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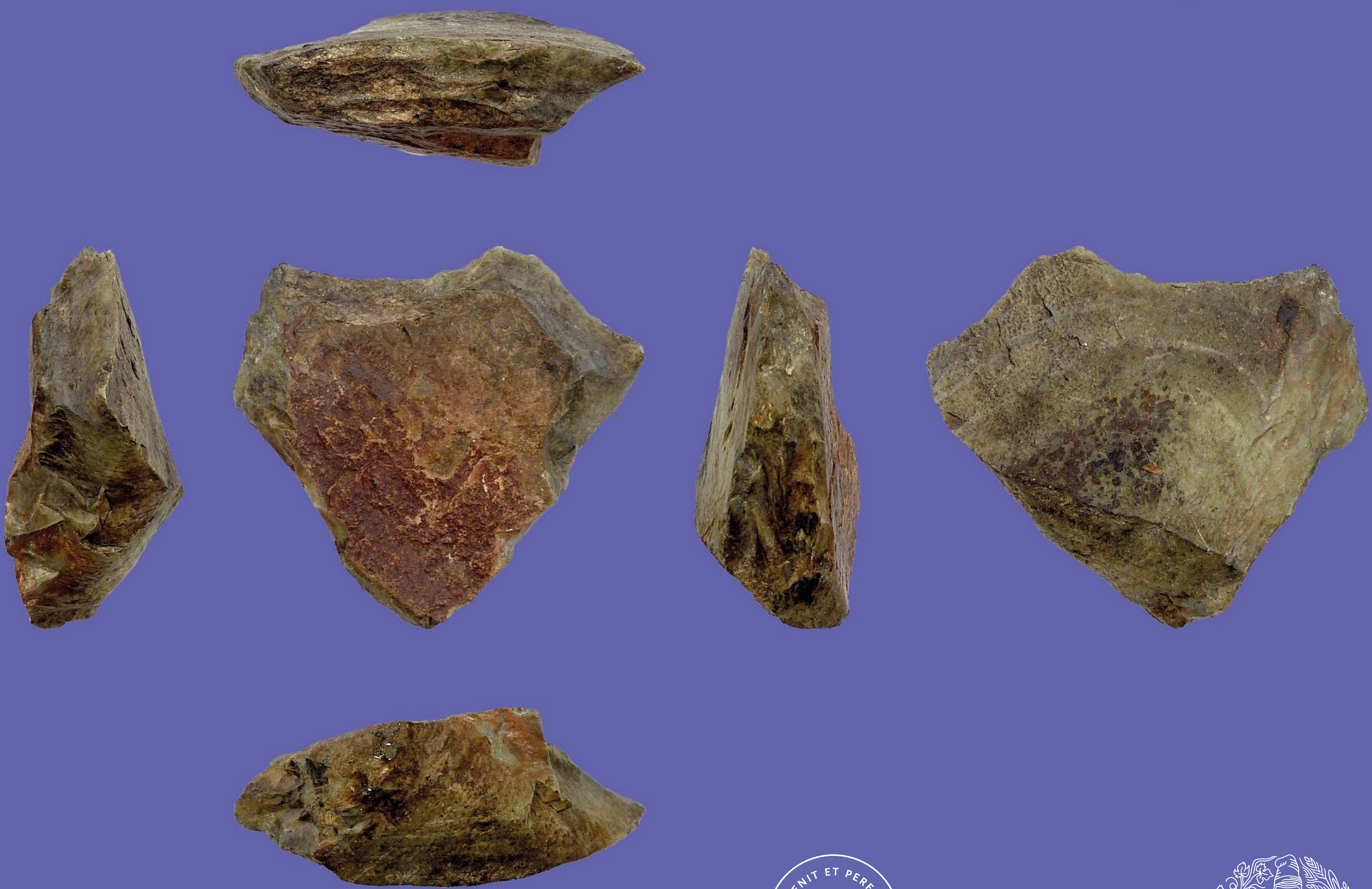

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ABSTRACT
This research examines the unique lithic technology at the Doi Pha Kan site dated 13300 to 12800 calBP in Northern Thailand during the Hoabinhian period (which globally extends from the final Late Pleistocene to Mid Holocene) by means of a technological and morpho-metric analysis. While it shares similarities with typical Hoabinhian assemblages, significant deviations in reduction methods, targeted tool types, and the singular presence of reduction sequences dedicated to the production of a diversity of slab tools. Nevertheless, the study blanks the existence of a distinct population within the Hoabinhian world, indicating a shift towards lighter, composite tools, which may represent a modern trajectory or the final phase of the Hoabinhian culture. The study also explores the potential influence of climatic fluctuations at the end of the Late Pleistocene on human behaviors and the evolution of modern human diversity in Southeast Asia. However, due to limited available paleoenvironmental data and data with a few seasonal contrasts in the tropics within a world without winter, a direct connection remains elusive for the moment. The study underscores the need for further research and interdisciplinary collaboration for comprehensive understanding of human paleoecology in the region as well as innovative technical adaptation.

KEY WORDS
Hoabinhian, lithic technology, Pleistocene-Holocene transition, paleoecology, Southeast Asia.

RÉSUMÉ
Variabilité technologique de l'Hoabinhien : l'exemple de la production lithique sur plaquette du site de Doi Pha Kan (Thaïlande du Nord).
Cette étude propose une analyse technologique et morphométrique de la singulière industrie lithique du site de Doi Pha Kan, daté de 13300 à 12800 cal BP, dans le Nord de la Thaïlande, pendant la période Hoabinhienne (qui s'étend globalement du Pléistocène supérieur final à l'Holocène moyen). Bien que cet assemblage présente des similitudes avec ceux des sites hoabinhiens « typiques », des écarts significatifs en ce qui concerne les méthodes de production, les types d'outils ciblés et surtout la présence singulière de chaînes opératoires visant à produire une diversité d'outils sur plaquette. Néanmoins, l'étude écarte l'existence d'une population distincte au sein du monde hoabinhien, indiquant une évolution vers des outils plus légers et composites, qui pourraient représenter une trajectoire moderne ou la phase finale de la culture hoabinhienne. L'étude explore également l'influence potentielle des fluctuations climatiques à la fin du Pléistocène supérieur sur les comportements humains et l'évolution de la diversité humaine moderne en Asie du Sud-Est. Toutefois, le cadre paléoenvironnemental tropical régional étant limité en données, et, par ailleurs, peu contrasté saisonnièrement dans un monde sans hiver, il est difficile d'établir un lien direct à ce stade. Enfin, ce travail souligne la nécessité de poursuivre les recherches et la collaboration interdisciplinaire dans la perspective d'une compréhension globale de la paléoécologie humaine dans la région ainsi que des adaptations techniques innovantes.

MOTS CLÉS
Hoabinhien, technologie lithique, transition Pléistocène-Holocène, paléoécologie, Asie du Sud-Est.

INTRODUCTION

The Hoabinhian, a term first coined by Madeleine Colani in Southeast Asia during the early 1930s (Colani 1929a; b; 1930; Collectif 1932), has since been examined in terms of its spatiotemporal distribution (Matthews 1964; Saurin 1969; Solheim & Wilheim 1974; Reynolds 1990; Bowdler 1994; Huong 1994), its typological and chronological definition (Matthews 1966; Reynolds 1990; Pautreau 1994; Tan 1994; Moser 2001), its economic implications (Gorman 1969; 1970; 1971; Glover 1977; Yen 1977; Vu 1994), and its role in reconstructing human-environment interactions in local areas of mainland Southeast Asia (MSEA) during the Pleistocene and Holocene (Gorman 1970; Anderson 1990; Mudar & Shoocongdej 2000; Shoocongdej 2006; Anderson 2007; Marwick 2013).

In terms of the technological, experimental, and functional analysis of lithic assemblages, the initial analyses (Gorman 1969; Sørensen 1982; Pookajorn 1985, 1995; Reynolds 1989; Jérémie 1990; White & Gorman 2004; Masojć *et al.* 2023) were expanded upon with morpho-techno-functional analyses (Forestier & Zeitoun 2005; Forestier *et al.* 2005, 2008, 2013, 2015, 2017, 2021, 2022; Zeitoun *et al.* 2008; Forestier 2020). This led to the identification of almost four operational production sequences on pebble and cobble (unifacial shaping, pebble/cobble splitted, chopper/chopping tool shaping and mixed/combined shaping-flaking (Forestier *et al.* 2023). Previous work allows us to deepen the discussion beyond the technological classification of lithic assemblages and explore their broader anthropological and ecological implications to the extent of available data.

The Hoabinhian phenomenon, which spans a temporal period from approximately 40000 to 4000 BP (Forestier *et al.* 2013; Ji *et al.* 2016) and a geographical area of about 2 million km^2, is now known to be marked by the ubiquitous presence of a macro-toolkit, typically shaped unifacially from whole, long, plano-convex or split pebbles/cobbles. It is also associated with a smaller toolkit crafted from shaping flakes. A recent study highlighted a ramification (branched productive sequences) of the reduction sequence

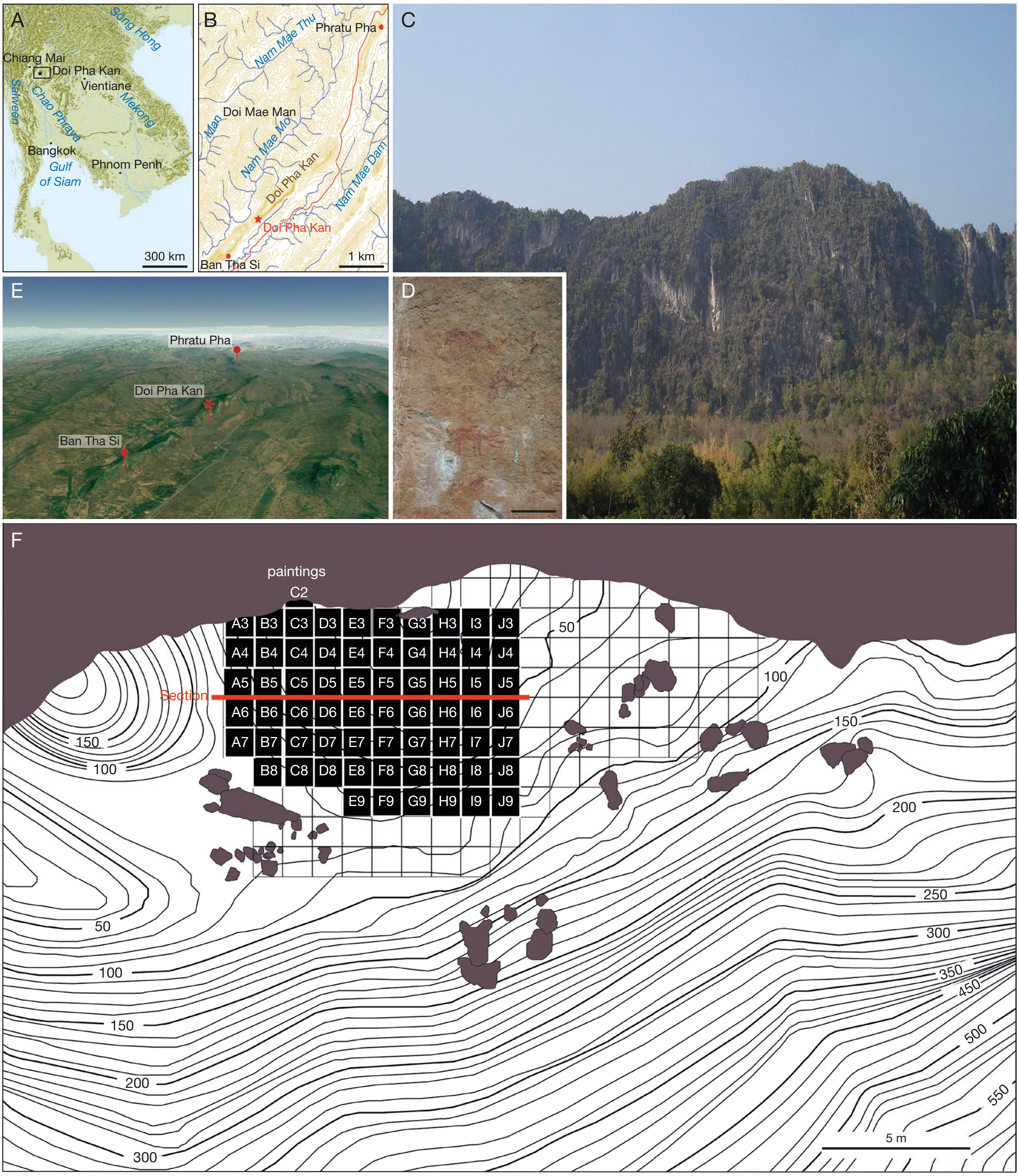

Fig. 1. — General presentation of the Doi Pha Kan site: **A**, **B**, geographic location of the site; **C**, **D**, panorama of the Doi Pha Kan cliff (**C**) and associated rock paintings (**D**); **E**, location of Doi Pha Kan, Ban Tha Si, and Phratu Pha; **F**, grid plan of the excavation area. The section represented in the Figure 2 is indicated in **red line**. Scale bar: E, 20 cm.

(Forestier *et al.* 2022), demonstrating its techno-economic variability. Recent research has underscored the diversity of its productions, extending beyond the omnipresent pebble/cobble toolkit.

In this context, a comprehensive and systematic study of the lithic assemblage of Doi Pha Kan has revealed a wide range of lithic productions, particularly from the exploitation of siliceous volcanic rock slabs sourced from the site's

Table 1. — Phases time range from ^{14}C modeling in the cultural sequence of Doi Pha Kan site. See stratigraphic sketch for the location of dating. Data was calibrated and modeled in ChronoModel 3.1.8 (Lanos & Dufresne 2019), using IntCal20 calibration curve (Reimer *et al.* 2020). The starting and ending points of the posterior distribution are defined as the maximum a posteriori (**MAP**) 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.

				Posterior distribution		
Phase	**^{14}C**	**Code**	**Material support**	**Begin MAP (cal BP) (95%)**	**End MAP (cal BP) (95%)**	**Phase Time Range (cal BP) (95%)**
dpk DE-5 (1)	11895 ± 45	SacA32917	Human femoral shaft	13709	13709	14093-11604
dpk D-4 (2)	12340 ± 50	SacA32916	Human femoral shaft	14052	14052	14484-12567
dpk E-5 (3)	11170 ± 40 12540 ± 50 12210 ± 50 12920 ± 80 12930 ± 50	SacA27054 SacA27053 SacA27055 SacA27057 SacA27056	Human third molar Human femoral shaft Muntjac metapod shaft Fresh water oyster shell Charcoal	15545	14153	17004-12889

immediate surroundings. This research marks a departure from traditional Hoabinhian studies, primarily characterized by heavy-duty toolkits based on cobble/pebble matrix. Several reduction sequences have been identified from the selection of these slabs, supplementing the more traditional ones that comprise the “Pebble/Cobble Hoabinhian”, known primarily from the Laang Spean cave in Northwest Cambodia (Forestier *et al.* 2015) and Southeast Asia (Zhang 1993; Moser 2001; Ji *et al.* 2016). This discovery raises critical questions about the adaptability and technological innovation of Hoabinhian communities during the Pleistocene-Holocene transition. Therefore, this paper seeks to address how does the Doi Pha Kan assemblage, with its unique “tool on slab” phenomenon, contribute to our understanding of Hoabinhian adaptability and technological diversity during significant environmental and climatic changes. To achieve this, we undertake a critical examination of the environmental records, utilizing various proxies derived from regional literature. Emphasis is placed on discerning different levels of resolution on facets of human behavioral ecology, leveraging the still limited yet valuable technological and environmental data available.

