding of its suitability for functional requirements. Sandstone's consistent but varied use across all facies further illustrates the multi-faceted approach to raw material exploitation. Its role in both flake production and the manufacture of cobble tools underscores its versatility and importance within the lithic toolkit.

The predominance of simple unidirectional flakes (48.66 % of blank production) across the sequence, especially in the more recent set (facies 9 and 10), suggest a continuity in the basic conception to lithic reduction strategies. This continuity, however, is nuanced by the introduction and eventual disappearance of other blank types like blade-like and "salami slices" in the upper facies, signaling a minor temporal shift in production methods, functional requirements, or both. The persistent, albeit rare, presence of slab blanks throughout indicates a consistent, if minor, role in the toolkit composition.

The similarity in tool diversity and frequency between the more recent set (facies 9 and 10) contrasts with the older set (facies 11a and 11b₁), reflecting a change in tool types and utilization. The dominance of unifaces in the upper facies underscores a change towards more specialized tool structures, possibly reflecting changes in subsistence strategies or resource exploitation patterns. The dimensional analysis of tools and blanks further underscores these diachronic changes. The distinction in dimension of choppers between the upper and lower facies, alongside the slightly progressive increase in size of some unifaces and some flakes moving from facies 11b₁ to facies 9, indicates a minor

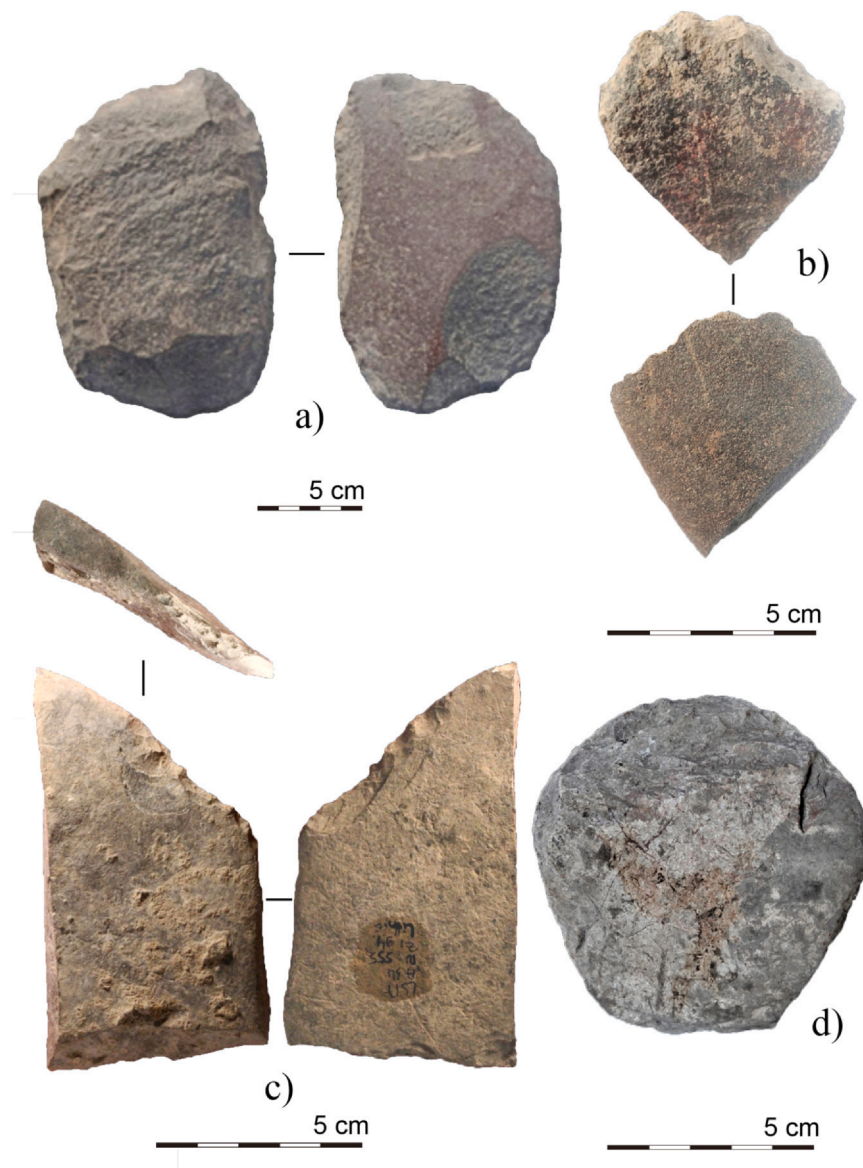


Fig. 8. Stone tools excavated from the squares yielding Hoabinhian human remains: a) Unifacial cobble; b) convex-denticulate edge on a fractured split-cobble; c) “limestone knife”: oblique denticulate cutting on a limestone slab edge characterized by a scalar/stepped altern retouch; d) chopper with convex cutting edge on limestone cobble. Source: H. Forestier / A. Pérez-Balarezo.

