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ABSTRACT

The presence of notches on European Palaeolithic flaked stone tools termed ‘denticulates’ has been variously ascribed to cultural, functional and taphonomic factors. In Southeast Asia prehistoric stone tool assemblages are dominated by unretouched flakes, so the rare retouched lithics, including denticulates, can be considered unique testimonies of the intention of the tool makers to control the shape and properties of tool edges. Here we report the results of plant processing experiments with modern unretouched flakes made of red jasper. Splitting plants with the help of a specific hand and arm movement (“twist-of-the-wrist”) resulted in a series of use-wear traces that included large crescent-break micro-scars. These are very similar in shape and appearance to the notches of prehistoric denticulated tools. These results suggest that some denticulated pieces in prehistoric Southeast Asia could be less intentional than previously thought, being instead the result of plant processing activities. We also report here the analysis of 41 denticulates from Tabon Cave, Philippines. While some are clearly intentionally retouch, others exhibit use-wear and nocth micro-morphology characteristic of plant splitting. The notches of others result from utilisation and taphonomy or trampling. Altogether, our observations raise the following question: should the term denticulates be restricted to the tools intentionally retouched or encompass all the tools with adjacent notches whatever the origin of the latter is?

1. Introduction

Denticulates, or “tooth-edged” pieces, are knapped stone tool blanks that present a series of adjacent or almost adjacent notches (two or more), their intersection creating projections or dentils (Bordes, 1961; Debenath and Dibble, 1994; Leroi-Gourhan, 2005 – 1st ed. 1998; Theodoropoulou, 2008; Thiébaut, 2005) (Fig. 1). This typological category encompasses a great variability of shapes, production techniques and perhaps function as well (Debenath and Dibble, 1994). They have been found in archaeological sites on all continents dating to different periods, although their frequency among the assemblages varies. In Europe for instance, they are common in early Acheulean and at the

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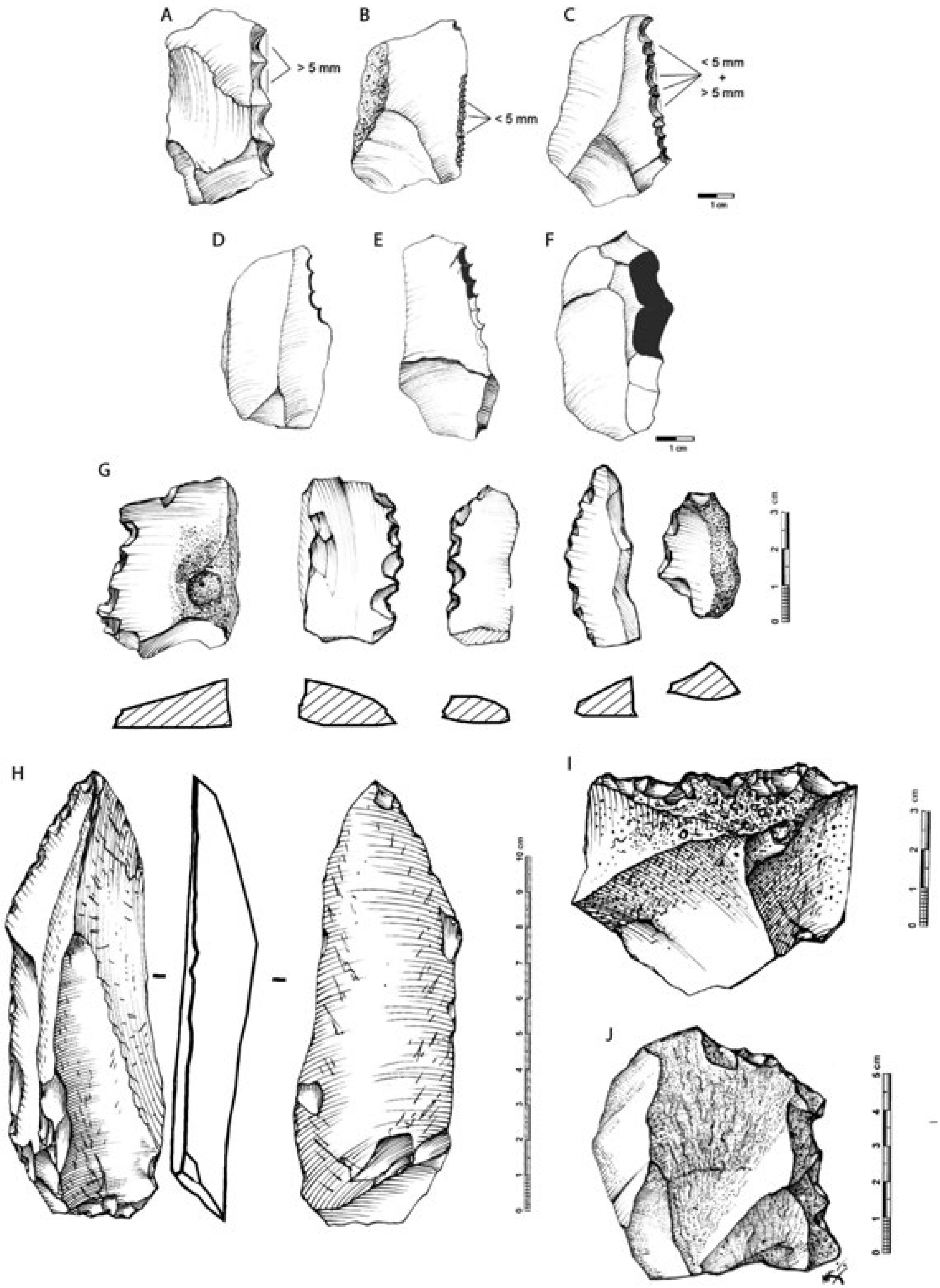


Fig. 1. A to C: Different types of denticulates (stylized): A) macrodenticulate, B) microdenticulate, C) festooned denticulate. D to F: Degree of edge modification in denticulates: D) small modification, E) average modification, F) invasive modification. (drawings: A. Theodoropoulou) G: Denticulates from Song Keplek, Java, Early Holocene. H & I: Denticulates from Guang Pandan, Sumatra, 9000 BP J: Denticulate from Togi Ndrawa, Nias, 11,000 BP (drawings: H. Forestier) (after Forestier, 1999, Forestier et al., 2017; Theodoropoulou, 2008).

Late Middle Palaeolithic (end of MIS 3) but rare in Upper Palaeolithic sites (e.g. Forestier, 1999; Lourdeau, 2015; Theodoropoulou et al, 2009; Cosgrove et al., 2014; Barton et al., 2016). In Southeast Asia, it is during the Late Pleistocene and Early/Mid Holocene that they are mainly found, for example in Java, Sumatra, Borneo, Luzon and Palawan (Forestier, 2007; Forestier et al., 2017, 2010; Patole-Edoumba et al., 2012). Different hypotheses have been offered to explain the origin and meaning of notches that constitute the stone tools named as 'denticulates'. The probably best known are the "cultural hypothesis" offered by the lithic typology of Bordes (1953), Bordes and de Sonneville-Bordes (1970), Debenath and Dibble (1994), who considered the large number of denticulates among some European Middle Palaeolithic assemblages as a marker for a particular cultural tradition, and the "functional hypothesis" defended by Binford (1973; and Binford and Binford, 1966) who argued that denticulates were specialised tools for wood working, found in high quantity in sites devoted to this activity. Later, it has been demonstrated, following a warning by Bordes (1961), that denticulates' notches can also be created on flakes by trampling and motions in the sediments, suggesting a taphonomic reason for denticulates in some cases (McBrearty et al., 1998; Vallin et al., 2001).