By presenting the variability of reduction methods and the diversity of the “slab toolkit”, our study challenges existing perceptions of the Hoabinhian toolkit and proposes that the singular tools from Doi Pha Kan provide insights into the complex decision-making their nuanced responses to ecological challenges, contributing new data to the general discussion in Southeast Asian archeology on *Homo sapiens* technological strategies and behavioral complexity.

DOI PHA KAN ROCK SHELTER: CHRONOSTRATIGRAPHY AND PALEOENVIRONMENT

The Doi Pha Kan site, located in the Ban Dong district, Mae Moh, Lampang Province, was recognized as a site of significant heritage value during the routine documentation of the Thai national archaeological map by the Fine Arts Department. This site was cataloged as a rock painting site following the discovery of the nearby Phratu Pha site (Srongsiri & Sangchan 1997; Doy Asa *et al.* 2001), which boasts one of Thailand’s longest painted frescoes (Winayalai 1998, 1999).

Doi Pha Kan, a rock shelter situated 7 km south of Phratu Pha (18°26.95’N, 99°46.62’E; Fig. 1), along with the Ban Tha Si site, located 3 km further south, have been the focus of archaeological exploration since 2011. These sites were investigated to test hypothesis regarding systematic burial placement at the base of locally decorated walls. Indeed, burials in an extended position, dating back to approximately 3000 BCE were discovered at the base of the Phratu Pha rock shelter (Srongsiri & Sangchan 1997; Winayalai 1999; Kongsuwan 2001). A flexed-position burial, dated to 7047 ± 53 14C BP (Wk 29559), was found at Ban Tha Si, at the base of red ochre animal paintings and handprints (Zeitoun *et al.* 2013).

At Doi Pha Kan, the paintings have been subject to detailed description and analysis (Surinlert *et al.* 2018), leading to the identification of three distinct pictorial generations. One of these generations could be associated with the burials due to the composition of the pigments used (Lebon *et al.* 2019). Three flexed-position burials were uncovered at the base of the decorated panel, with dates obtained from various materials (see Table 1) ranging from 11170 ± 40 to 12930 ± 50 14C BP (SacA 27054 and SacA 27056) (Imdirakphol *et al.* 2017). On the basis of similarities in sepulchral practices, bioanthropological data and the joint presence of perforated stone and partially polished axes between the Doi Pha Kan site in northern Thailand, the Early Da But culture in northern Vietnam and the Liyuzui for period I or Zengpiyan for period IV cultures in Guangxi, we have proposed that there may be a particular cultural ensemble limited in time (13000-7000 BP) to distinguish in this area situated at the heart of a larger regional Hoabinhian ensemble (Imdirakphol *et al.* 2017; Zeitoun *et al.* 2019).

Based on a nearby test-pit drilled by mining prospectors at the bottom of the wall of the rock shelter Doi Pha Kan deposits are sediments accumulated to a depth of at least 3 m. Due to the loose nature of the dusty loamy deposits, it is not possible to undertake large excavations without disturbing sediments and the embedded archaeological remains. Thus, in term of geostratigraphy (mineral nature, colour, texture),

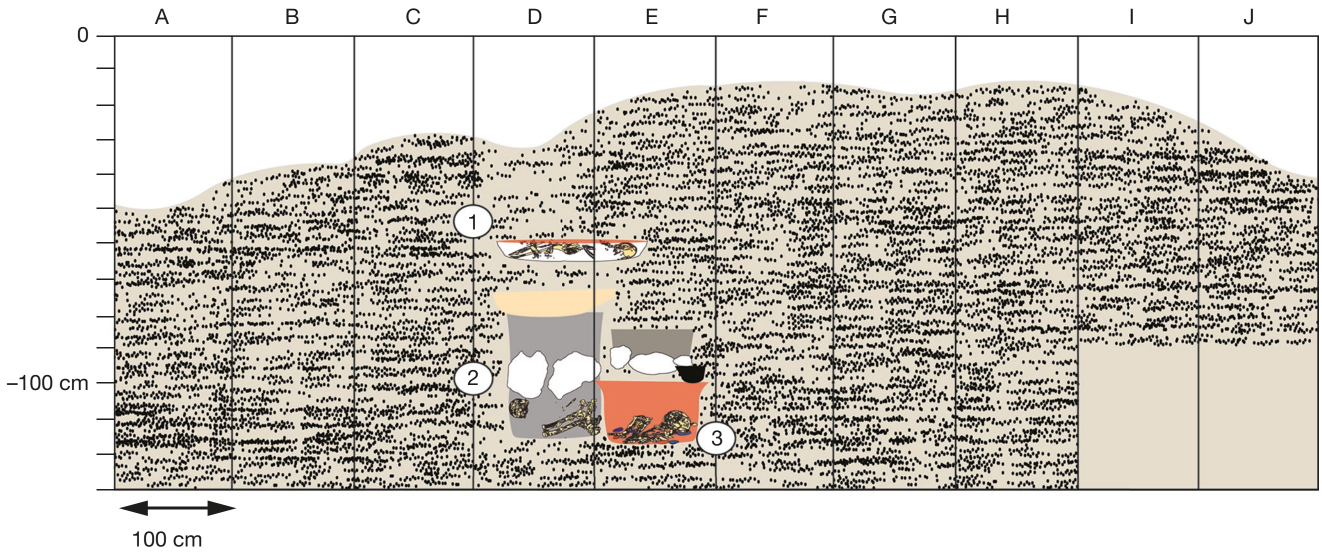

Fig. 2. — Synthetic section drawing with projection of the material for lines 4 and 5 according to the grid from square **A** to **J** including the position of the burials: **1**, burial dpk DE-5: 11 955-11 641 BC (cal); **2**, Burial dpk D-4: 12 719-12 081 BC (cal); **3**, dpk E-5: 13 169-12 462 BC (cal) according to Zeitoun *et al.* 2019.

no distinctive layer can be identified during the excavation (Fig. 2). Moreover, the deposits have been locally (Fig. 2 squares D and E) disturbed by the excavation and refilling of graves. Given that the excavation is not yet complete (only 1.3 m of the stratigraphic sequence has been explored only in relation to a total depth of several meters still at work), it is currently impossible to definitively determine the precise age of the associated lithic material and fauna. However, it is more plausible that this material is primarily older than the age attributed to the graves, as it is included in the sediments excavated to place the graves.

The Thai-French Paleolithic Mission (MEAE) conducted detailed excavations from 2011 to 2019, meticulously recording the three-dimensional position of all artifacts exceeding 1 cm in length in any dimension. Smaller objects were collected by sieving the sediments in a volume of 5 cm thickness for each 1m² square. Up to the current stage of the excavation the site has yielded a total of 19 478 lithic objects (including all the debris and fragments like perforated stones or pieces of raw material including ochre) and 100 851 faunal remains, the average density of material was high, with 7 290 objects per m3 over the currently excavated area of 65 m². However, the excavation and subsequent analysis processes have been temporarily halted due to the COVID-19 pandemic. This interruption means that the total of 19 478 lithic objects, which encompasses the most recently discovered items, has not yet undergone complete analysis due to the constraints imposed by the pandemic.

The chronology of occupations at Doi Pha Kan aligns it with the transition from the Pleistocene to the Holocene (roughly 13 300 to 12 800 calBP, based on calibration in ChronoModel software, using intcal20.14c) (Table 1), a period distinguished by unstable climatic conditions. Nevertheless, there is a paucity of paleoenvironmental data from 17 000 to 10 500 calBP, or the period spanning the end of the Last Glacial Maximum and the onset of the early Holocene (Cook & Jones 2012). Numerous models point to a predominantly cold, dry global climate subject to regional variations, and a winter monsoon regime from approximately 25 000 to 17 000 BP (Fig. 3). Around 10 500 BP, the climate shifted towards warmth and humidity, governed by a summer monsoon pattern (Fig. 4). However, these models are challenged by the lack of spatial-temporal resolution, and contradictions in the results obtained by different proxies, especially for Northern Thailand, where data scarcity is a significant issue.

Although several reservations have been expressed about the robustness of the proxies or tools used to reconstruct the evolution of the impact of global climate change in the tropics (Zeitoun *et al.* 2023) from the data provided by available proxies, that due to both latitude and altitude, northern and southern Thailand were likely subject to distinct paleoenvironmental changes (White *et al.* 2004; Marwick & Gagan 2011; Marwick 2013; ; Chabangborn 2014; Chawchai 2014; Suraprasit *et al.* 2021; Shoocongdej & Wattanapituksakul 2020). Furthermore, since the beginning of the early Holocene, there would appear to be a consensus between almost all proxy types indicating a steady increase in rainfall across Thailand (Suraprasit *et al.* 2024).

THE LITHIC MATERIAL OF DOI PHA KAN

Technological, petrographic and geometric morphometric characteristics

In this study, we applied a technological, geometric morphometric, and structural analysis to the lithic material found at Doi Pha Kan (White & Thomas 1972; Aschero 1975; Oswalt 1976; Dauvois 1976; Tixier *et al.* 1980; Lepot 1993; Inizan *et al.* 1995; Boëda 2001; Bonilauri & Lourdeau 2023). This approach allowed us to examine the tools from a systemic perspective, identifying active cutting (retouched) parts or what we refer to as techno-functional units (UTFs) (see Lepot

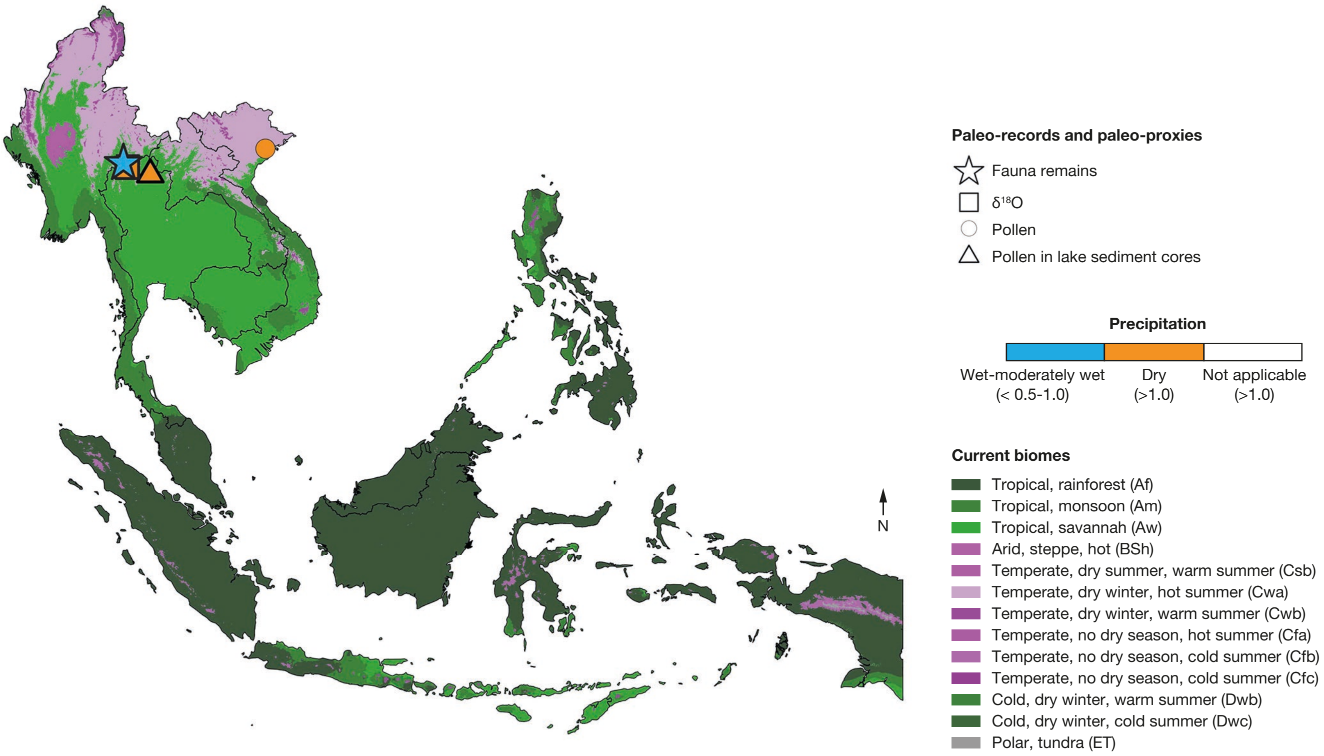

FIG. 3. — Paleo-records and paleo-proxies available in Thailand during Late Pleistocene (between 19000 and 17000 cal BP) (White *et al.* 2004; Marwick & Gagan 2011; Marwick 2013; Chabangborn 2014; Chawchai 2014; Shoocongdej & Wattanapituksakul 2020; Suraprasit *et al.* 2021). Base map: Köppen-Geiger climate classification of Southeast Asia (Beck *et al.* 2018).