change in tool manufacture and function. This trend is complemented by the facies-specific dimensions of used flakes and split, which suggest possible adaptations to specific environmental or cultural needs. Interestingly, facies 11a emerges as a transitional phase in several respects, maintaining certain characteristic of the lower facies while integrating elements that are more pronounced in the upper facies. This could indicate a period of experimentation or adaptation, leading to the technological features observed in the upper facies.

In summary, the Hoabinhian sequence at Laang Spean reveals minor diachronic changes in lithic technology, as well as continuities between the oldest facies, 11b₁ and 11a (~12900–11500 cal BP) in one hand, and the more recent facies 10 and 9 (~10000–5500 cal BP) in the other hand. These minor alterations within a shared *savoir-faire* likely reflect real adaptations of this population to changes in the resources available in their environment, especially at the end of the Younger Dryas. The term “environment” is used here in its broadest sense, i.e. the climate, the natural forest environment, the sediment context of the cave site, the animals selected for hunting/catching or trapping, water resource and the spot of the raw materials available for stone knapping.

For the facies 11a, (12026 – 11018 cal BP) it seems that a more humid event (the end of the Younger Dryas) could be recorded at Laang Spean, which appears to be a period of experimentation for a more stable and extensive technology during the monsoon. In fact, the beginning of the monsoon appears to coincide with a general increase in the quantity, diversity, and size of artifacts. Considering the close proximity of the Chanob River as a source of pebbles and cobbles near Laang Spean limestone hill, this could indicate that between 10000 and 5000 cal BP, in the context of monsoon phenomenon, lithic technology in the cave was less constrained by the risk involved in maintaining a supply of technology from a distance. Therefore, during this period, technology was possibly less constrained by risks associated with budgeting time and energy for resource procurement (Torrence 1983).

Following Kuhn (1995)’s scheme of technological organization, which Marwick (2006) applied at sites like Tham Lod and Ban Rai, Laang Spean’s approach in this respect is more akin to Tham Lod, indicating that people at these sites adopted a “place provisioning” strategy. This strategy implies a technological approach suited to low variation in the location and timing of foraging activities and low mobility in the Battambang floodplain. Under these conditions, an

Table 5

Classification of lithic remains by facies, recovered from the Hoabinhian Layer of Unit I, Laang Spean.