In Southeast Asia, retouched stone tools remained a minority found amongst generally informal lithic assemblages composed mostly of unretouched flakes (e.g. Reynolds, 1993; 2017; Pawlik, 2009; Forestier et al., 2010; Patole-Edoumba et al., 2012; Marwick et al., 2016). Denticulates are part of this retouched minority and can therefore be considered as unique testimonies of the intention of the tool makers to control the shape and properties of tools edges in this region. Nevertheless, denticulates' notches may be due to a completely different reason: plant processing. Indeed, we report here plant splitting experiments with unretouched stone tools that resulted in the creation of large notches on the tools edges, as well as the analysis of denticulates from Tabon. While some of the latter are clearly retouched, others present the same features than the experimental tools used to split plants suggesting that they are by-products of plant splitting.

2. Material and methods

2.1. Plant splitting experiments based on observations in ethnographic context

The experiments we report here are embedded in an ongoing interdisciplinary program, aiming at building up a reference collection of use traces on stone tools resulting from plant processing, adapted to the specific vegetation of Southeast Asia (Xhauflair, 2014; Xhauflair et al., 2016, 2017a, b). For the experiments to be as realistic as possible, they were designed after real activities documented in the field among indigenous Pala'wan people, who use wild resources from the forest on a daily basis (Fig. 2).

After being introduced by NR, HX and TV, assisted by the interpreter Kristine Joy Colili, conducted a field investigation for a total of three months among Pala'wan communities from four different hamlets in the municipality of Brooke's Point, Palawan Island, Philippines. Data were collected in four different ways: participatory observation, semi and non-directive interviews, focal person follow (following someone for half a day, or a day), and spontaneous initiatives from our collaborator-informants (Sanjek, 1990; Copans, 2008-1st ed. 1999; David & Kramer, 2001). The latter were both men and women of all ages, although men aged of 40–50 were the most represented. In addition to written observations and pictures, we recorded the activities encountered with the help of a video camera. These activities involved the use of 95 plant taxa, whose species were identified by J.R.C. and D.T. (Xhauflair et al., 2017a). To reproduce selected activities as closely as possible, they were analysed based on their video recording with the help of the *chaîne opératoire* concept (or operating sequence) (Fig. 3): the series of operations forming each activity were identified, divided into different gestures and described (Leroi-Gourhan, 1964; Cresswell, 2010- 1st ed. 1976; Sigaut, 2010 – 1st ed. 1987; Balfet, 1991; Lemonnier, 1992).

Ethnoarchaeology tries to identify regularities which are cross-cultural. Within the scope of technical studies, they lie in elementary mechanisms that are due to immanent properties of the materials and remain the same independently of the place and the period (Roux, 2007; Gallay, 2011). In the frame of our research, the regularities lie in the physical structure of plants, as it has an influence on the way they can be worked. For instance, bamboo culms, palm petioles or stems are easier to split longitudinally to their fibres than transversally. This is true today and during the past and whether the tools used are made of metal or stone.

Selected activities were reproduced experimentally with replicas of archaeological stone tools made of red jasper, a locally available raw material preferentially used by prehistoric knappers in southern Palawan Island, Philippines, and dominant in the lithic assemblages of sites in this area such as Tabon and Pilanduk Caves (Fox, 1970; Schmidt, 2009; Xhauflair et al, 2016). In the case of plant splitting, the tools used were all unretouched flakes. The experiments on fresh plants took place in Makiling Forest Reserve, Luzon Island, Philippines, and we collected parts of the plants to process them once dry in Manila and in France. HX conducted all of the experiments to avoid interpersonal variability. Each operation was conducted twice on a specific plant, first with a first flake for 10 or 15 min, and then with a second one for 30 min. (See Fig. 6 for a list of the experiments and the Supplementary Material for more details)

HX analysed the experimental stone tools after performing all the experiments at the laboratory for use-wear analyses of the Université Côte d'Azur (CEPAM), first at low magnifications under a stereomicroscope (Olympus SZH) and a macroscope (Leica Z16 APO), and second at high magnifications (100 and 200X) under an Olympus Bh2-UMA. Before microscope observations and after sampling residues (see Xhauflair et al., 2017b), the tools were cleaned in an ultrasonic tank with soapy demineralised water and were then rinsed with demineralised water and left to dry at the air on tissue papers. If needed, reluctant residues obstructing the surface and possible use-wear were removed using alcohol (70–90%) applied locally with impregnated tissue papers. If it was not enough, the tools were soaked in acetone (1 h maximum). The usual attributes were recorded using a digital data base (see Xhauflair et al., 2016 for details and Supplementary Material). Use traces were mapped on pictures of both faces for each tool and recorded with cameras mounted on the microscopes.

2.2. Retouching experiments

In order to determine if the morphology of the notches resulting from splitting plants could be distinguished from the ones created by intentional retouch, we created a total of 56 notches on 19 flakes made of red jasper using hard hammers (small river pebbles). HX and TP observed the morphology of these notches under stereomicroscopes and compared it to the morphology of the notches resulting from splitting plants, following the methodology described above.

2.3. Analysis of archaeological artefacts from Tabon Cave

Tabon Cave is located on the Southwest coast of the island of Palawan in the Philippines and is one of the major sites of Philippine Prehistory, as it yielded thousands of lithic artefacts, human and animal bones and a fire place, dating to the end of the Pleistocene and the early Holocene (Fox, 1970; Choa, 2018). Recently, the assemblages II and III were re-dated to between 30,000–39,000 years cal. BP (Choa, 2018). The raw materials of the lithic tools are red jasper (Schmidt, 2009), white chert and andesite. Four knapping methods by direct percussion have been identified: discoïd, kombewa, volumetric and system of alternating debitage surface (SSDA) (Forestier, 1993; Jago-on, 2007, Arzarello et al, 2009). Nucleus, flakes and debitage have been found, indicating that knapping took place at the site. While only a few elongated blade-like flakes and retouched artefacts (8% -scrapers, denticulates, notches) were observed (Fox, 1970; Jago-on, 2007, Arzarello et al, 2009), the most common knapping products are unretouched flakes. The Assemblage I which is the closest to the surface and has been dated to 9,000 BP (Fox, 1970) has a more important number of retouched tools (14,1%) such as scrapers, denticulates and

Fig. 2. Examples of wild plants that are turned by the Pala'wan into final products by splitting (among other operations). The arrows link the plant taxa to final products that can be made from them. a) *Schizostachyum* cf. *brachycladum* b) *Donax cannaeformis* c) *Dinochloa* sp. d) *Arenga pinnata* e) *Calamus* cf. *usitatus*. 1) Different bamboo tools, including adze, knives, spoon and grates. 2) Bamboo floor of a family house. 3) Small basket '*tingkäp*' 4) Fish trap 5) Mouth harp played by the musician Undu Apäl† (videos of his music can be watched on YouTube) 6) Blowgun dart 7) A weaving instrument used to tighten weaving strips 8) Rattan ties holding together the beams, posts and laths of a house. 9) Ties holding together the different parts of a bamboo container '*aläp*'. The larger one is made of split rattan.