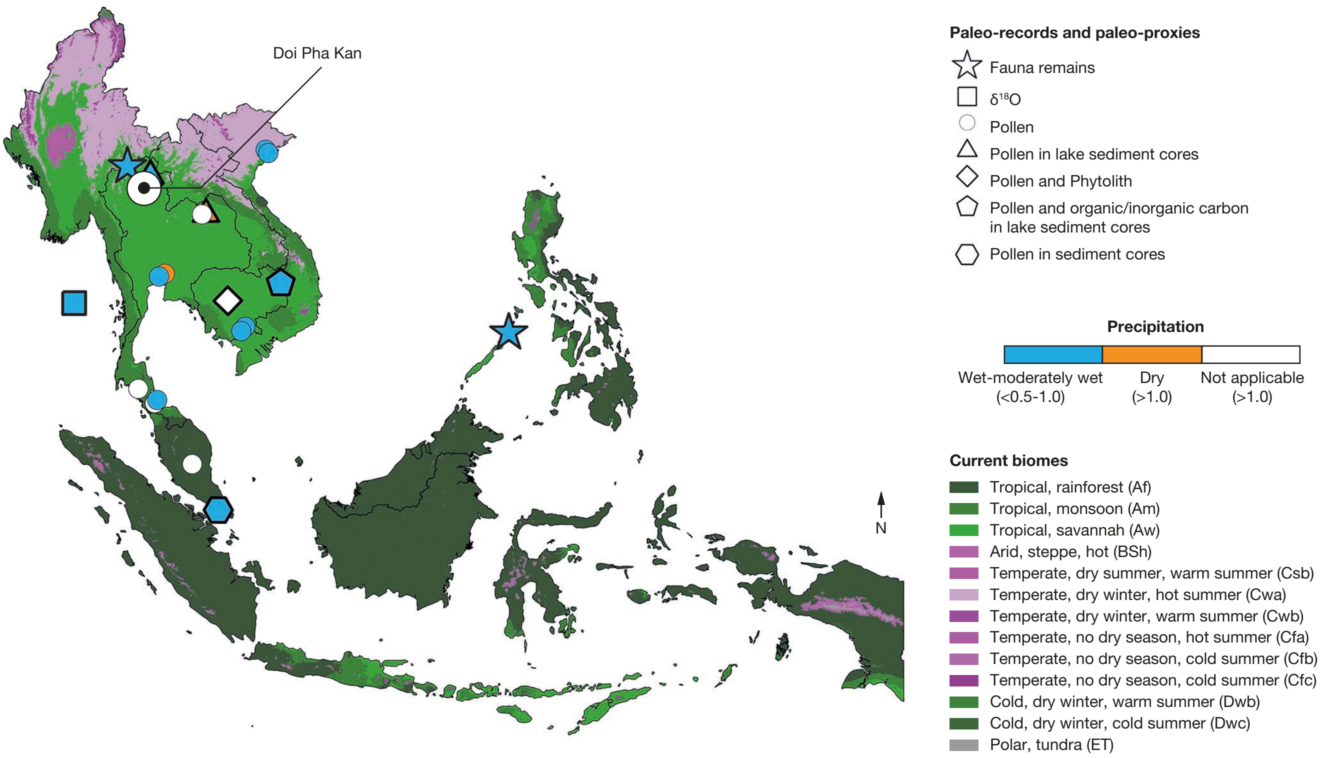

FIG. 4. — Paleo-records and paleo-proxies available in Thailand during Early Holocene (between 10500 and 8000 calBP. (White *et al.* 2004; Chabangborn 2014; Chawchai 2014; Ochoa *et al.* 2014; Shoocongdej & Wattanapituksakul 2020). Base map: Köppen-Geiger climate classification of Southeast Asia (Beck *et al.* 2018).

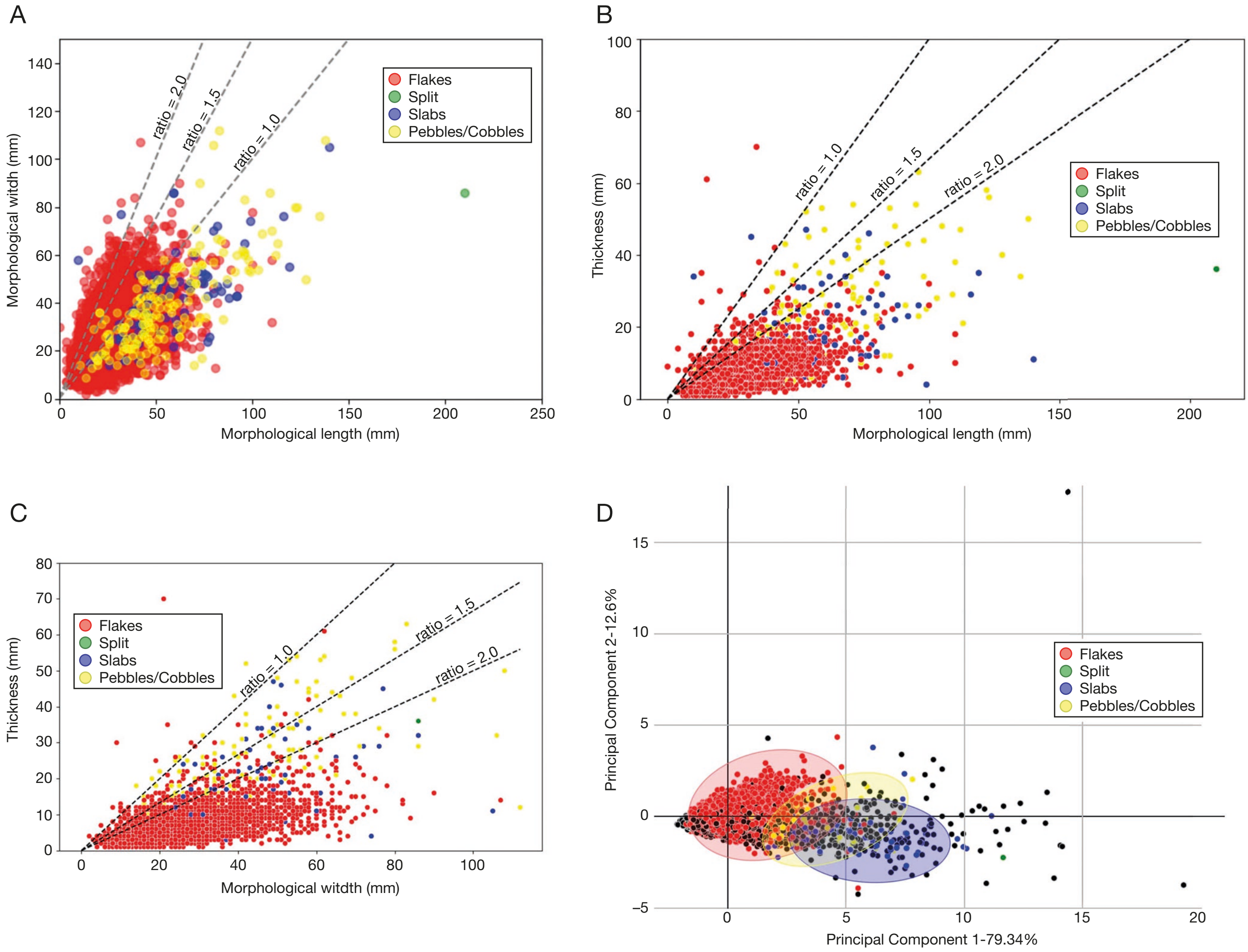

FIG. 5. — Biplots of morphological length, width, thickness: **A**, elongation (length/width); **B**, fineness index (length/width); **C**, fineness index (width/thickness); **D**, principal component analysis (PCA) of the different blank types.

TABLE 2. — Assemblage analyzed from the Doi Pha Kan site, categorized by their technological classification and raw material.

Type	Siliceous rock	Limestone	Sandstone	Quartz/Quartzite	Volcanic stones	Total
Flakes	913	5621	1408	91	14	8047
Manuports	3	55	27	8	2	95
Fragment/debris	147	2193	282	105	3	2730
Cores	10	14	2	–	–	26
Flake tools	25	104	29	3	1	162
Slab tools	25	121	29	1	1	177
Cobble tools	6	26	16	2	6	56
Others	1	44	27	–	1	73
Total	1130	8178	1820	210	28	11366

1993; Boëda 2001). This reading of the lithic assemblage was combined with the production of 3D models of the slab tools. In addition, an automated geometric morphometric analysis was applied to the 3D models using the AGMT-3D software (Herzlinger & Grosman 2018) for statistical shape analysis. The models were created using a Shining – EinScan SP V2 3D scanner, ensuring a measurement accuracy of 0.05 mm at a single point. The geometric morphometric approach has been increasingly used in the analysis of bifacial pieces (Herzlinger *et al.* 2017; Archer *et al.* 2018; Weiss *et al.* 2018). AGMT-3D automatically acquires data from a grid consisting of 50 meridians and 50 parallels, totaling 2 500 semi-landmarks on each surface. After a semi-automatic orientation of the pieces, the analysis involves a Generalized Procrustes Analysis (GPA) to

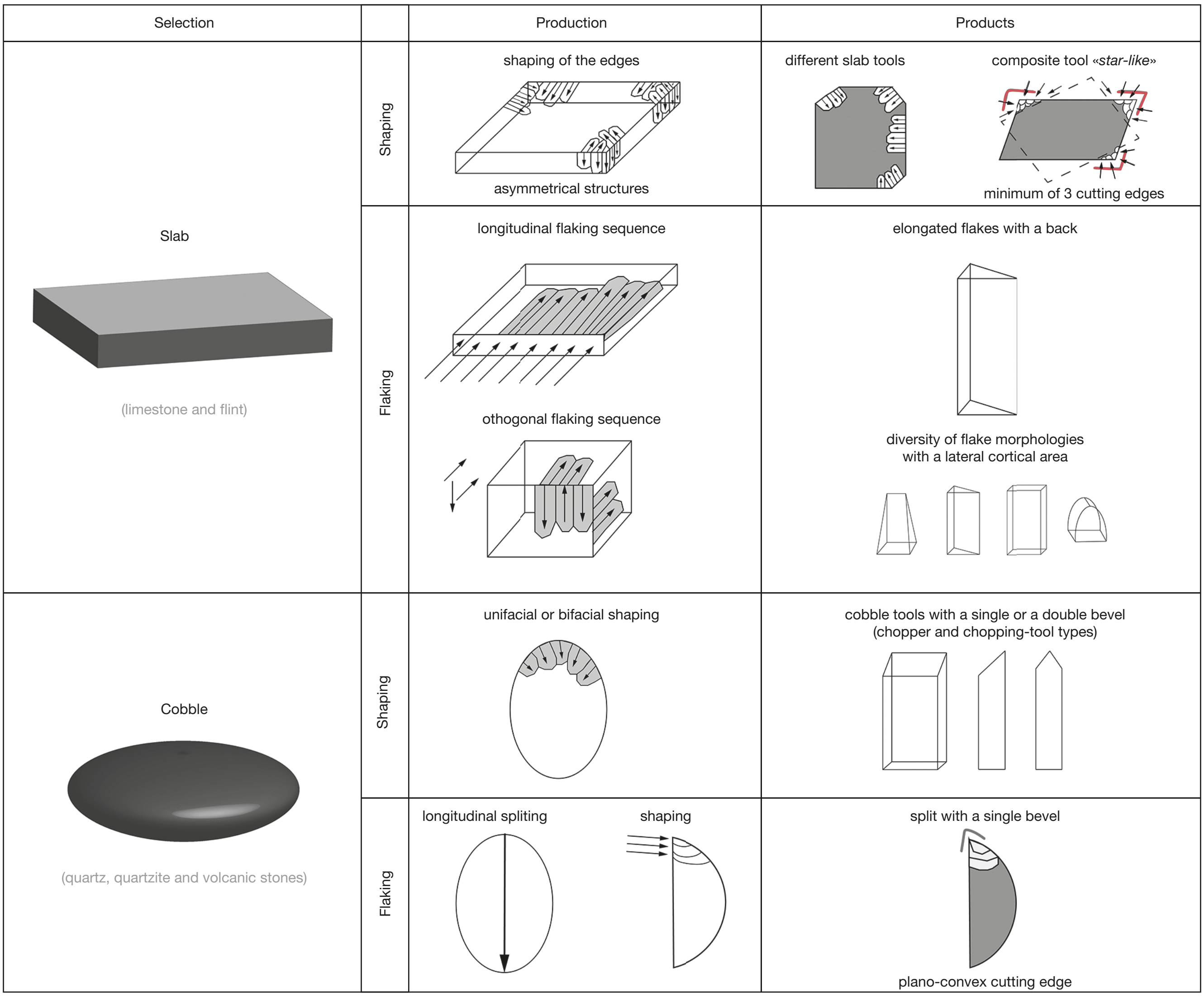

Fig. 6. — Scheme of the different lithic production operational modes at the Doi Pha Kan rock shelter.

normalize the variables of location, orientation, and scale, followed by principal component analysis (PCA). The PCA results, particularly the first two principal components, are visually represented in a two-dimensional scatter plot, accompanied by a detailed report on the absolute and relative variability of all components. A significant feature of AGMT-3D is the warp tool, which illustrates the shape differences indicated by each principal component relative to a hypothetical median shape. The software categorizes objects into groups based on attributes, facilitating the comparison of their variability and differences in mean shapes between categories. In this study, the objective is to test whether there is internal variability within the slab tools and to determine if, at the 3D level, the concept of the star tool is significantly different in geometric structure and silhouette from the other slab tools. The objects (n = 32) are color-coded by attribute in the scatter plot, with confidence ellipses and centroids for each group or convex hulls. The assembly variability panel includes tools such as a mean distance calculator and a mean shape comparison tool for statistical analysis.

For the technological study, raw material items and ochre fragments were removed from the initial 19 478 lithic objects.

From the 11 366 lithic objects available for this study, an initial classification of the assemblage allows us to distinguish the different technological categories and their proportions. The table above presents these various technological categories, organized by raw materials (Table 2). This provides insights into several aspects, such as: the significant predominance of flakes in the series, largely derived from the shaping of siliceous rock slabs (Fig. 6); the presence of numerous debris and fragments of slabs or pebbles/cobbles; a limited number of cores relative to the quantity of products (Fig. 7); approximately equal proportions of tools made from flakes and slabs; a few pebble/cobble tools, primarily of the simple bevel type such as choppers and chopping-tools; and finally, pieces classified as manuports, which include tested pebbles and blocks, hammerstones, and mortars or grindstones found at the site.