| Types | Facies 9 | | Facies 10 | | Facies 11a | | Facies 11b ₁ | | TOTAL | |
|--|------------|---------------|------------|---------------|------------|---------------|-------------------------|---------------|-------------|---------------|
| | N | % | N | % | N | % | N | % | N | % |
| TOOLS | 95 | 17.15 | 61 | 20.00 | 27 | 18.75 | 10 | 24.39 | 193 | 18.49 |
| Chopper | 13 | 2.35 | 13 | 4.26 | 5 | 3.47 | 2 | 4.88 | 33 | 3.16 |
| Chopping tool | 7 | 1.26 | 1 | 0.33 | 1 | 0.69 | 0 | 0.00 | 9 | 0.86 |
| Other cobble tool | 3 | 0.54 | 0 | 0.00 | 2 | 1.39 | 0 | 0.00 | 5 | 0.48 |
| Split tool | 1 | 0.18 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.10 |
| Flake tool | 8 | 1.44 | 9 | 2.95 | 2 | 1.39 | 2 | 4.88 | 21 | 2.01 |
| Used flake | 26 | 4.69 | 15 | 4.92 | 8 | 5.56 | 3 | 7.32 | 52 | 4.98 |
| Uniface | 33 | 5.96 | 21 | 6.89 | 7 | 4.86 | 2 | 4.88 | 63 | 6.03 |
| Limace | 0 | 0.00 | 2 | 0.66 | 0 | 0.00 | 0 | 0.00 | 2 | 0.19 |
| Slab tool | 3 | 0.54 | 0 | 0.00 | 1 | 0.69 | 0 | 0.00 | 4 | 0.38 |
| Debris tool | 1 | 0.18 | 0 | 0.00 | 0 | 0.00 | 1 | 2.44 | 2 | 0.19 |
| Stemmed tool | 0 | 0.00 | 0 | 0.00 | 1 | 0.69 | 0 | 0.00 | 1 | 0.10 |
| BLANK PRODUCTION | 318 | 57.40 | 177 | 58.03 | 76 | 52.78 | 12 | 29.27 | 583 | 55.84 |
| Flake | 273 | 49.28 | 158 | 51.80 | 66 | 45.83 | 11 | 26.83 | 508 | 48.66 |
| Blade-like | 3 | 0.54 | 2 | 0.66 | 0 | 0.00 | 0 | 0.00 | 5 | 0.48 |
| Slab | 1 | 0.18 | 1 | 0.33 | 1 | 0.69 | 1 | 2.44 | 4 | 0.38 |
| Split | 40 | 7.22 | 16 | 5.25 | 9 | 6.25 | 0 | 0.00 | 65 | 6.23 |
| "Salami slides" (unidirectional flakes) | 1 | 0.18 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.10 |
| CORES AND FLAKING BYPRODUCTS | 59 | 10.65 | 12 | 3.93 | 20 | 13.89 | 6 | 14.63 | 97 | 9.29 |
| Core | 0 | 0.00 | 0 | 0.00 | 1 | 0.69 | 0 | 0.00 | 1 | 0.10 |
| Debris | 59 | 10.65 | 12 | 3.93 | 19 | 13.19 | 6 | 14.63 | 96 | 9.20 |
| OTHER TOOLS | 8 | 1.44 | 1 | 0.33 | 1 | 0.69 | 4 | 9.76 | 14 | 1.34 |
| Half-moon | 7 | 1.26 | 0 | 0.00 | 1 | 0.69 | 0 | 0.00 | 8 | 0.77 |
| Horse-hoof | 1 | 0.18 | 1 | 0.33 | 0 | 0.00 | 4 | 9.76 | 6 | 0.57 |
| MACRO-TOOLS and MISCELLANEOUS | 74 | 13.36 | 54 | 17.70 | 20 | 13.89 | 9 | 21.95 | 157 | 15.04 |
| Grindstone | 1 | 0.18 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.10 |
| Hammerstone | 20 | 3.61 | 14 | 4.59 | 4 | 2.78 | 2 | 4.88 | 40 | 3.83 |
| Pestle grinder | 2 | 0.36 | 1 | 0.33 | 0 | 0.00 | 0 | 0.00 | 3 | 0.29 |
| Manuport | 13 | 2.35 | 7 | 2.30 | 1 | 0.69 | 0 | 0.00 | 21 | 2.01 |
| Tested block | 1 | 0.18 | 0 | 0.00 | 3 | 2.08 | 1 | 2.44 | 5 | 0.48 |
| Tested cobble | 21 | 3.79 | 29 | 9.51 | 10 | 6.94 | 2 | 4.88 | 62 | 5.94 |
| Ochre | 0 | 0.00 | 1 | 0.33 | 0 | 0.00 | 0 | 0.00 | 1 | 0.10 |
| Indeterminate | 16 | 2.89 | 2 | 0.66 | 2 | 1.39 | 4 | 9.76 | 24 | 2.30 |
| TOTAL | 554 | 100.00 | 305 | 100.00 | 144 | 100.00 | 41 | 100.00 | 1044 | 100.00 |

assemblage is expected to have high tool affordances with a significant proportion of relatively large pieces that show minimal reduction before being brought to the site, and once inside, also exhibit short shaping and retouch sequences, suggesting that the raw material already met morpho-techno-structural criteria suitable for the functionalization of tools. This is the case for the upper set of facies of the Hoabinhian layer of Laang Spean.

On the other hand, we observe a less quantity, diversity, size, and mass of lithic artifacts, coinciding with humidity and denser forest environment of the facies 11a (12026 – 11018 cal BP) than for the younger period. The relative scarcity of massive tools compared to the later period, and their replacement by tool and blank production made from other raw materials (mainly limestone and sandstone) with lighter characteristics, likely indicates that lithic technology was responding to different ergonomic and functional needs.