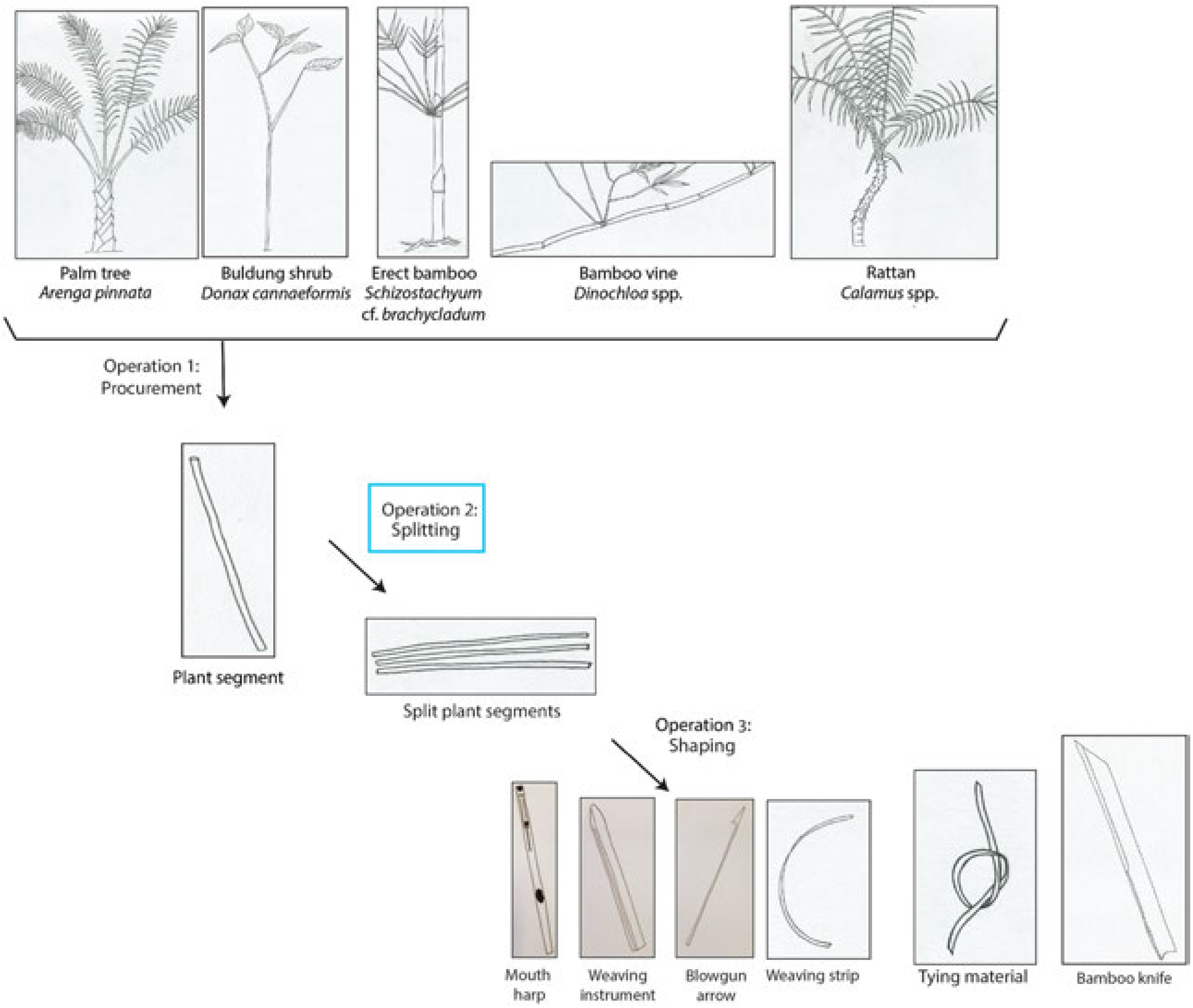


Fig. 3. Schema representing the *Chaîne opératoire* of activities that include "splitting" as one of the main operations.

burins (Patole-Edoumba, 2002). We selected 41 artefacts (see Table 4) from the assemblages II and III that carry adjacent notches (denticulates) to determine if some could be the result of plant splitting instead of intentional retouch. They were observed with the naked eye and under Leica stereo- and metallographic microscopes in the GPR laboratory of the McDonald Institute for Archaeological Research, University of Cambridge and at the Université Côte d'Azur, with the equipment described above. They were analysed following the methodology described for the analysis of the experimental tools. We compared the macro- and micro-morphological attributes of their notches to the ones observed on the experimental stone tools used to split plants on one hand and on experimentally retouched tools on the other hand. We also recorded the use-wear present on the artefacts from Tabon and compared it with the traces observed on the experimental tools.

3. Plant splitting documented in ethnographic context: the twist-of-the-wrist process.

Splitting plants is part of the *chaîne opératoire* or operating sequence of several activities that we documented among Pala'wan communities: manufacturing tools and other utilitarian items such as bamboo knives, blowgun darts, spoons, coconut grates or weaving instruments, making supple strips for basket weaving, tying materials from rattan, mouth harp or bamboo flooring. (See Fig. 2)

These activities comprise three main operations: 1st Procurement, 2nd roughing out or splitting, and 3rd shaping. (See Fig. 3 – *chaîne opératoire*) The first operation consists of procuring a fresh segment from plants growing in the forest or fallow lands. It is usually a segment of the stem, except in the case of palms, whose long leaf petioles are used as raw materials. Then, these plant segments, fresh or dry, are split into different parts which are as many blanks or preforms. The latter are eventually shaped into the final desired products.

The Pala'wan use a specific process to split plants, that we called the "twist-of-the-wrist" as it implies using one's tool as a lever by twisting one's wrist. (See Fig. 4 and Video 1) While this technical process is nowadays carried out using steel knives, our study tested its applicability for stone tools.

Plant splitting is made of two crucial sub-operations: First, a nick is made at the tip of the plant segment, in parallel to its fibres, with the help of a machete or a small knife, respectively by dynamic (=chopping) and resting (=sawing) percussion (Leroi-Gourhan, 1971- 1st ed. 1943, Lemonnier, 1992). Second, the tool is inserted into the nick it made and used as a lever to propagate the fissure: in a fast motion, the wrist of the arm holding the tool is swivelled a quarter-turn to the right or the left, forcing the plant to diverge on either side of the nick, making it grow longer. Then, either the plant can be split into two, using hands, or the tool is slid down the crack and the twist-of-the-wrist is repeated lower, until the plant is completely split into two parts. (Videos of this

Fig. 4. The two sub-operations of plant splitting documented among Pala'wan communities: First, making a nick by dynamic or resting percussion. Second, the twist-of-the-wrist (the blade of the tool is used as a lever, forcing the plant to diverge on either side of the nick, making it grow longer. a) Splitting a culm of the bamboo *Schizostachyum* cf. *brachycladum*. b and c) Splitting a stem of the rattan *Calamus* cf. *usitatus*. d) Splitting a long leaf petiole of the palm *Arenga pinnata*.