From a petrographic viewpoint, the primary raw material is a green limestone that displays internal variability, as it can be more or less siliceous. This material is present at the

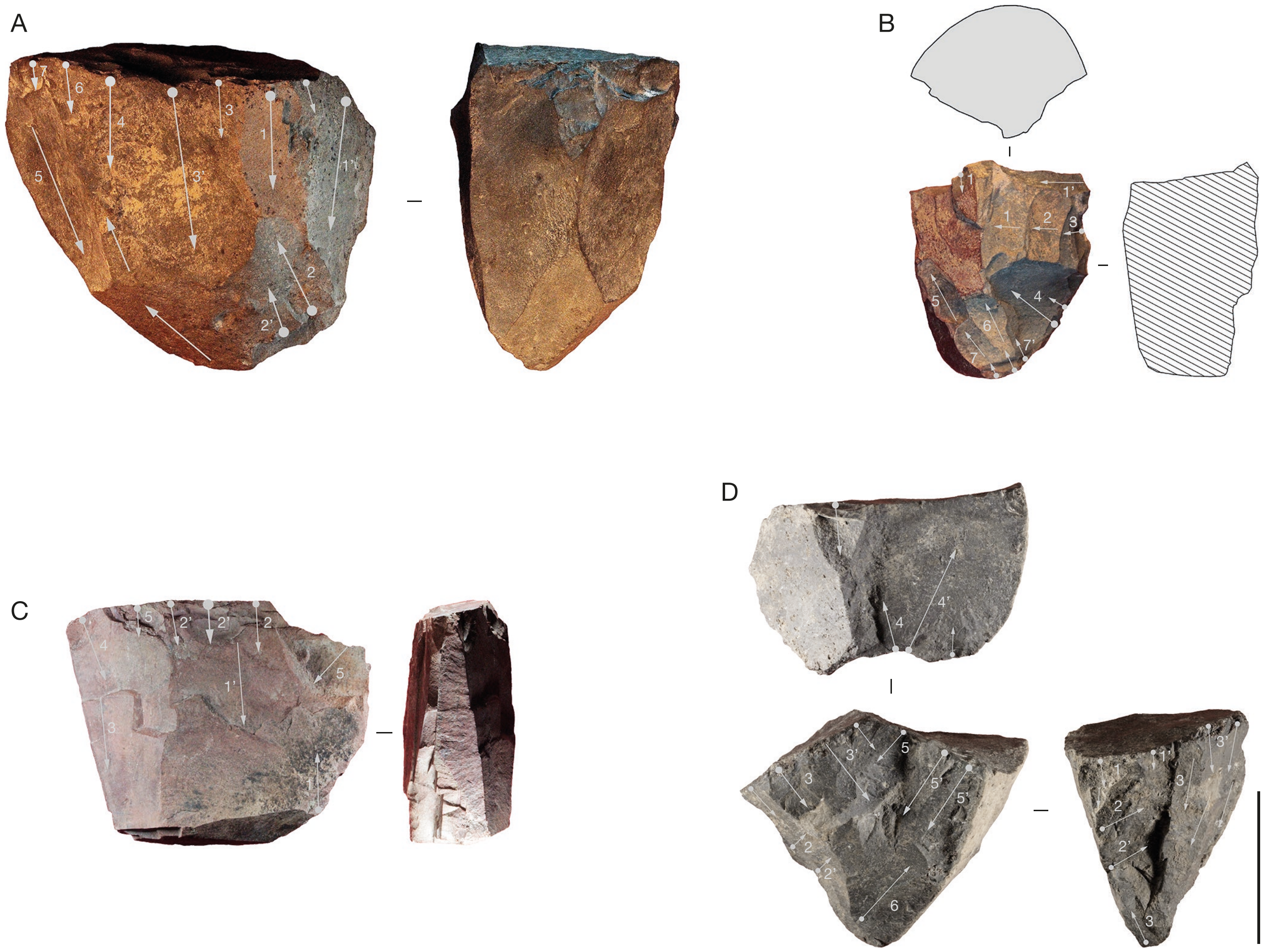

Fig. 7. — Dynamic sketch of siliceous limestone cores with orthogonal and unipolar flaking from Doi Pha Kan (arrows indicate the direction of removal): **A**, D3 no. 306; **B**, D5 no. 281; **C**, B6 no. 1766; **D**, A4 no. 1867. Scale bar: 5 cm.

Ban Tha Si site outcrop and appears as natural quadrangular slabs in the local limestone. Sandstones, which also exhibit more or less grainy aspects, are well represented by numerous flakes. Additionally, siliceous materials have been extensively exploited, especially for crafting tools on flakes or slabs. Finally, the lithological spectrum is rounded out with elements of quartz and quartzite in the form of pebbles, as well as volcanic rocks mainly procured locally from limestone outcrops especially slabs at the foot of cliffs or cobbles/pebbles from the alluvial deposits of the nearby Mae Dam or Mae Mo rivers which is consistent with the geological setting of Mae Moh district and Lampang province more generally.

Basic morphometric analyses (length, maximum width, and maximum thickness) reveal significant variability, both within and among object categories. The standard deviation is also quite high in many cases, indicating substantial variability in measurements within each object category. However, the length/width ratio that predominates in all the data is 1.0 (n = 7701, 68.27%). This suggests that the majority of objects have similar lengths and widths, and are therefore approximately square or circular in shape. Furthermore, most objects have a length of less than 40 mm, with the <20 mm and 20-40 mm groups together accounting for nearly 87.5% of all objects. Objects with a length of more than 60 mm are quite rare, representing less than 4% of the total.

Regarding blanks (flakes, splits, slabs, pebbles/cobbles), the elongation index (length/maximum width), the fineness index 1 (length/maximum thickness), and the fineness index 2 (maximum width/maximum thickness) (Fig. 5) indicate a similar behavior among the four different types of blank in terms of length and width, but not in terms of thickness. Theses indexes are especially useful for comparing sets of tools between different sites or within the same site (here) but in different strata or cultural levels. By identifying patterns in these indexes, we can infer changes in manufacturing strategies, adaptations to different environments or resources, or even cultural contacts that may have influenced lithic technologies.

To assess this differentiated behavior and explore morphological trends, we conducted a PCA considering the length, width, and thickness of all the blanks (Fig. 5D). The weightings of the variables in the first two principal components are as follows: principal component 1 (PC1): 0.586 for length, 0.560 for width, and 0.586 for thickness.

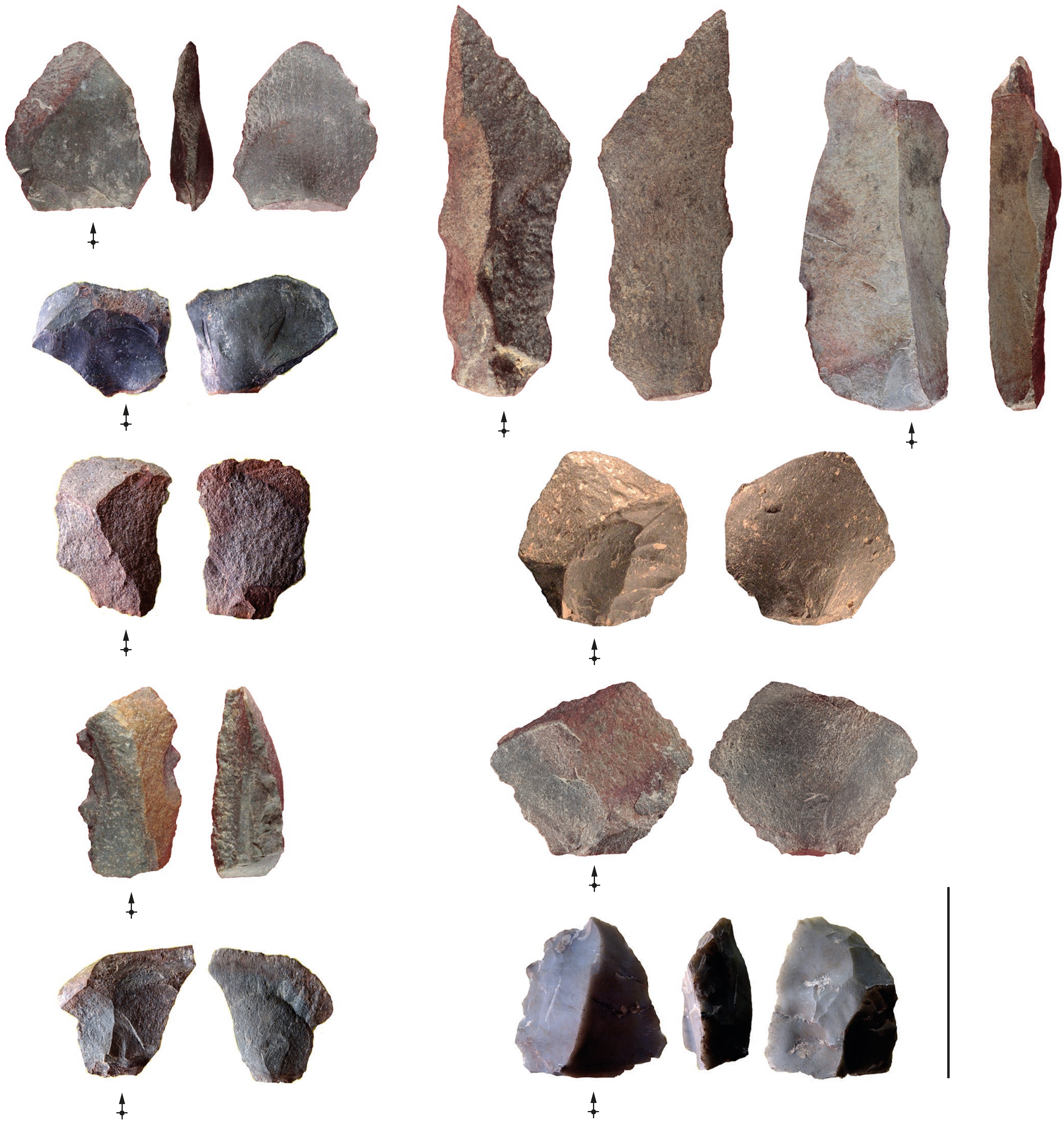

Fig. 8. — Illustration of the morphological diversity of flakes produced by the production operational modes. Scale bar: 5 cm.

Principal component 2 (PC2): –0.394 for length, 0.828 for width, and –0.398 for thickness. PC1, exhibiting similar weights for length, width, and thickness, encapsulates the variation in the overall size of the pieces. This implies that pieces which are large in one dimension, such as length, are likely to be large in the other dimensions, namely width and thickness, and the same correlation applies for smaller pieces. PC2, on the other hand, with a high weight for width and negative weights for length and thickness, captures the variation in the shape of the pieces.

The variance explained by the first two principal components is as follows: PC1: 79.3%. PC2: 12.3%. Together, these two principal components capture approximately 91.6% of the total variability of the entire data set. This means that nearly 80% of the variation in the data can be attributed to differences in the size of the pieces.

Based on the knapping scars (removals), a technique seems to have been preferentially used for the flaking and shaping of the lithic objects of Doi Pha Kan, namely direct percussion with hard stone. This technique is sometimes associated

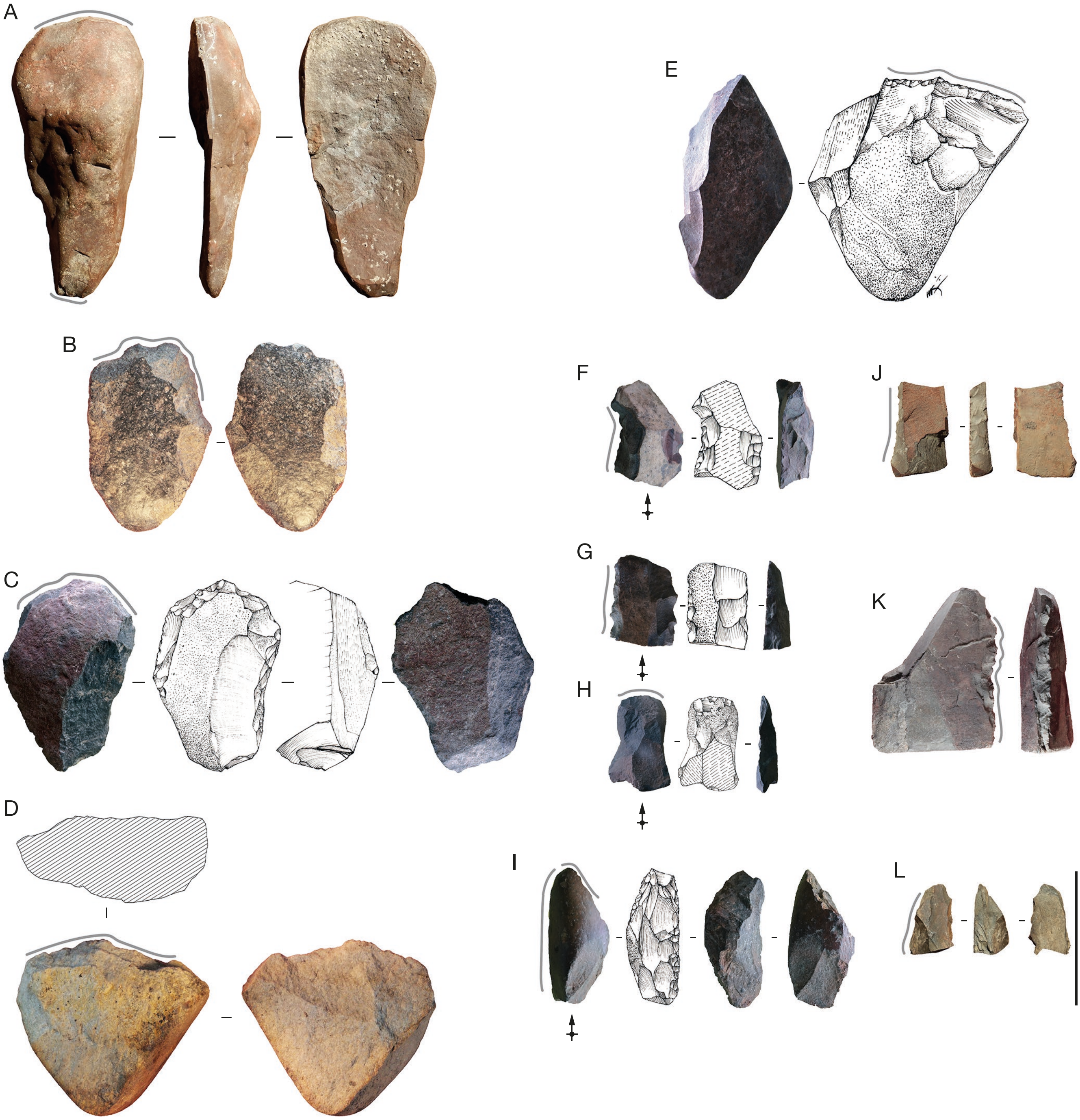

FIG. 9. — Illustration of the toolkit diversity from Doi Pha Kan: **A**, lateral tool on split, H6 no. 703; **B**, Hoabinhian uniface tool, G3 no. 23; **C**-**E**, Pebble/cobble tools: **C**, D4 no. 114; **D**, C6 no. 164; **E**, D7 no. 404; **F**-**H**, flake tools: **F**, D7 no. 5; **G**, D7 no. 110; **H**, E6 no. 124; **I**, Limace, E6 no. 34; **J**-**L**, slab tools: **J**, SURF no. 2; **K**, A4 no. 1475; **L**, H7 no. 1330. The continuous grey lines on each object designate the potential transformative techno-functional unit, or UTFt. Scale bar: 10 cm.

TABLE 3. — Different types of tools from the Doi Pha Kan rock shelter by raw materials.