Given the proximity to a nearby source of raw materials, all this supports the hypothesis that changes in environmental resources caused by changes in precipitation throughout the Laang Spean sequence likely pushed populations to shift their technological strategies from a lighter toolkit associated with a more closed and humid environment, to a heavier and more robust toolkit associated with a more open and less humid environment. The location of Laang Spean, near a source of provisioning, also explains why these changes are associated with certain technological continuities observed especially in terms of blank production.

Only further technological (extending our ongoing diacritical analysis of each lithic piece) and functional studies (use-wear and residues analysis) will be able to offer us more pieces of information in the future.

5.3. The Hoabinhian human remains of Laang Spean and their significance

From the 1920s, human remains have been reported in various Hoabinh province shelters or from Laos (Colani, 1927, 1930; Fromaget, 1940a, 1940b; Fromaget and Saurin, 1936; Mansuy, 1924, 1925a, 1925b) with the question arisen as to the position or age of the human remains unearthed. Former attributions to "Mesolithic" or "Lower Neolithic" periods have arisen and the difficulty of contextualizing the human remains and associated culture was underlined very early (cf. Robequain and Mansuy 1925). A major question remains whether it is really possible to attribute the human bones to the Hoabinhian, given that the links between the lithic material, which is the most emblematic for Hoabinhian, and the human skeletons are far from being established. In particular, due to the presence of more recent burials, the excavation of which contributes to bringing up older material and re-burying it in the tombs in cave and rockshelter sites in Mainland Southeast Asia.

Yet Hoabinhian populations are key to understanding the settlement of Southeast Asia (Matsumura et al., 2015) but although the striking similarities between the Hoabinhian in Southeast Asia and the Upper Palaeolithic and Lower Neolithic cultures of southern China cannot be overlooked, the lack of archaeological studies in Mainland Southeast Asia still prevents archaeologists from demonstrating the links between these ancient cultures. Regional archaeologists acknowledge that datasets in Mainland Southeast Asia are biased due to limited sample sizes and uneven geographical coverage of finds (White, 2011). Thus, following a synthesis that takes into account Hoabinhian burials from several sites of Thailand, Laos, Vietnam and Malaysia, and contemporary sites in Guangxi province it has been shown that the position