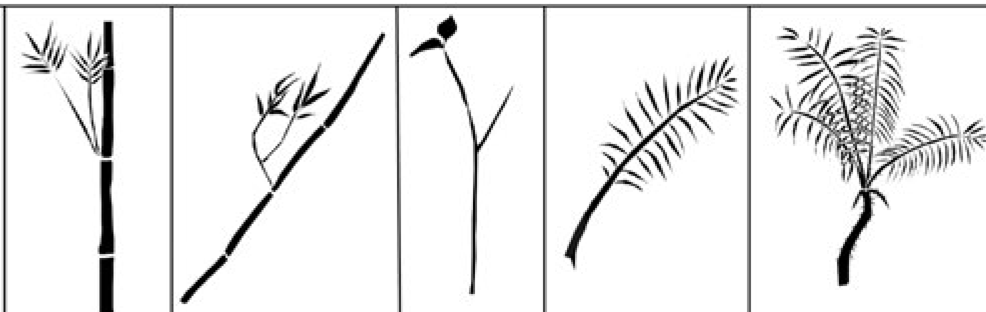
operation within activities can be watched on www.plantuseinseasia.net)

4. Experimental reproduction.

(See the Supplementary Material for more details)

Plant splitting, using the "twist-of-the-wrist" process was reproduced experimentally with 16 flakes made of red jasper, also known as radiolarite, a chalcedony-like sedimentary rock with features similar to chert and a Mohs hardness of 6.5–7 (Schmidt, 2009; Xhauflair et al, 2016) on five different plant species: the erect bamboo *Schizostachyum* cf. *lima* (fresh and dry), the bamboo vine *Dinochloa luconiae* (fresh and dry), the rattan *Calamus merrillii* (fresh and dry), the palm *Arenga pinnata* and the shrub *Donax cannaeformis* (the two latter were split only fresh, just after gathering fresh plant segments, as the Pala'wan do with these taxa). A different splitting method has been used by Bar-Yosef et al (2012) in bamboo processing experiments, using a flake as a wedge or chisel, hitting it with a stone pebble. The same method for splitting wood and another one consisting of making a first nick, then pulling rattan fibres by hand were also reported by Davenport (2003) in the frame of experiments. These other methods imply gestures that are different from the technique we documented among Pala'wan communities and subsequently different consequences on the stone tools. As our protocol consisted in reproducing as closely as possible the *chaînes*

Fig. 5. Examples of plant splitting experiments. a) Bamboo culms (*Schizostachyum* cf. *lima*) b) Stems of *Donax cannaeformis*. c) Rattan stem (*Calamus merrillii*) d) Long palm leaf petioles (*Arenga pinnata*).



Plant taxa	*Schizostachyum* cf. *lima*				*Dinochloa luconiae*				*Donax cannaeformis*		*Arenga pinnata*		*Calamus merrillii*			
Freshness	Fresh		Dry		Fresh		Dry		Fresh		Fresh		Fresh		Dry	
Duration (in minutes)	10	30	10	30	10	30	10	30	10	30	10	30	10	30	15	30
Success of the twist-of-the-wrist method to split plants	✓				✓				✓		✓		X			

Fig. 6. List of plant splitting experiments and success of the twist-of-the-wrist method to split plants using stone tools (V = successful, X = unsuccessful).

opératoires used by our Pala'wan informant-collaborators, we attempted splitting these five plant taxa using the twist-of-the-wrist process described above. (Fig. 5)

We selected experimental stone tools that were thin (average max. thickness = 10,1 mm) so they could be inserted between plant fibres inside a cut, but that also seemed to be resistant enough to bear the pressure generated by the twist-of-the-wrist without breaking into pieces.

Our Pala'wan informants used hafted metal knives with acute edge angles whose morphology differs from unretouched stone flakes. The morphological and physical features of a tool (shape, dimensions, angle of the cutting edge, hafting, etc.) have some influence on the gestures that one can do with it. It implies that some adjustments had to be made to reproduce the technique recorded in ethnographic context. We used a resting percussion (sawing motion) to make first nicks in plant segments, like the Pala'wan do with their small knives called *'päqis'*. We did a test using a dynamic percussion (chopping motion) as the Pala'wan do with their machete but the cuts were not neat enough and the fibres were crushed instead. Likewise, while a big machete can make a first nick through the entire diameter of a bamboo culm in one blow, with stone tools, we had to make a nick on one side first by sawing, then repeat on the other side.

The twist-of-the-wrist process itself was perfectly reproduceable with stone tools. (see Fig. 5 and Video 2 - videos of this operation within larger activities can be watched on www.plantuseinseasia.net) We were able to split the two bamboo genera involved (*Schizostachyum* and *Dinochloa*, the first one is the only genus used by the Pala'wan to make knives, because of the length of the internodes and its sharpness after splitting), leaf petioles of the palm *Arenga pinnata*, and stems of *Donax cannaeformis*. This splitting process nevertheless did not prove to be efficient to split rattan stems (Fig. 6). This could be because the stems involved were particularly thick (4,5 and 3,5 cm of diameter). Another reason could be related to the structure of rattan stems whose fibres are strongly attached to each other. The gestures performed experimentally also included sliding the tools further down after a first twist-of-the-wrist, to repeat it lower, and pulling the plant segments aside by hands, like in the ethnographic records.

5. Resulting use-wear on the experimental tools.

(See Tables 1 and 2 and the Supplementary Material for the terminology used and details about the use-wear on the experimental tools).

The experimental reproduction of splitting plants with the twist-of-the-wrist process resulted in a set of specific features affecting the stone implements. Breakages, i.e. angular macro-fractures, were relatively frequent as they occurred on 7 of the 16 tools used to perform this task. The tools were nevertheless still efficient afterwards. These breakages exclusively occurred in the cases of processing harder materials (*Schizostachyum* and *Dinochloa*) and plants difficult to split because their fibres were strongly bound together (*Calamus*). Such breakages did not occur on the tools used to split *Donax cannaeformis* and the leaf petioles of *Arenga pinnata* that were easier to split (offering less resistance) than bamboo and rattan (See Fig. 7).