Type	Siliceous rock	Limestone	Sandstone	Quartz/Quartzite	Volcanic stones	Total
Flake tools	25	104	29	3	1	162
Slab tools	25	121	29	1	1	177
Cobble tools	6	26	16	2	6	56
Total	56	251	74	6	8	395

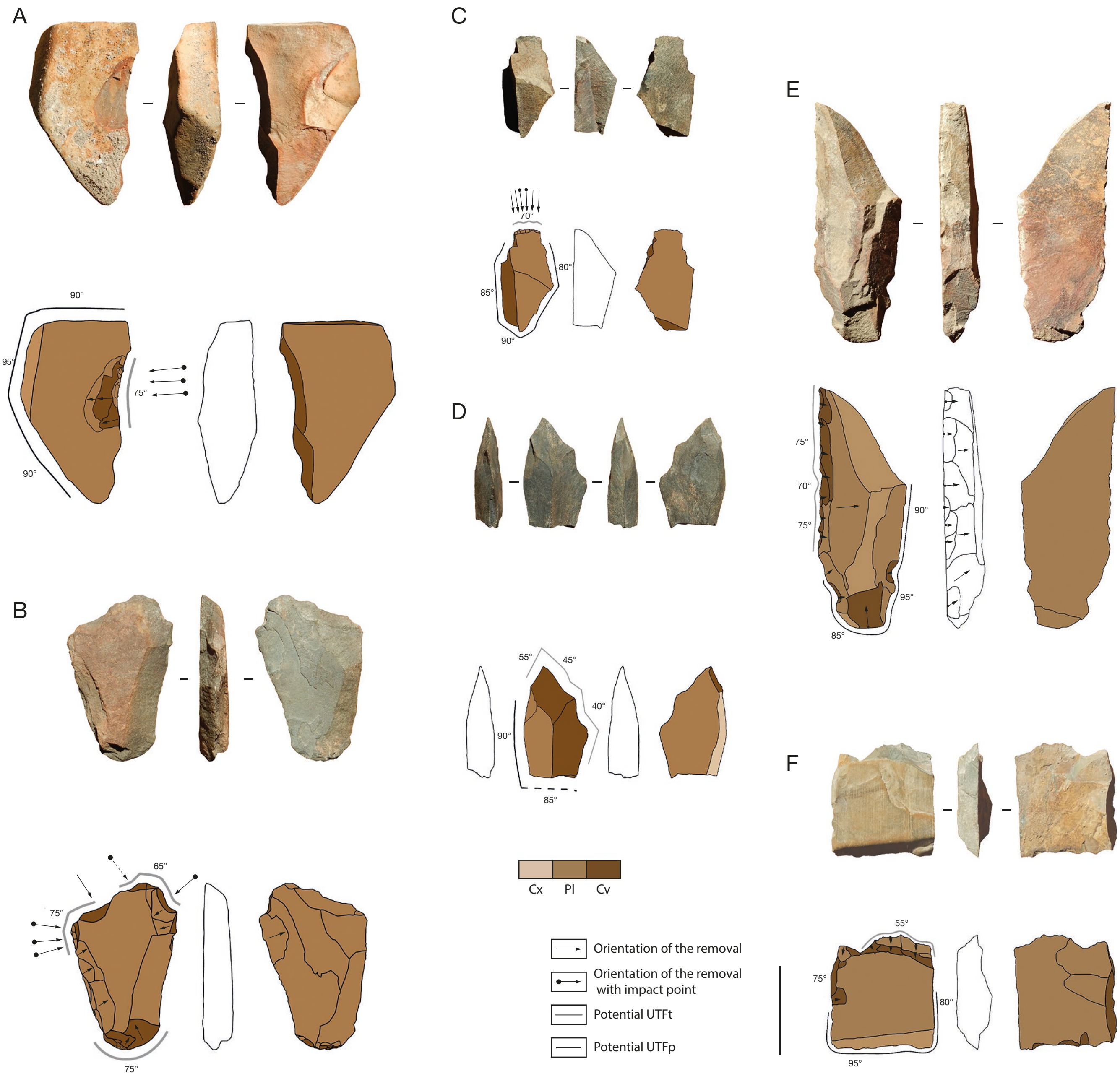

FIG. 10. — Pictures and morpho-structural schemes of several slab tools from Doi Pha Kan: **A**, C7 no. 1371; **B**, H5 no. 725; **C**, C7 no. 1559; **D**, H5 no. 643; **E**, C8 no. 1123; **F**, C8 no. 930. The continuous **black** and **grey lines** on each object designate the potential transformative (**UTFt**) and prehensile techno-functional (**UTFp**) units. Abbreviations: **Cv**, concave; **Cx**, convexe; **Pl**, plan.Scale bar: 5 cm.

with bipolar-on-anvil percussion to fracture/split the slabs and pebbles/cobbles.

The lithic assemblage testifies to five main production reduction sequences (Fig. 6) that differ according to the type of selected raw material. In this regard, siliceous slabs are exploited following three reduction modes:

– the production of tools made on slabs (cf. scrapers, planes, denticulates, beaks, and "stars", the latter representing 7.9% of a total of 177 slab tools) is achieved through an asymmetrical modification of the initial volume, which facilitates the production of multiple cutting edge around the volume;

– longitudinal flaking of elongated flakes with a back (Fig. 8) is used for crafting backed knife-type tools;

– orthogonal flaking on more quadrangular slabs enables the production of small flake tools (cortical and semi-cortical), exhibiting a high degree of morphometric variability.

In addition to these, pebbles/cobbles composed of granular rocks (such as quartz, quartzite, sandstone, and volcanic rocks) are exploited following two reduction modes:

– the shaping of ovoid pebbles, using a uni- or bifacial shaping in the transverse part, allows for the creation of macro-tools on pebbles with either a single or double bevel, such as chopper/chopping-tool types;

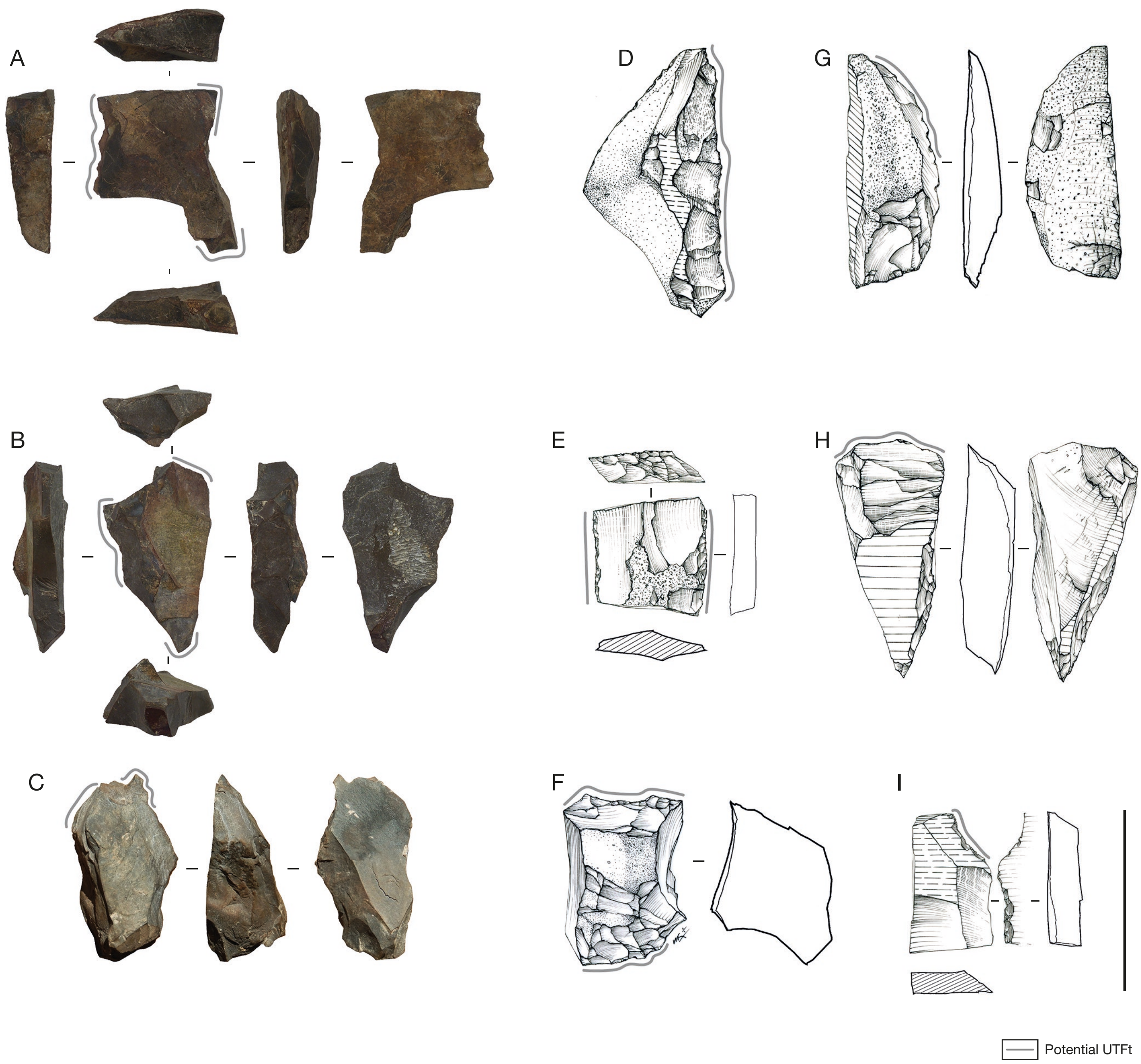

Fig. 11. — Some original slab tools from Doi Pha Kan: **A**, **B**, composite tools (star-like): **A**, A4 no. 833; **B**, B3 no.521; **C**, composite tool (micro-rostrum), H7, no. 1283; **D**, **G**, backed knives with lateral cutting edge: **D**, C3 no. 1021; **G**, H6 no. 602; **E**, **F**, double composite tool: **E**, C3 no 286; **F**, H5 no. 229; **H**, tool with transverse cutting edge, H6 no. 1063; **I**, tool with denticulated lateral cutting edge, A6 no. 3. The continuous grey lines on each object designate the potential transformative techno-functional unit (**UTFt**). Scale bar: 10 cm.

– the longitudinal fracturing of rather oblong pebbles into two half longitudinal pebble or "splits" results in blanks with a plano-convex cutting dihedral (as shown in Figures 3; 6).

The lithic tools of Doi Pha Kan

From the five identified reduction sequences in the lithic industry of Doi Pha Kan, the four types of material used (flakes, splits, slabs, and pebbles/cobbles) correspond to and explain the diversity of tools (Table 3). We find the classic macro-tools on pebbles (such as chopper and chopping-tool types) made from quartz, quartzite, or sandstone pebbles with a single "classic" Hoabinhian uniface (Fig. 9B).

The longitudinal fracturing of pebbles into splits, producing hemi-pebbles with a plano-convex cross-section, also recalls the Hoabinhian tool blanks. On these split blanks, single-bevel edges are created with unifacially removals.

The flaking of slabs in siliceous rocks is carried out by longitudinally and orthogonally oriented knapping, which allows the production of longitudinally knapped flakes and orthogonally knapped flakes of variable morphometry.

These elongated flakes are the bases of original tools with denticulate or straight lateral edges opposed to a cortical or semi-cortical back, similar to backed knives. The other flakes of variable morphometry, in turn, serve as the bases of tools of scraper, denticulate, notch, limace, or beak types.

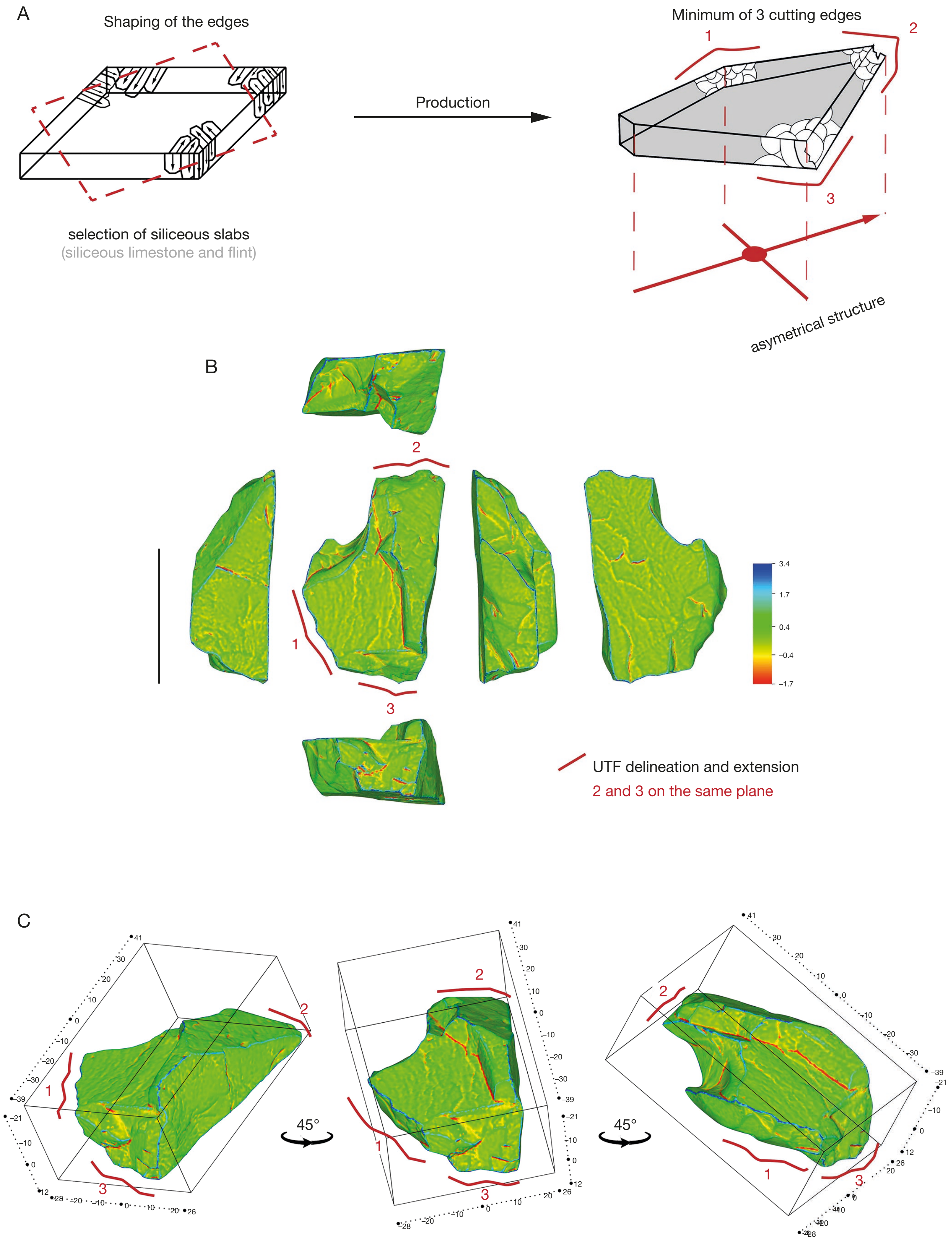

FIG. 12. — Synthesis scheme of the volumetric design of a composite tool "star-like" at Doi Pha Kan: **A**, the **dotted red rectangle** corresponds to the initial volume of the slab); **B**, 2D orthogonal projection of an example composite tool; **C**, 3D projection of an example composite tool. Scale bar: B, 5 cm.