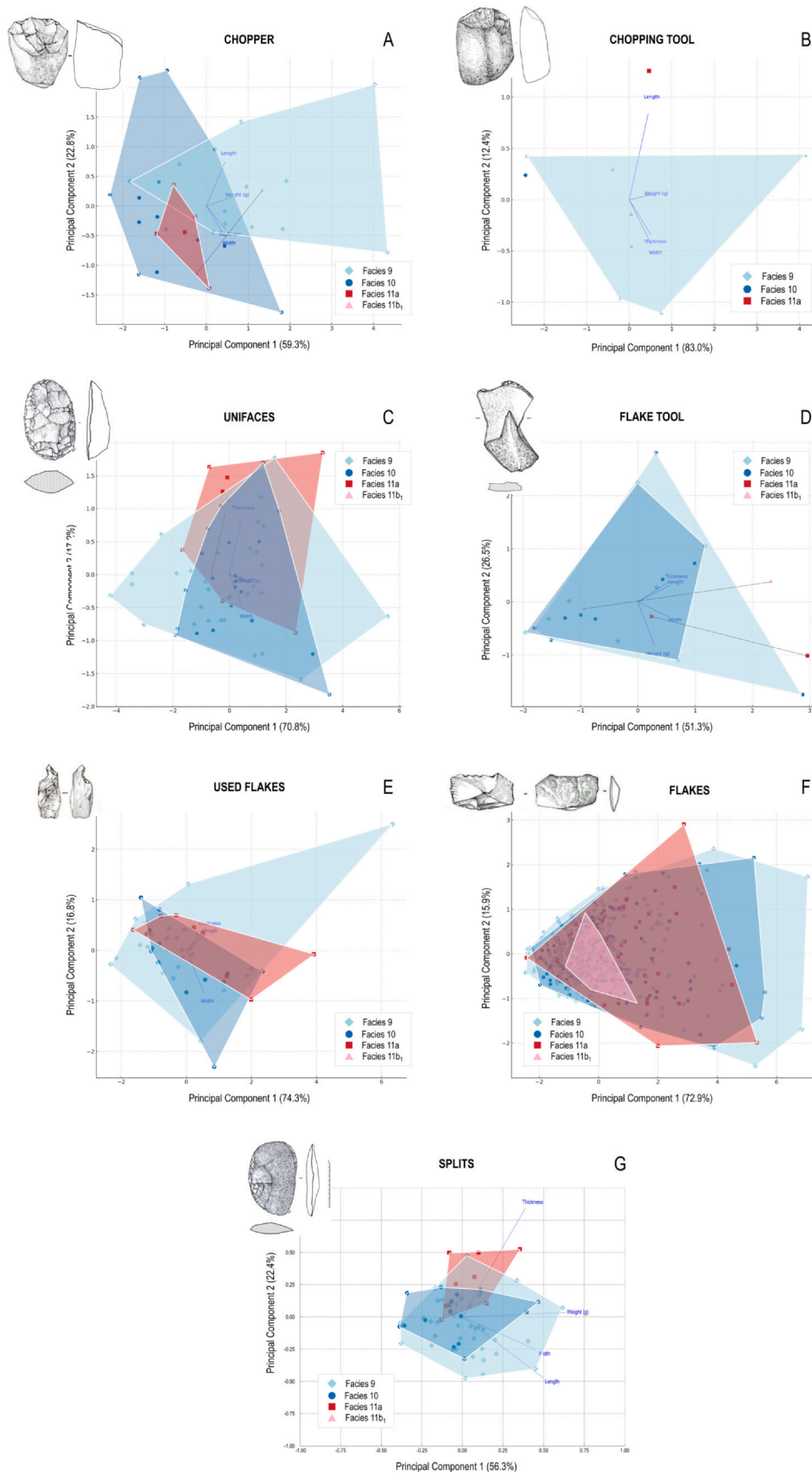


Fig. 9. Representative tool and blanks categories and sizes distributions over time in the Hoabinhian component of Laang Spean. The Principal Component Analysis (PCA) take into account length, width, thickness (all in mm) and in some cases also weight (g).

of the individuals buried in the tombs alone was not relevant in distinguishing a “Neolithic of Chinese origin” from more ancient “indigenous practices” (Zeitoun et al., 2019a).

If in Mainland Southeast Asia the Hoabinhian techno-complex corresponds to the legacy of using massive tools made on cobbles or pebbles, which perpetuated in a tropical environment for about 40,000 years, during this long period funerary practices were described to be uniform and limited to “flexed” burials as stated by Bellwood (1993) or Higham (2002). The only notable changes observed at the end of this period were related to the start of the Neolithic originated from China and included a sedentary way of life, the start of agriculture, the final abandonment of the chipping/flaking stone industry, and an increase in burials in the extended position. Imprecise descriptive terminology and a lack of illustrations prevents a review of old data, although recent decades there has been a recent increase in the archaeo- thanatological approach in Southeast Asia (Harris and Tayles, 2012; Pautreau et al., 1998, 2001; Willis and Tayles, 2009; Zeitoun et al., 2013, 2021). Finally, the search for new sites and the detailed excavation of burials using archaeo- thanatology will enable us to identify regional particularities and/or chronological changes in funerary practices that are signs of different cultural identities.

Isolated remains are not very numerous either and it is all the more difficult to qualify the funerary contexts and identify the practices on these isolated remains. The age of these remains is even more problematic than for tombs, especially when the stratigraphic data and/or the dating of the remains is problematic or questionable (cf. Kuzmin and Keates, 2014; Pierret et al., 2012) or re-evaluated (Conrad et al., 2022; Schaarschmidt et al., 2019). Consequently, it is difficult to use this material to complete the corpus of Hoabinhian human remains. For example, with regard to isolated human remains or those whose funerary context is not specified, it is only because of the similarity of the lithic material and the contemporaneity of the radiocarbon ages that we proposed to associate the neighbouring Hoabinhian sites of Huay Pano (Zeitoun, et al., 2019b) and Tam-Pong, where human bones were found (Fromaget and Saurin, 1936). Systematic studies in the 1980s by Hanoi's 'Paleolithic Research Department of the Institute of Archaeology' led to excavations across Hoabinhian sites in Northern Vietnam. Notably, at sites like Mai Da Nuoc and Mai Da Dieu, two well-preserved human crania were unearthed but it is as-well only based on the artifacts, that these sites had been affiliated to dates between 20,000 and 10,000 years ago (Cuong, 1986). Obviously, these are only extrapolations, and cannot be used to construct a completely satisfactory history of Hoabinhian settlement and adaptation to their environment.