We also observed a combination of two different types of micro-scars. The first kind can be correlated to the "twist-of-the-wrist" and consists of large (1–2 mm) to very large (> 2mm) crescent-break micro-scars (Vaughan, 1985) predominantly perpendicular to the edge and which are distributed mostly on one face of the tool. Some very long low angle chips were also observed on the tools used to split *Arenga* and *Donax* which are softer materials than bamboo and rattan. (See Fig. 8) This first type of micro-scars was produced by pressure as the tool was used as a lever and forced against the plant to oblige it to diverge and make the crack grow longer. The pressure exerted by hard materials (*Dinochloa* and *Schizostachyum*) and plants whose fibres are tightly bound together (*Calamus*) resulted in a high number of very large crescent-break micro-scars. The pressure exerted by softer materials (*Arenga* and *Donax*) resulted in a high number of long and rather shallow (low angle) micro-scars. These large micro-scars appeared along the edge on the face opposite to the one on which pressure was exerted. During the experiments, the twist-of-the-wrist was performed by turning the wrist to the left or to the right and was not restricted to one side. Therefore, the resulting large micro-scars are in most cases on one face (81%-13/16 tools), but in a few cases on both. The experimental tools were used for more than one sequence of nick-making and twisting and analysed after performing for 10, 15 or 30 min and not after each twist-of-the-wrist. Nevertheless, we observed in the field that the large micro-scars were produced progressively, and not all at once. These large micro-scars created by the "twist-of-the-wrist" make some of the lithic pieces (11/16) look like denticulates although they are not intentionally retouched (See Fig. 9).

The second type of micro-scars observed can be correlated to the sawing motion performed to make the first nick. It consists of smaller micro-chips in transverse bidirectional orientation to the edge, due to the back-and-forth gesture. These scars are distributed on both faces of the tool (which is typical of sawing motions – e.g. Vaughan, 1985; Xhauflair, 2014). This second type of micro-scars was absent on a few tools (4/16) probably because they were removed as larger scars broke off during the "twist-of-the-wrist".

Additionally, splitting using this process is characterized by an invasive polish which can be explained by the fact that almost the entire surface of the tool is in contact with the worked material as it is inserted inside the nick, between fibres.

This operation also produces numerous striations which are

Table 1
Use-traces resulting from plant splitting on the experimental flakes.

Breakage	Micro-scars	Micro-polish	Striations
-in the case of hard or difficult to split materials (44% − 7/16 tools)	1st type, related to the "twist-of-the-wrist": -large (1–2 mm) to very large (> 2mm) (94% − 15/16 tools) -crescent-break (87,5% − 14/16 tools) or long (44% − 7/16tools) -perpendicular to the edge (100%, exclusively in 75% − 12/16 tools) -mostly on one face of the tool (81% − 13/16 tools) 2nd type, related to "nick making" by sawing (75% − 12/16 tools): -smaller -transverse bidirectional –on both faces of the tool	-invasive (81% − 13/16 tools)	(94% − 15/16 tools) -perpendicular (69% -11/16 tools) and diagonal (56% − 9/16 tools) to the active edge (related to the "twist-of-the-wrist") -parallel to the active edge (related to the "nick making" by sawing motion. (56% − 9/16 tools)

Table 2
Use-wear attributes recorded on the flakes used to split plants experimentally. X indicate the the attribute is present.

Tool ID	Use-wear resulting from splitting plants experimentally													
	Plant – freshness -duration	Macro-breakage	Micro-scars								Invasive polish	Striations		
			large to very large	long	crescent-break	perpendicular to the edge	mostly on one face of the tool	smaller	transverse bidirectional	on both faces of thetool		perpendicular to the edge	parallel	diagonal
EX12-12	***Schizostachyum*(fresh) 10 min**	X	X		X	X	X	X	X	X		X		X
EX12-11	***Schizostachyum*(fresh) 30 min**		X		X	X	X	X	X	X	X	X		
EX12-9	***Schizostachyum*(dry) 10 min**	X	X		X	X		X	X	X	X	X	X	X
EX12-10	***Schizostachyum*(dry) 30 min**		X	X		X	X	X	X		X	X	X	
EX12-27	***Dinochloa*(fresh) 10 min**		X		X	X	X	X	X	X	X			X
EX12-28	***Dinochloa*(fresh) 30 min**	X	X		X	X		X	X	X	X		X	X
EX12-30	***Dinochloa*(dry) 10 min**	X	X		X	X					X	X	X	X
EX12-29	***Dinochloa*(dry) 30 min**		X	X	X		X	X	X	X	X	X		X
EX12-86	***Arenga*(fresh) 10 min**		X	X	X		X				X	X	X	X
EX12-85	***Arenga*(fresh) 30 min**		X	X			X				X	X	X	
EX12-92	***Donax*(fresh) 10 min**		X	X	X		X	X	X	X	X	X		X
EX12-91	***Donax*(fresh) 30 min**			X	X	X	X	X	X	X	X		X	
EX12-53	***Calamus*(fresh) 10 min**	X	X		X		X	X	X	X	X	X	X	
EX12-52	***Calamus*(fresh) 30 min**	X	X		X	X	X	X	X	X	X		X	
EX12-50	***Calamus*(dry) 15 min**		X	X	X	X	X	X	X	X				
EX12-49	***Calamus*(dry) 30 min**	X	X		X	X	X					X		X

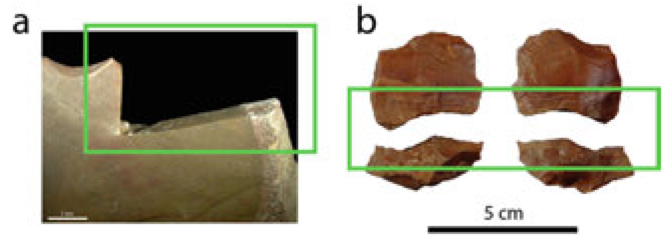


Fig. 7. Examples of breakages resulting from the pressure exerted on the tools during the twist-of-the-wrist. a) Splitting fresh bamboo (*Schizostachyum* cf. *lima*) for 10 min. b) Intent to split fresh rattan (*Calamus merrillii*), 10 min.

oriented in different directions. Perpendicular and diagonal striations can be correlated to the “twist-of-the-wrist” and to the fact that the tool was slid down into the subsequent crack, and parallel and slightly diagonal striations to the sawing motion used to make a nick (See Fig. 10).

6. Results of the retouching experiments

A comparison between the micro-morphology of the notches obtained by splitting plants and retouch with hard hammer revealed differences: intentional retouch produces notches whose edges and surface are irregular (vs. neat in the case of plant splitting), they often present a counter-bulb (or conchoidal fracture) and steep initiations (vs. crescent-break in the case of plant splitting). On the striking face, striations resulting from the impact with the hard hammer have been observed, as previously reported by others (Rots, 2010). Crushing and impact marks were also observed (Fig. 11 and Table 3).