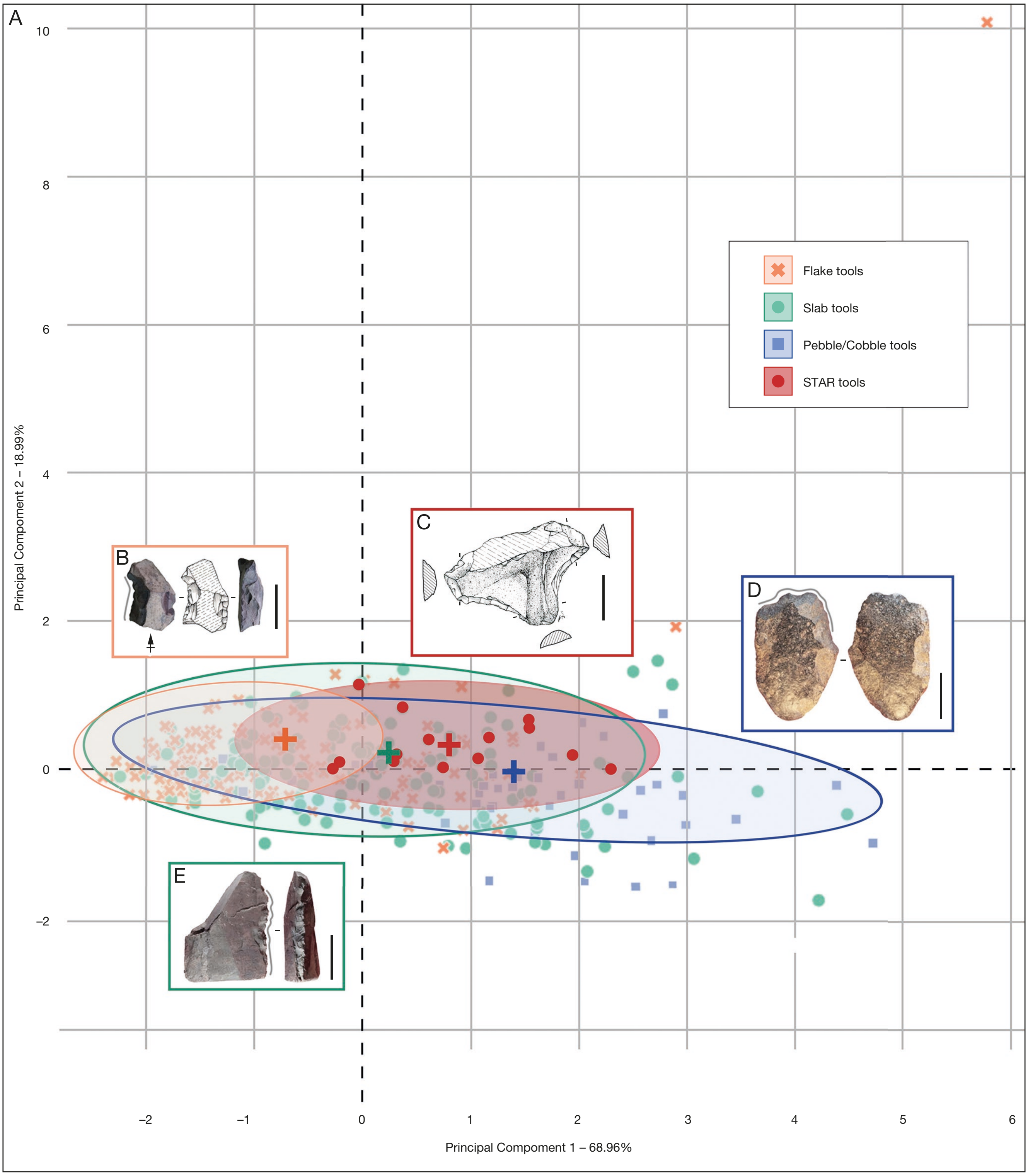

Fig. 13. — Principal component analysis (**PCA**) biplot of morphological length, width, and thickness of the different tool types in DPK assemblage: **A**, 95% confidence ellipses are plotted. The mean of each group in the plot are identified with crosses; **B**, flake tools; **C**, star tools; **D**, pebble/cobble tools; **E**, slab tools. Scale bars: B-E, 5 cm.

Finally, other atypical tools in a "Hoabinhian" context include pieces made from fractured slabs or raw collected ones, presenting two, three, or sometimes four modified cutting edges at their tip on the same generally flat blank. These are tools of the scraper, plane, or denticulate type, as well as asymmetrical pieces with several edges/branches that we categorize as "star tools" or composite tools, presenting a peripheral arrangement with several cutting edges. A proposal for a technical and volumetric definition of these composite tools is given below.

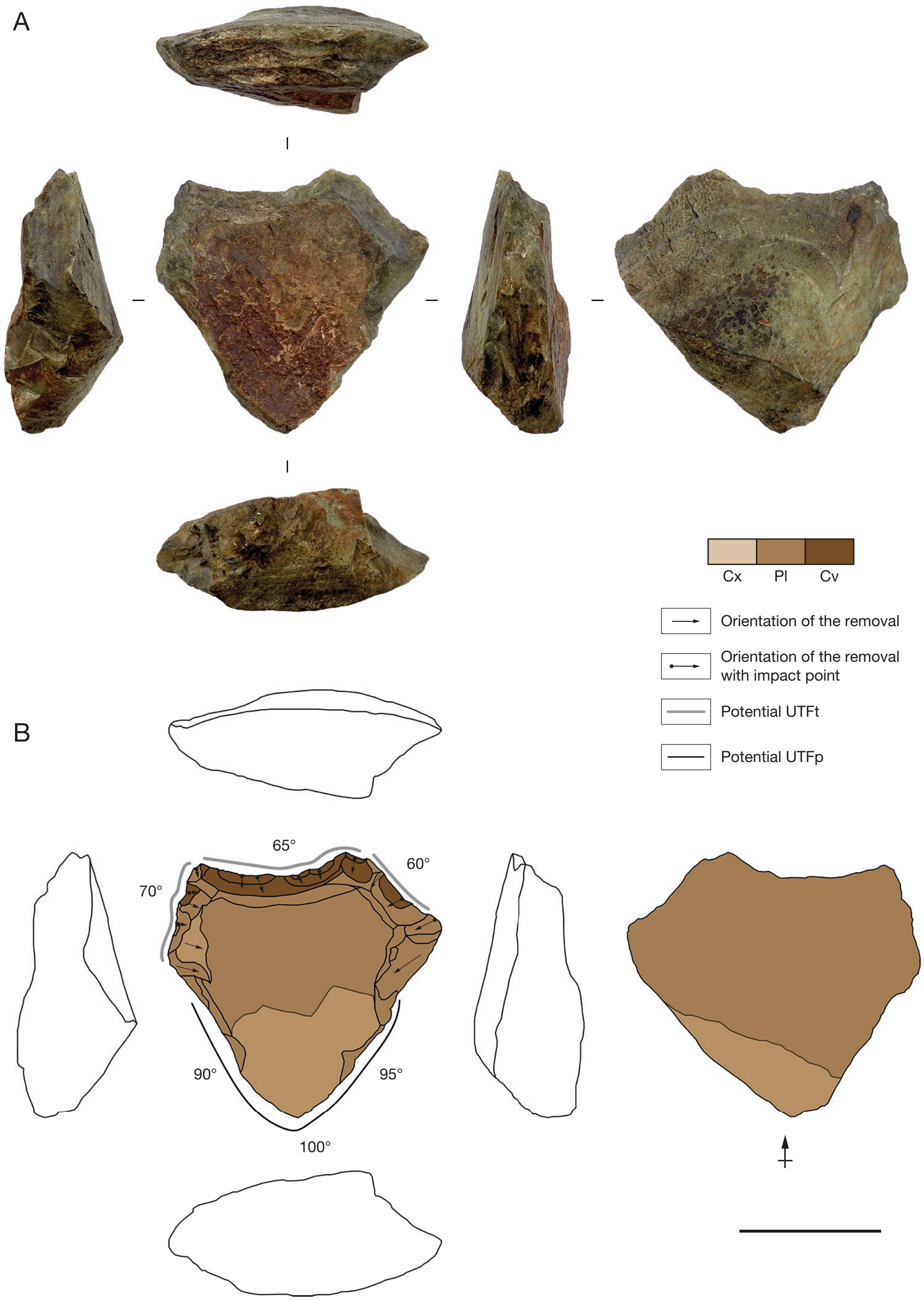

Fig. 14. — Drawings of some of the composite tools from Doi Pha Kan: **A**, photography; **B**, techno-structural scheme. Abbreviations: **Cv**, concave; **Cx**, convexe; **Pl**, plan. Scale bar: 5 cm.

THE COMPOSITE SLAB TOOLS: A NEW VOLUMETRIC CONCEPTION IN THE HOABINHIAN TOOLKIT?

Technological definition

As mentioned earlier, the lithic assemblage of the Doi Pha Kan rock shelter stands out due to the preferential selection and utilization of siliceous rock slabs, in contrast to the significant modification of pebbles/cobbles commonly found in known Hoabinhian assemblages in the region (see Forestier *et al.* 2022). This focused investment in slabs has resulted in a diverse range of tools including scrapers, planes, and denticulates. Particularly notable are 14 asymmetrical tools with multiple cutting edges that vaguely resemble a "star" in their shape (Figs 11; 14; 15). According to our review of the literature this type of tool conception is unprecedented in contemporary or sub-contemporary sites in the area. These unique composite slab tools "star-like" constitute a distinct lithic component specific to Doi Pha Kan, expanding upon the conventional repertoire of modified pebbles/cobbles observed in Hoabinhian sites in Northern Thailand and Southeast Asia at large. The distinguishing

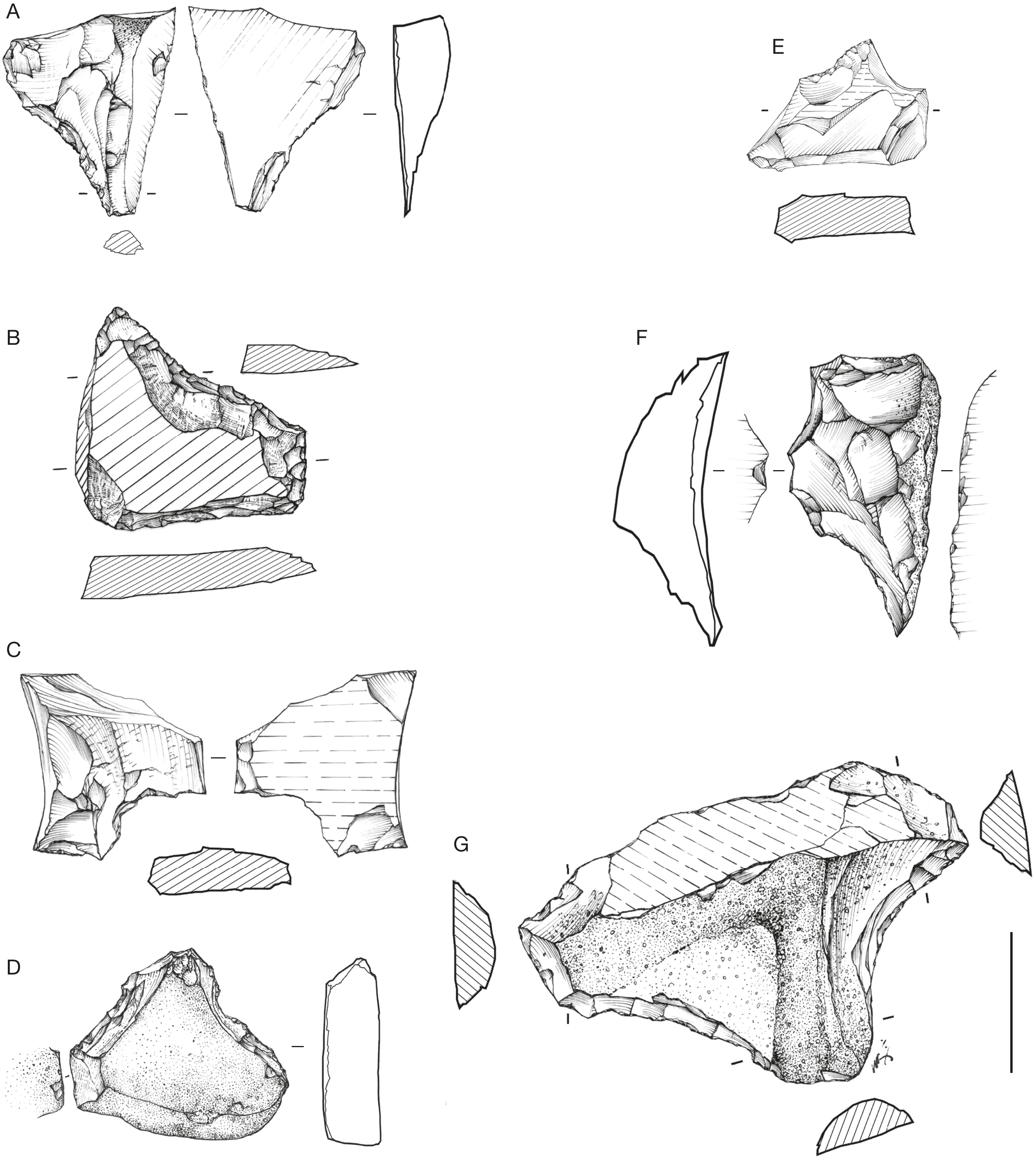

Fig. 15. — Photography and morpho-structural scheme of a composite tool "star-like" from Doi Pha Kan: **A**, F6 no. 931; **B**, G4 no. 228; **C**, C8 no. 764; **D**, A4 no. 1781; **E**, B3 no. 521; **F**, H6 no. 571; **G**, A4 no. 858. The continuous **black** and **grey lines** on each object designate the potential transformative (**UTFt**) and prehensile techno-functional (**UTFp**) units. Scale bar: 5 cm.

feature of these quadrilateral or trapezoid-shaped unifacial or bifacial pieces is their possession of three to four distinct and contiguous active parts on a single blank. These active parts can include consecutive sharp cutting edges, linear convex or concave cutting edges (such as scrapers or denticulates) (Figs 14; 15).

These previously unknown tools are composite pieces with heterogeneous and complementary active parts, prompting questions regarding their multifunctional nature compared to other tools commonly found within the Hoabinhian toolkit.