The Hoabinhian is now Southeast Asia's most distinguished *Homo sapiens* technocomplex due to its unique tool-making techniques. However, only a few sites have produced a chronological sequence from recent excavations and Laang Spean is the only site in Cambodia to have yielded faunal and human remains, and lithics in the same clear and well-dated stratigraphic Hoabinhian layer. Consequently, the new findings from recent excavations at the Laang Spean cave in Northwest Cambodia by the 'French-Cambodian Prehistoric Project' (2009–2023) seek to contribute to this understanding.

6. Conclusion

In the comprehensive study of Laang Spean cave in Northwest Cambodia, we have elucidated the intricate interplay between human activity, faunal exploitation, and lithic technology within the context of Southeast Asia's Quaternary period. The evidence from Laang Spean cave distinctly indicates human presence, as suggested by the deliberate selection and utilization of non-cave dwelling taxa, the presence of fresh bone fragmentation, fire traces, and the notable absence of non-human predatory marks. This pattern of human activity aligns with the Hoabinhian cultural complex, known for its unique subsistence strategies and technological innovations.

The faunal assemblage at Laang Spean, dominated by Bovines, Turtles, Molluscs and Cervids, alongside evidence of a varied

ecosystem encompassing both humid and dry forests as well as significant wetland areas, underscores the adaptivity of the Hoabinhian peoples. Their ability to exploit a diverse range of habitats is mirrored in the comparative zooarchaeological data from similar sites across Southeast Asia, although limitations in data prevent definitive comprehensive comparisons. Despite these constraints, the nuanced understanding of faunal and environmental shifts offers glimpses into the complex relationship between climate change, cultural evolution, and human adaptation in tropical contexts. The strategic selection of specific animals for consumption and the use of fire for processing these resources illustrate an intimate connection with their surroundings, enabling the Hoabinhian to thrive in a diversified environment.

Noteworthy is the lithic assemblage at Laang Spean, distinguished by its lower representation of unifaces and the innovative use of split cobbles, reflecting a sophisticated material economy and technical knowledge. This lithic diversity, alongside faunal evidence, and the sedimentary analyses provides a nuanced perspective on the Hoabinhian lifestyle, underscoring a dynamic interaction with the environment. The diachronic changes observed in the lithic technology, from raw material selection to tool production and use, indicate adaptive strategies to environmental and possibly techno-economical shifts over time.

Furthermore, the study sheds light on the broader implications of Hoabinhian culture in understanding the settlement patterns and technological phenomena of *Homo sapiens* in Southeast Asia. The presence of human remains in various contexts across the region raises questions about the chronological and cultural links between the Hoabinhian and other contemporary cultures. Despite the challenges in establishing direct associations between lithic material and human remains due to potential disturbances in archaeological layers, the consistent identification of Hoabinhian sites across Southeast Asia contributes to a deeper understanding of the region's prehistoric landscape. The isolated skull of Laang Spean, identified as Hoabinhian, represents a small but important element in the context of regional archaeo- anthropological research, where very few human bones are indisputably affiliated with this technocomplex.

In conclusion, the Laang Spean cave study contributes significantly to our understanding of the Hoabinhian cultural complex, highlighting the interdependence of human activity, faunal exploitation, and lithic technology in Southeast Asia's prehistory. While limitations in comparative data and the complexities of interpreting climatic and environmental impacts on cultural adaptation persist, this research offers valuable insights into the adaptive strategies of early human populations in tropical environments. Future research, especially in the realm of functional studies and further archaeological excavations, promises to enrich our understanding of the Hoabinhian and its significance in the broader narrative of human evolution and cultural development in Southeast Asia.

CRedit authorship contribution statement

Lisa Gollette: Formal analysis. **Christophe Griggo:** Writing – original draft, Investigation, Formal analysis. **Corentin Bochaton:** Formal analysis. **Véronique Pois:** Formal analysis. **Valéry Zeitoun:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ngov Kosal:** Resources, Investigation. **Antonio Pérez-Balarezo:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Hubert Forestier:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Heng Sophady:** Resources, Project administration, Data curation. **Yuduan Zhou:** Formal analysis. **Simon Puaud:** Formal

analysis. **Antoine Zazzo**: Formal analysis. **Olivier Tombret**: Formal analysis. **Florent Déroît**: Formal analysis, Data curation.

Declaration of Competing Interest

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