7. Results of the analysis of Tabon Cave artefacts

Among the 41 denticulates studied, we observed on 10 artefacts the set of attributes recorded on the experimental tools used to split plants: neat crescent-break micro-scars associated with breakages, an invasive distribution of the micro-polish and striations parallel and perpendicular to the notches (Figs. 12 and 13). Our interpretation is therefore

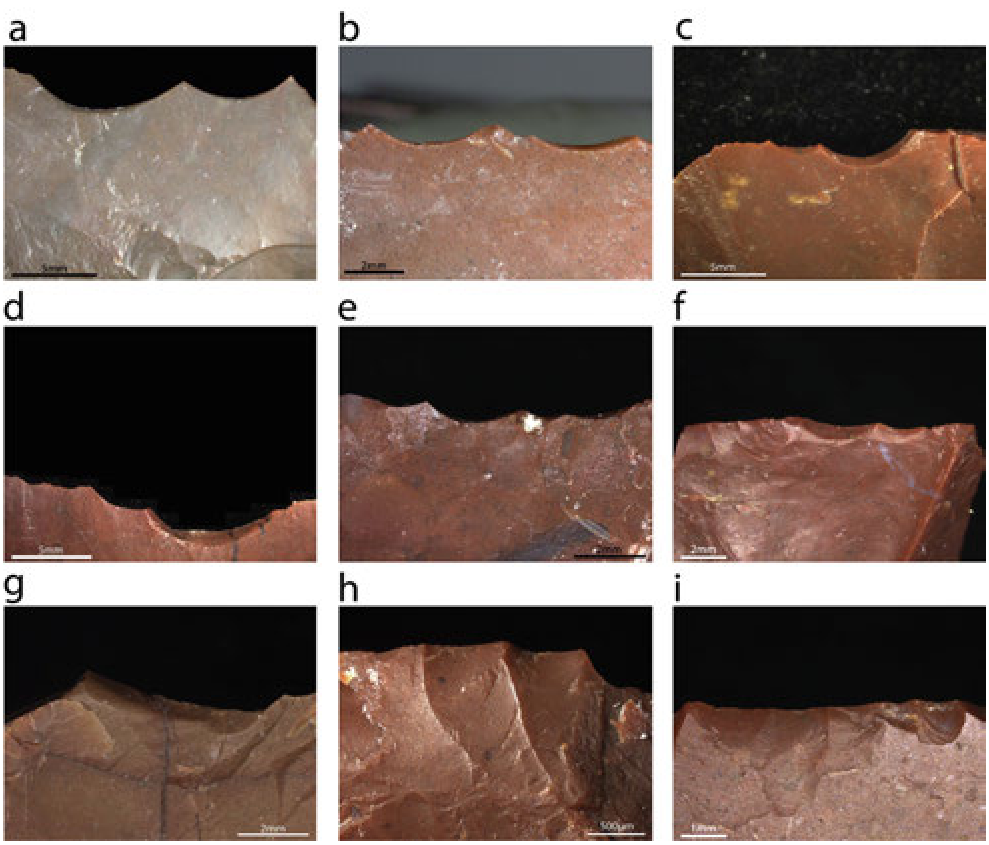


Fig. 8. Large crescent-break micro-scars resulting from the twist-of-the-wrist process to split the bamboo *Schizostachyum* cf. *lima* (fresh) for 10 (a) and 30 min. (b), fresh rattan for 30 min (c), the bamboo vine *Dinochloa luconiae* (dry) for 10 min (d), *Donax cannaeformis* (fresh) for 30 (e) and 10 min. (f) and the palm *Arenga pinnata* for 10 min. (g). Long invasive micro-scars resulting from the twist-of-the-wrist process to split softer plants: leaf petioles of the palm *Arenga pinnata* for 30 min. (h) and stems of *Donax cannaeformis* for 30 min. (i). Despite the fact that rattan did not cede under the pressure and was not split, the gestures were the same than for the other plants. The resulting use-wear is therefore very similar and large crescent-break micro-scars also occurred in the case of rattan processing.

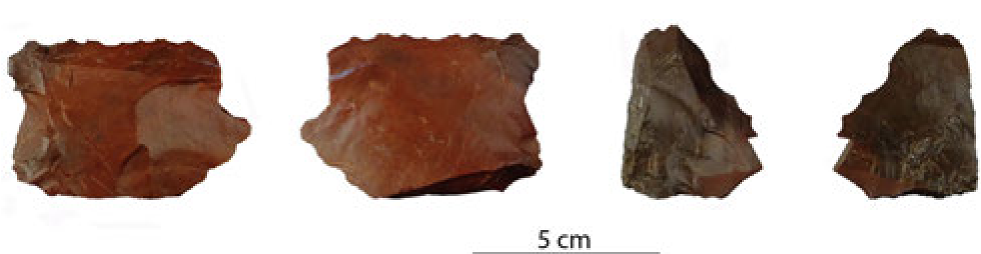


Fig. 9. Two experimental flakes used to split fresh bamboo (*Schizostachyum* cf. *lima*) for 10 (right) and 30 (left) minutes. Their active edge is affected by large crescent-break micro-scars. Although these scars are the result of utilisation, these flakes do fit into the definition of denticulates : blanks whose one or more edge(s) present(s) adjacent notches more or less regular (Bordes, 1961; Leroi-Gourhan, 2005 – 1st ed. 1998; Theodoropoulou, 2008; Thiébaut, 2005). Denticulates correspond to a stone tool type usually considered as intentionally retouched.

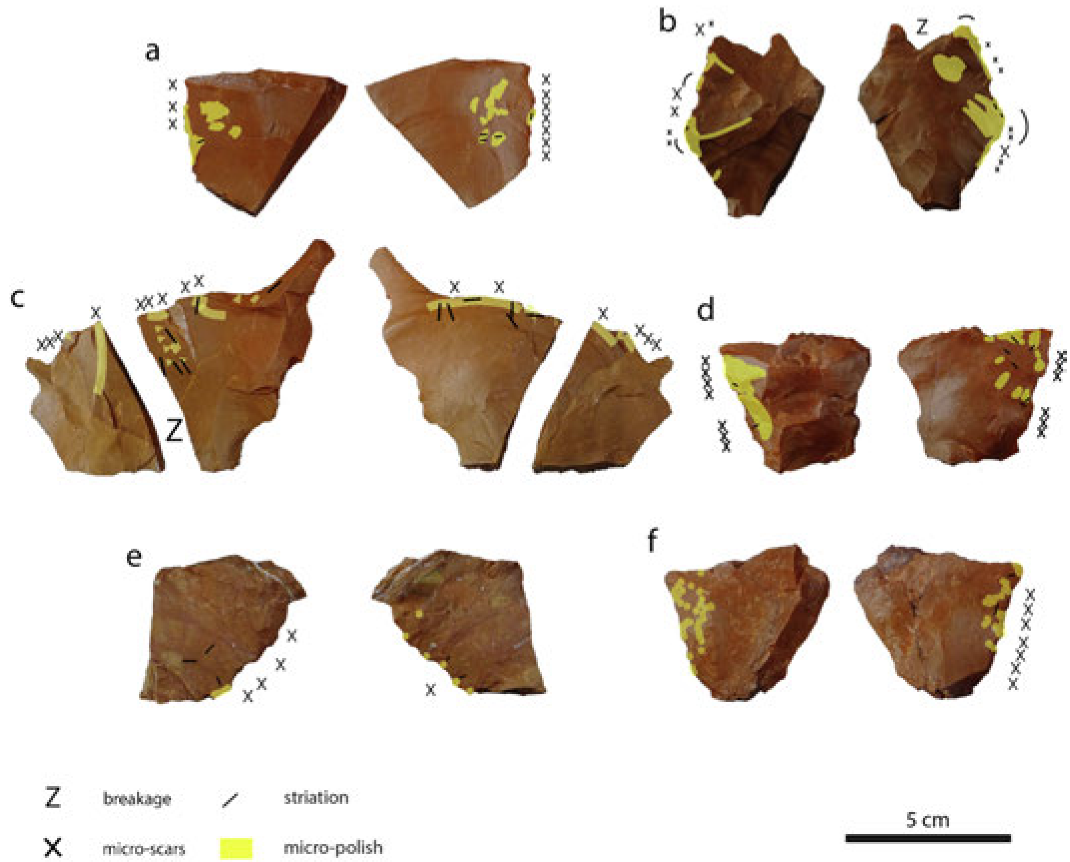


Fig. 10. Distribution of the use-wear on experimental stone tools used to split (or intent to split in the case of rattan): a) dry bamboo vine (*Dinochloa luconiae*) for 30 min b) fresh rattan (*Calamus merrillii*) for 30 min c) dry erect bamboo (*Schizostachyum* cf. *lima*) for 10 min. d) fresh *Donax cannaeformis* for 10 min e) and f) fresh leaf petioles of the palm *Arenga pinnata* for respectively 10 and 30 min.