Drawing from these observations and the technological analysis of the 14 composite tools or "star-like" from Doi

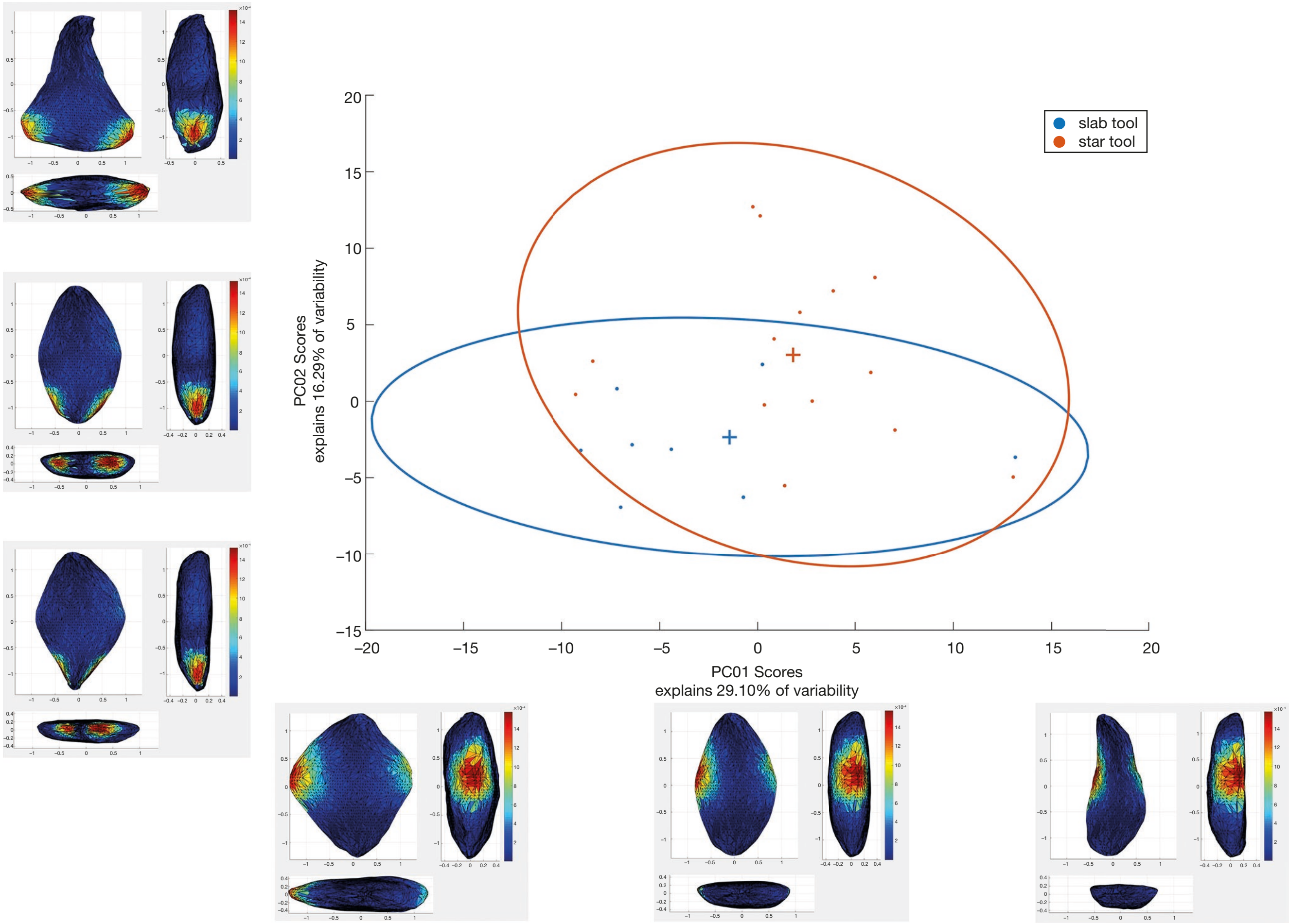

FIG. 16. — Geometric morphometrics: Principal Component Analysis (**PCA**) on slab 3D models by type. Illustrations show hypothetical objects situated at the extremities of each principal component, reflecting the shape trend it represents. The percentages represent the proportion of variability for which it accounts. Ellipsoids reflect 95% confidence ellipsoids.

Pha Kan, we propose the following definition: "asymmetrical blanks on raw or fractured slabs featuring at least three edges/branches created through direct or inverse retouching or alternating episodes. The retouch is mainly "scalariforme" and abrupt. Tools that meet these structural and volumetric criteria possess independent and complementary active parts at each of their peripheral ends" (Fig. 12).

Following this definition, we expect that other authors will be able to recognize such tool conceptions elsewhere in the region to identify a possible chronological or geographical extension. To resume, these composite tools represent a category of artifact identified within the Hoabinhian archaeological context that is characterized by: having multiple actives edges (>3), which resemble the points of a "star"; being made from slab-like raw materials with a flat and generally quadrangular shape. Denticulates, on the other hand, are typically characterized by: a toothed or serrated edge, which is a result of a series of notches or "teeth" along a stone tool's working edge. The difference between composite tools and denticulates is in the overall shape and the number of working edges. Composite tools have a more complex shape with multiple edges that radiate outward, whereas denticulates have a singular focus on the toothed edge. This new volumetric conception makes it possible to represent a novel conceptual approach to toolmaking during the Hoabinhian period in Northern Thailand.

The conducted PCA (Fig. 13) confirms the morphometric consistency between the blanks and the tools, demonstrating a homogeneity in the tool material. Additionally, it reveals the distinctive morphometric characteristics of the slabs, which serve as intermediate blanks between flakes and pebbles/cobbles, and explains their preferential use as blanks for specific tool types, including the composite tools "star-like". These particular tools, with multiple edges/branches (>3) are the most original tool at the Doi Pha Kan assemblage and they are unparalleled in other contemporary sites across MSEA.

Testing through 3D geometric morphometrics

The 3D geometric morphometric analysis was conducted using AGMT3-D software on the 32 3D models from our sample. The PCA revealed morphological criteria with an intermediate level of discrimination: the first two principal components explained 45.34% of the overall shape variability. The main axis of variation corresponds to a deformation of the lateral edges (PC1) and a deformation of the base (PC2),

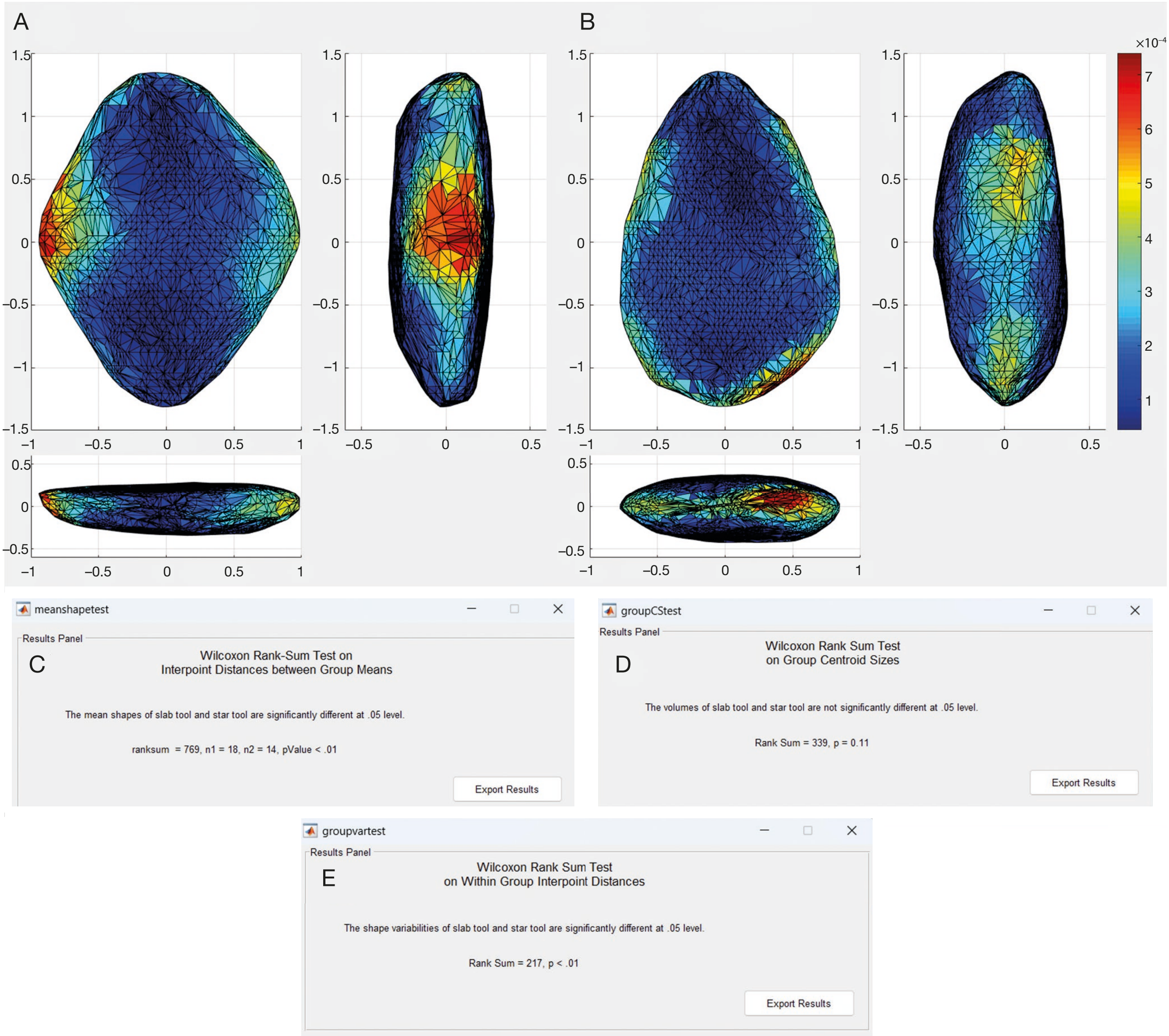

FIG. 17. — Mean shapes differences between slab and star tools: **A**, mean shape of slab tools; **B**, mean shape of star tools; **C**, Wilcoxon Rank-Sum Test on Interpoint Distances between Group Means; **D**, Wilcoxon Rank-Sum Test on Group Centroid Sizes; **E**, Wilcoxon Rank-Sum Test on Within Group Interpoint Distances.

primarily in frontal view, as well as an expansion/thinning of the base and the mesial part in profile view (PC1 and PC2; Fig. 16). The comparison of the "type" attribute (whether a slab or a star tool) in relation to the three-dimensional space revealed by the PCA clearly shows a difference between the two groups (Fig. 16).

To test whether this variability is statistically significant, we conducted three Wilcoxon Rank-Sum Tests. The first one, on Interpoint Distances between Group Means (Fig. 17C), indicates that there is a significant difference between the mean shapes of slab and star tools. Furthermore, the Wilcoxon Rank-Sum Test on Group Centroid Sizes (Fig. 17D) reveals that the volumes of both groups are not statistically different. Finally, the Wilcoxon Rank-Sum Test on Within Group Interpoint Distances (Fig. 17E) shows that shape variabilities in slab and star tools are indeed significantly different. All of this indicates that while both groups share the same volume (slab 3D geometry or "structure"), star tools are distinguished by the location of the UTFs.

DISCUSSION AND CONCLUSION

UNDERSTANDING THE UNIQUE CHARACTERISTICS OF LITHIC TECHNOLOGY AT DOI PHA KAN WITHIN THE HOABINHIAN CONTEXT

Given the considered chronological period (13 000 to 11 000 BP), the toolkit of Doi Pha Kan is contemporaneous and chronologically comparable to the so-called "Hoabinhian" period as known in MSEA (Gorman 1969; Pookajorn 1985; Reynolds 1989; Jérémie 1990; White & Gorman 2004; Marwick 2008; White 2011; Forestier *et al.* 2017, 2021).

However, the Doi Pha Kan assemblage diverges significantly from typical Hoabinhian assemblages in terms of reduction methods and targeted tool types, while still retaining some typo-technological fundamentals such as choppers and chopping-tools, along with rare unifacial tools with plano-convex sections. The presence of orthogonal and unipolar flaking, the production of small-sized blanks, and the preference for siliceous rock slabs distinguish Doi Pha Kan's lithic assemblage, demonstrating a typo-technological originality previously unknown in the northern regions of MSEA.

Flake or "small tools" production is a significant component of the toolkit at the Doi Pha Kan site. This is evident from the abundance of medium-sized flakes with pronounced cortex, arch-shaped morphology wider than long, and relative homogeneity within the assemblage, along with occasional overshot flakes (Fig. 8). The striking platforms, generally unrefined, consist predominantly of cortical or smooth surfaces, but linear and punctiform platforms are also present.

The dominant knapping technique at Doi Pha Kan is direct percussion with hard stone (freehand), characterized by predominantly oblique and inward motion gestures. In cases of pebble fracturing/knapping, knappers occasionally employ a bipolar-on-anvil percussion mode. The presence of orthogonally oriented cores confirms the direction of tool-blank production, which deviates from the predominantly shaping activities on oblong pebbles with plano-convex sections commonly found in Hoabinhian sites (Fig. 7). At Doi Pha Kan, knappers utilized pebbles differently, primarily focusing on choppers, sometimes chopping-tools, and to a lesser extent, splitted-cobbles (i.e., half-cobbles) (Fig. 9A).

Among the noteworthy findings at Doi Pha Kan are the composite tools "star-like" asymmetrical tools with multiple (>3) modified active edges, which are unique within the Hoabinhian context and have not been found in contemporary sites across MSEA. These tools are made from fractured or naturally sharp-edged raw slabs, with a minimum of three, or sometimes four modified active edges on a generally flat and quadrangular-shaped blank (Fig. 15).

Although the limaces, highly diagnostic flake-based tools, characterized by their thick and heavily carinated morphology, are attested in the neighboring Ban Tha Si site dating from 11 393 ± 36 to 7 047 ± 53 14C BP (Wk 29560 and Wk 29559) (Zeitoun *et al.* 2013), they are almost absent (n = 9) at Doi Pha Kan. These tools, featuring a thick back and convergent edges with abrupt retouch, are generally more present at southern Thai sites such as Moh Khiew, dated from 25 800 ± 600 to 8420 ± 90 14C BP (Tk 933 and OAEP 1292), where mixed/combined "shaping/flaking" reduction sequences are observed in Layers 2 and 3, between 11 000 and 9 000 BP (Auetrakulvit *et al.* 2012; Forestier *et al.* 2021).

Although classifying or comparing the Doi Pha Kan assemblage based on the lithic variability of a fundamentally "Hoabinhian" toolkit remains challenging, it can be placed within the group of uncommon and original "Hoabinhian" in Northern Thailand, alongside other sites such as the lithic industry of the Ban Tha Si site (11 400 to 8 000 BP) (Zeitoun *et al.* 2013). These sites seem to fit into a distinct subset within the Hoabinhian cultural tradition that displays unique features not typically associated with the majority of Hoabinhian sites. The tools and methods from Doi Pha Kan, such as the "composite tools" and specific production techniques, exemplify such uncommon and original traits within the broad spectrum of Hoabinhian technology.

Furthermore, these neighboring sites exhibit technological choices that foreshadow a typo-technological shift, with a shift away from pebbles towards lighter, composite, and specific tools made on flakes (e.g. limaces) or limestone/siliceous slabs (e.g. denticulates, notches, composite tools, etc.). Classic types of unifacial flat pebbles, which are relatively massive and thick (200-300 g), are rare. This suggests a deliberate lightening of tool blanks, with new tool morphologies represented by the composite slab tools, backed knives, and other slab-based tools such as scrapers, planes, and denticulates, possibly indicating a modern trajectory and/or the final phase of the Hoabinhian culture. The transition from heavier pebble-based tools to lighter, more diverse slab-based forms potentially could indicate a broader socio-cultural and environmental adaptation. The emergence of these tools at Doi Pha Kan might be also tied to changes in mobility patterns, resource availability, or socio-cultural dynamics, reflecting a combination of environmental, economic, and cultural factors in the Hoabinhian populations.

The analysis of lithic materials blanks and tools from Doi Pha Kan challenges the traditional understanding of the Hoabinhian toolkit, possibly suggesting a distinct population within the Hoabinhian world (Zeitoun *et al.* 2019), as described based on archaeothanatological and anthropobiological data and associated materials found in burials (perforated stones, partially polished axes). To confirm this hypothesis and facilitate qualitative and quantitative comparisons, it will be necessary to seek and excavate similar sites in the years to come or at least review the already known lithic assemblages and look for this type of newly described conception of tools.

Focusing on the archaeological sites in Vietnam related to the Hoabinhian culture, with a timeline post-15 000 BP, seems revealing specific similarities and differences. Similarities among these sites include the consistent presence of flake tools, indicative of the widespread Hoabinhian lithic technology. There is also a recurring feature of adapting and modifying tools according to available materials and possibly regional needs. Differences are evident in the specific types of tools and the emphasis on certain tool-making techniques. For instance, Con Moong Cave features a unique aspect of freshwater shell scrapers according to Ha Van Tan (1999), Pham Huy Thong (1980) or Pham Huy Thong *et al.* 1990), while the Tràng An sites and Hang Ch'o Cave deviate from the classic Hoabinhian types, with Tràng An sites showing less emphasis on pebble tools according to Yi *et al.* (2008) and Rabett *et al.* (2009, 2011). Mái Dá Điều stands out for its high proportion of flake-based tools and early edge-ground pieces, suggesting regional variations in tool-making practices according to Trình Năng Chung (2008). These Hoabinhian sites in Vietnam, therefore, would therefire reflect both a continuity and evolution in lithic technology within the

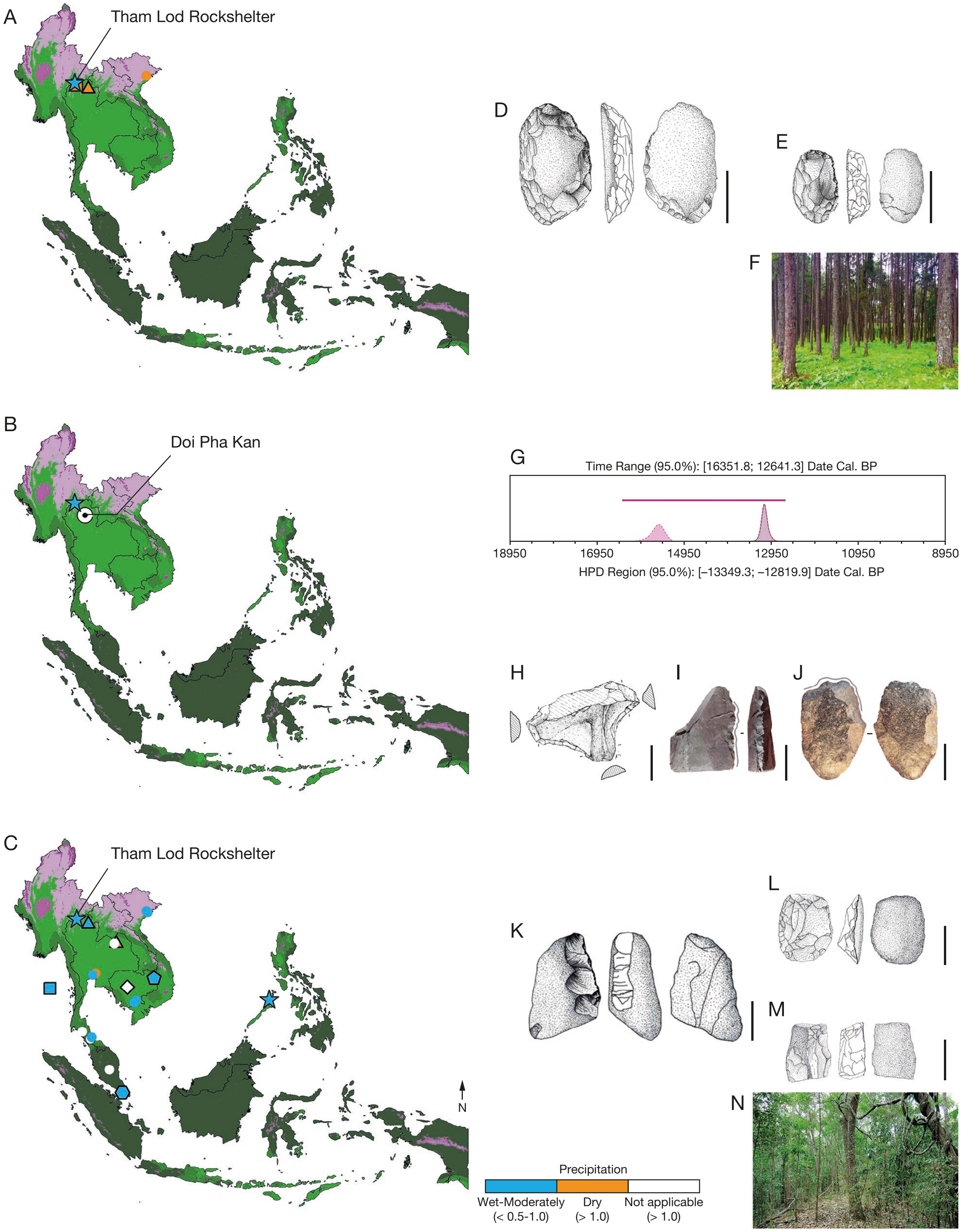

Fig. 18. — Ecological and cultural developments drawing from existing paleoenvironmental and technological data in Northern Thailand, spanning the Late Pleistocene to the Early Holocene (Marwick & Gagan 2011; Marwick 2013; Chabangborn 2014; McAllister *et al.* 2022; Zeitoun *et al.* 2023): **A**, Late Pleistocene (19 000-17 000 cal BP), last Glacial Maximum; **B**, Late Pleistocene (17 000-10 500 cal BP), late Glacial/Pleistocene-Holocene transition; **C**, Early Holocene (10 500-8 000 cal BP); **D**, large sumatralith, n = 26, 19%; **E**, small sumatralith, n = 11, 9%; **F**, pine/oak forests, White *et al.* (2004); **G**, *terminus ante quem* for Doi Pha Kan lithic assemblage; **H**, star tools, n = 14, 4%; **I**, slab tools, n = 177, 45%; **J**, Hoabinhian uniface, n = 1; 0.3%; **K**, large side chopper, n = ?; **L**, small sumatraliths, n = ?; **M**, small denticulates, n = ?; **N**, decidous and evergreen broadleaf taxa but pine/oak in norwest Thailand, White *et al.* (2004). Scale bars: D, E, H, I, J, K, L, M, 5 cm. Sources of the drawings: Chitkament *et al.* 2015; Chitkament 2016. Base map: Köppen-Geiger climate classification of Southeast Asia (Beck *et al.* 2018).

Hoabinhian culture post-15 000 BP in Vietnam, highlighting how different communities adapted to their environments and resources over time. Interestingly, the Doi Pha Kan site shares with these sites a pattern of short, dense lithic discard at the end of the Pleistocene, in addition to notable exceptions to the classic Hoabinhian pattern.

The introduction of the composite tools, the singular slab reduction sequences and the overall technological diversity observed at Doi Pha Kan could be therefore interpreted as an adaptive response to the unique geological and environmental conditions of the site. This interpretation aligns with the hypothesis that the development of such tools is related to changes in mobility and raw material transport. The shift from traditional pebble-based tools to lighter, slab-based forms may reflect a 'place provisioning' strategy, possibly linked to prolonged stays at the site for activities such as burial rituals and art production. The presence of pebbles/cobbles from local river alluvium indicates that Doi Pha Kan artisans were able to produce typical macro-tools of the Hoabinhian toolkit. However, it is crucial to note that the current material evidence does not provide a direct link between the lithic tools, burials, and art production at the site. The lithic tools are older than the known burials, and the art has not been definitively dated. Therefore, while the idea of a connection is intriguing, for now, it remains speculative without concrete archaeological evidence.

Linking technology and ecology: problems and working hypotheses

In exploring the interplay between technology and ecology, we acknowledge significant climatic variations at the end of the Late Pleistocene and the beginning of the Holocene in Mainland Southeast Asia. In Vietnam, for example, Nguyen Viet (2000) has suggested the existence of different climatic phases and their impacts on the Hoabinhian culture, ranging from a cold Hoabinhian during the Last Glacial Maximum to a warm postglacial Hoabinhian, marked by changes in flora and dietary strategies. Other studies have suggested an evolution in tool-making from flake-based to pebble-based industries (e.g. Rabett 2012). Even is, this shift's reasons are partly obscured by recovery inconsistencies, widespread lithic industries, particularly the Hoabinhian "techno-facies" show tool type, material use, and subsistence similarities in some sites across Mainland Southeast Asia, showcasing inter-site variability and changes over time in Hoabinhian industries, and suggesting local adaptations (Bellwood 2007; Rabett 2012). These technological and ecological changes likely influenced human behaviors and shaped modern human diversity in Southeast Asia as suggested by Soares *et al.* (2008).

From 10 500 BP onwards, there was a return to intense summer monsoons and overall warm and humid conditions (Cook & Jones 2012; Chabangborn *et al.* 2014; Chabangborn & Wohlfarth 2014). These paleoclimatic and paleoenvironmental factors should be considered when comprehensively examining variations in the typotechnological compositions of lithic assemblages during this period in MSEA (Fig. 18). By incorporating data from available paleoenvironmental studies, we provide a nuanced backdrop against which technological changes can be assessed in near future. The approach taken in this study is an attempt that integrates multiples lines of evidence to understand the complex interplay between human technology and the environment. This endeavor not only respects the complexity of past human behaviors but also provides a solid foundation for hypothesizing about the adaptative strategies of ancient populations in the face of climatic and environmental shifts.

At present, for a variety of reasons (for instance, we face challenges such as a shortage of site-specific environmental proxies, difficulties in comparing technological data across sites due to methodological disparities, and the possible limited sensitivity of technological strategies to climate variations on a millennial scale in tropical regions worldwide), establishing a direct link between technology and paleoecology with a satisfactory degree of accuracy is not feasible in Northern Thailand. Marwick's (2013) research on multiple optimal solutions amidst changing conditions presents an exception. It yielded local climate proxies at Tham Lod and Ban Rai sites by analyzing oxygen isotope ratios in the freshwater bivalve *Margaritanopsis laosensis* (Marwick & Gagan 2011) and their relationship to the stone artefact sequences at both sites in Northwest Thailand's highlands. By modeling and linking technological and ecological risks, Marwick (2013) introduced a formalization of the intricate human-environment dynamics in Thailand. This led to the conclusion that both proximity to resources and climatic changes significantly influenced Hoabinhian technology. Specifically, during the colder, drier conditions of the Late Pleistocene, there was less time invested in stone artefact reduction, reflecting a more residential strategy at Tham Lod. Conversely, the warmer, wetter conditions of the early Holocene saw more time dedicated to lithic reduction, aligning with a more logistical approach at the Ban Rai site (Marwick 2013).

Recognizing the value of formalizing human paleoecology at Doi Pha Kan, our primary focus has been to cultivate a comprehensive and precise technological description to feed potential future models. This process inherently requires an understanding of the production goals of each reduction sequence, evaluating it specific role within the Hoabinhian technical system, and recognizing the interplay between different knapping strategies. From this perspective, the degree of lithic reduction in retouched and non-retouched products, when assessed independently, appears to be a problematic marker for gauging the adaptation of technological strategies to environmental conditions. Considering the scarcity of retouched tools in Northern Thailand, the composition of the toolkit in the Doi Pha Kan assemblage gains significant relevance in better addressing variations in human paleoecology.

The Doi Pha Kan assemblage ends around 12 800 calBP, a period for which further paleoenvironmental data from Northern Thailand are missing, except for the faunal remains (Bochaton *et al.* 2019; Shoocongdej & Wattanapituksakul 2020) and the oxygen isotope data (Marwick & Gagan 2011) at Tham Lod Rockshelter in a mountainous area. Faunal remains point to a humid climate and a diverse array of forest biomes from 17 000 to 10 500 calBP (Shoocongdej & Wattanapituksakul 2020), while the δ18O analysis of freshwater bivalves suggests that from 20 000 to 11 500 calP, the climate was drier, with a peak in aridity around 15 600 calBP (Marwick & Gagan 2011). Additionally, it has been suggested that mixed tropical forest/grasslands were more widespread and connected in MSEA during the terminal Pleistocene, and that they were replaced by more closed forest environments (Rabett 2012; Suraprasit *et al.* 2021) but this question remains debated throughout the region (Hamilton *et al.* 2024). Moreover, there is a lack of information on the paleovegetation of Northern Thailand from the end of the Last Glacial Maximum to the start of the early Holocene. White *et al.* (2004) propose that the area may have had pine/oak forests from 25 000 to 17 000 calBP. During this time, the mountainous Tham Lod Rockshelter indicates a decrease in both large and small Sumatralith, contributing to roughly 10% of the toolkit (Fig. 16A) (Chitkament *et al.* 2015; Chitkament 2016). From 10 500 to 8 000 calBP, or the early Holocene, this site notes a nearly complete disappearance of Sumatraliths/unifacial tool conception, replaced by an assemblage dominated by large side choppers and small flake tools (Fig. 18C). In this period, several proxies suggest increased rainfall, the emergence of deciduous and evergreen broadleaf taxa, and the continuation of pine/oak forests in Northwestern Thailand (White *et al.* 2004). Amid this broad pattern, Doi Pha Kan stands out due to its intermediary chronological position and unique technological profile in Northern Thailand, with slab tools constituting about 45% of the toolkit (Fig. 18B). The appearance of a single Hoabinhian uniface (Fig. 9B) appears to follow the general temporal trend of a gradual decrease in these tools, moving towards the early Holocene. As it stands, our comprehension of the lithic technology at Doi Pha Kan does not allow us to conclusively determine how these technological behaviors reflects ecological adaptations to locally available resources.

Finally, the appearance of composite tools “star-like” during the Pleistocene-Holocene transition, as depicted in Figure 15, suggests potential correlations worth exploring. We propose two hypotheses for future research. First, the unique composite slab tools at Doi Pha Kan may represent an innovative phase in Hoabinhian culture, influenced by environmental shifts or resource availability. Second, these distinct tool types could indicate specific cultural practices or adaptations in the region, reflecting a diversification in response to ecological and social factors. Our future work aims to conduct a detailed functional analysis of these artifacts and comparative studies with other Hoabinhian sites. As part of these future functional studies, the question of the hafting of some objects will be considered given the observation of characteristic retouched parts or “slimming zona” (see Figures 10E and 11G, H).

In the same time, we urge researchers working in the region to verify whether the presence of any conception of composite tools has not been omitted until now in their lithic assemblages.

Preliminarily, it is evident that Doi Pha Kan represents a distinctive example within the broader Hoabinhian context of Southeast Asia, as previously hinted by the funeral practices. Whether this indicates a less stable technological system than what is typically attributed to the Hoabinhian of these areas, potentially in response to heightened precipitations, the data is still inconclusive. This underlines the urgent necessity for more robust interdisciplinary collaboration to produce more fine-grained technological and environmental data in order to build better models of human paleoecology dynamics in this part of the world tropical region.

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