that these artefacts have very likely been used to split plants using the twist-of-the-wrist technique. 13 other artefacts present notches whose morphology is matching the one recorded on notches obtained experimentally by retouch with hard hammer (irregular edges, uneven inner surface, steep initiations and presence of a counter bulb). Impact marks, crushing and retouch striations materialising the contact with a hard hammer were also observed. (Fig. 14) These features point to an intentional origin of the notches on these artefacts. In 4 cases, these intentional notches were cutting micro-polish attesting of a first use of the tools that took place before the retouching. This suggests that the reason for retouching these artefacts was to resharpen the edge or to clean them from a previous use (Fig. 15). In four cases, the notches seem to have occurred without any human intention by motions in the sediments or trampling. It has been showed by McBrearty et al. (1998) and Vallin et al. (2001) that such factors also produce notches that make actually unretouched tools fit into the category of denticulates. This interpretation for the origin of the notches on 4 stone tools is based on the fact that the morphology of their notches is not characteristic of intentional retouch and that they either present no microwear at all or microwear with no coherent distribution, attesting of motions in the sediments (Fig. 16). In addition, the serrated edges of these tools are very acute (between 16° and 36°) allowing notches to appear easily. The notches of nine artefacts turned out, based on their use-wear distribution and morphology, to result from utilisation other than plant splitting. The results of their analysis is beyond the scope of this paper and will be published elsewhere. On the remaining five tools, the origin of

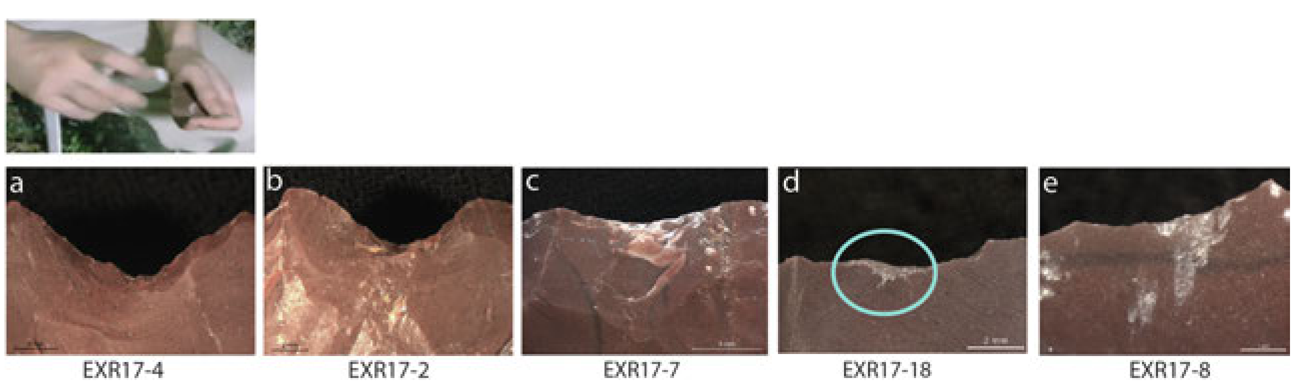


Fig. 11. Examples of notches produced experimentally by retouch with hard hammer. (d) and (e) show the other side of notches, on the striking face. (a), (b) and (c) present irregular edges and a counter-bulb (or conchoidal fracture); the surface of (b) and (c) is uneven; crushing and impact marks from the contact with the hard hammer can be seen in (d) within the circle; (e) presents macro-striations, also resulting from the contact with the hard hammer.

Table 3
Comparison of the morphology of notches resulting from plant splitting and from intentional retouch with hard hammer. In the case of plant splitting, we considered as a notch any large micro-scar creating a concavity in a tool's edge and presenting dentils when associated with others in a row.

Attributes of the notches		Intentional retouch with hard hammer (n = 56)	Plant splitting (n = 53)
Presence of macro-striations		55.36%	0%
Presence of crushing		73.2%	9.43%
Edges	Irregular	96.4% (mainly strongly irregular)	13.21% (slightly irregular)
	Neat	3.6%	86.79%
Inner surface	Uneven	80.35%	7.55%
	Even	19.65%	92.45%
Inner surface 2	Faceted	25%	9.43%
	Non-faceted	75%	90.57%
Presence of negative bulb		66%	6.12%
Steep initiations (proximal cross-section)		50%	3.77%
Crescent-break cross-section		3.57%	88.68%

the notches was unclear. It is interesting to note that the mean and median edge angle of the intentionally retouched artefacts are wider than the average edge angle of the tools from the other categories (see Table 4).

8. Discussion

We recorded the use of a specific process to split plants in ethnographic context among Pala'wan communities: the twist-of-the-wrist. We reproduced it using stone tools and it proved to be efficient to split the culms of two bamboo genera (*Schizostachyum* cf. *lima* and *Dinochloa luconiae*), leaf petioles of the palm *Arenga pinnata* and stems of *Donax cannaeformis*. We were unable to split large stems of rattan (*Calamus merrillii*) with this process, which is probably due to their large diameter. Rattan fibres are strongly bound together, and this material is well-known to be difficult to split, some species more than others (Avé, 1988; Davenport, 2003). Davenport (2003) reports successful splitting of thinner rattan stems using experimental stone tools with what appears from the photographs to be the twist-of-the-wrist process, specifying that it required great strength. More experiments with other species of bamboo would be necessary to know if it is possible to split

Table 4
Mean and median values of morphological measurements of the 41 denticulates from Tabon Cave that we analysed. The length and width were measured with the tools oriented with their notches facing up. The angles were measured on the edges presenting notches.

Origin of the notches	Length (notches axis) in mm	Width (notches axis) in mm	Maximum Thickness in mm	Maximum Edge Angle in degrees	Minimum Edge Angle in degrees
Splitting plants (n = 10)					
mean	35.2	41.3	12.2	29.8	27.1
median	33	41	13	30	25
Retouch (n = 13)					
mean	30.6	42.4	15	49.3	44.3
median	28	33	16	50	46
Taphonomy or Trampling (n = 4)					
mean	41.3	42	16.3	24.7	23.7
median	49	40	15	20	22
Use (n = 9)					
mean	37	45.2	12.2	29	22.1
median	39	40	11	24	21
Unclear (n = 5)					
mean	39.4	41.4	14.7	28.4	20.8
median	38	40	13	30	18

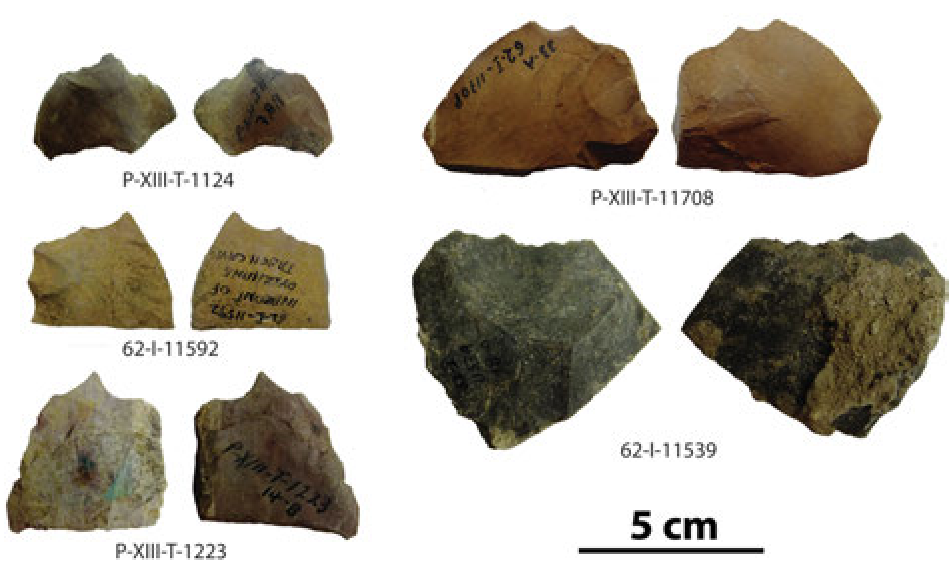


Fig. 12. Examples of denticulates from Tabon Cave that are good candidates for plant splitting based on the morphology of their notches and use-wear. They are oriented with the notches upwards.

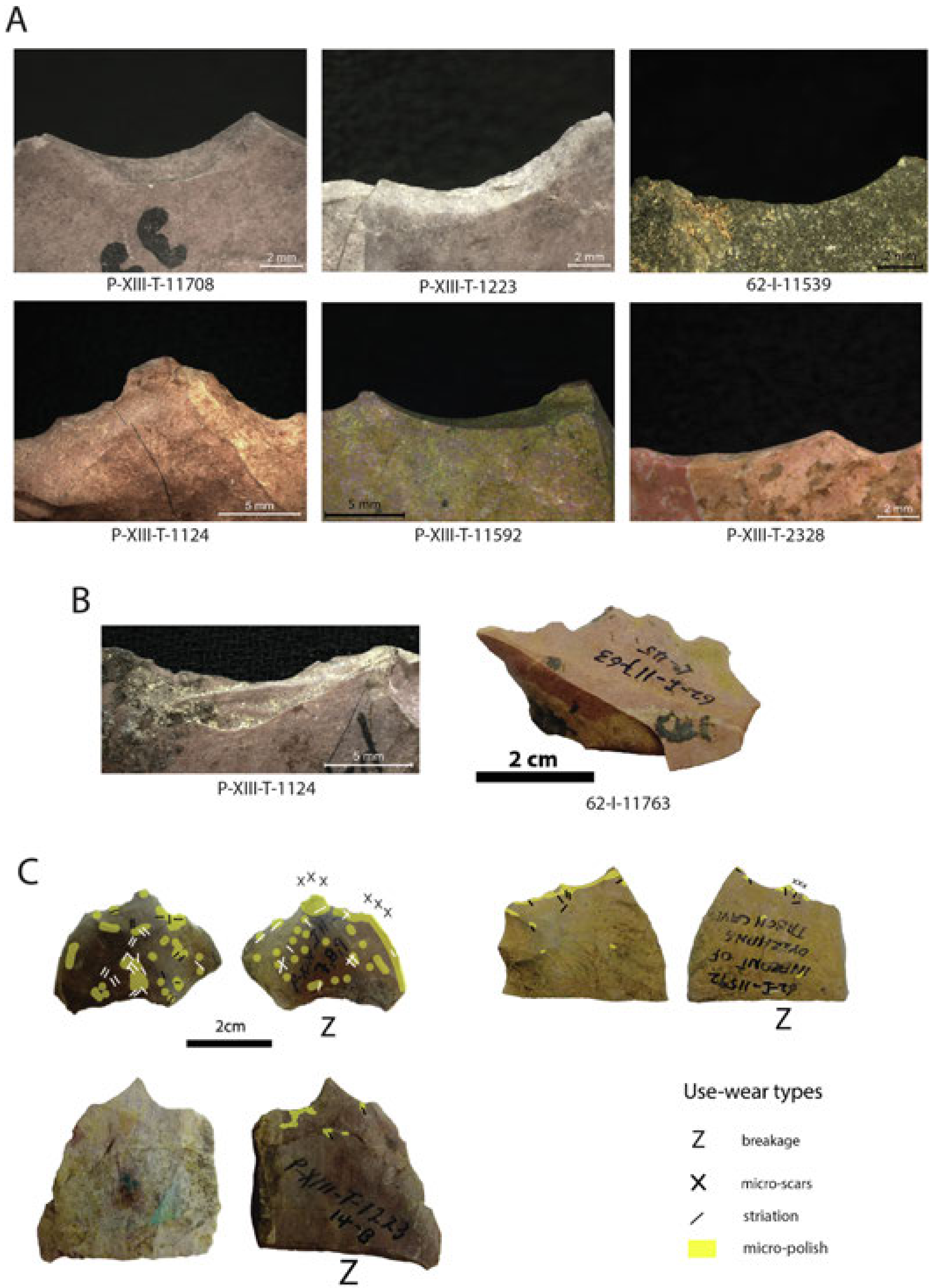


Fig. 13. Attributes characteristic of plant splitting observed on archaeological artefacts from Tabon: A) Very neat crescent-break notches. B) Breakages. C) Use-wear distribution: invasive polish, striations perpendicular and parallel to the edge(s), breakages, smaller micro-scars. The crosses indicate here the smaller scars.

larger culms with the twist-of-the-wrist process or if another technique would be needed, such as the one reported by Davenport (2003) and Bar-Yosef and his colleagues (2012), involving a wedge and a hammer.

Splitting plants with the twist-of-the-wrist process resulted in a combination of traces on the experimental stone tools associated with two different kinds of motion: the twist-of-the-wrist and sawing. The twist-of-the-wrist is responsible for frequent breakages, large micro-scars, crescent-break in most cases, perpendicular to the edge, invasive polish and striations perpendicular to the edge. The sawing motion on the other hand produced smaller micro-scars distributed on both faces and transverse bidirectional to the edge. It also resulted in striations diagonal and parallel to the edge and polish along the active edge.

The large crescent-break micro-scars resulting from the pressure exerted during the twist-of-the-wrist are in some cases adjacent (in 11 cases/16 experimental stone tools), making the experimental flakes appear as if they had been retouched. They fit into the category of denticulates which are defined as blanks whose one or more edge(s) present(s) adjacent notches more or less regular, specifically

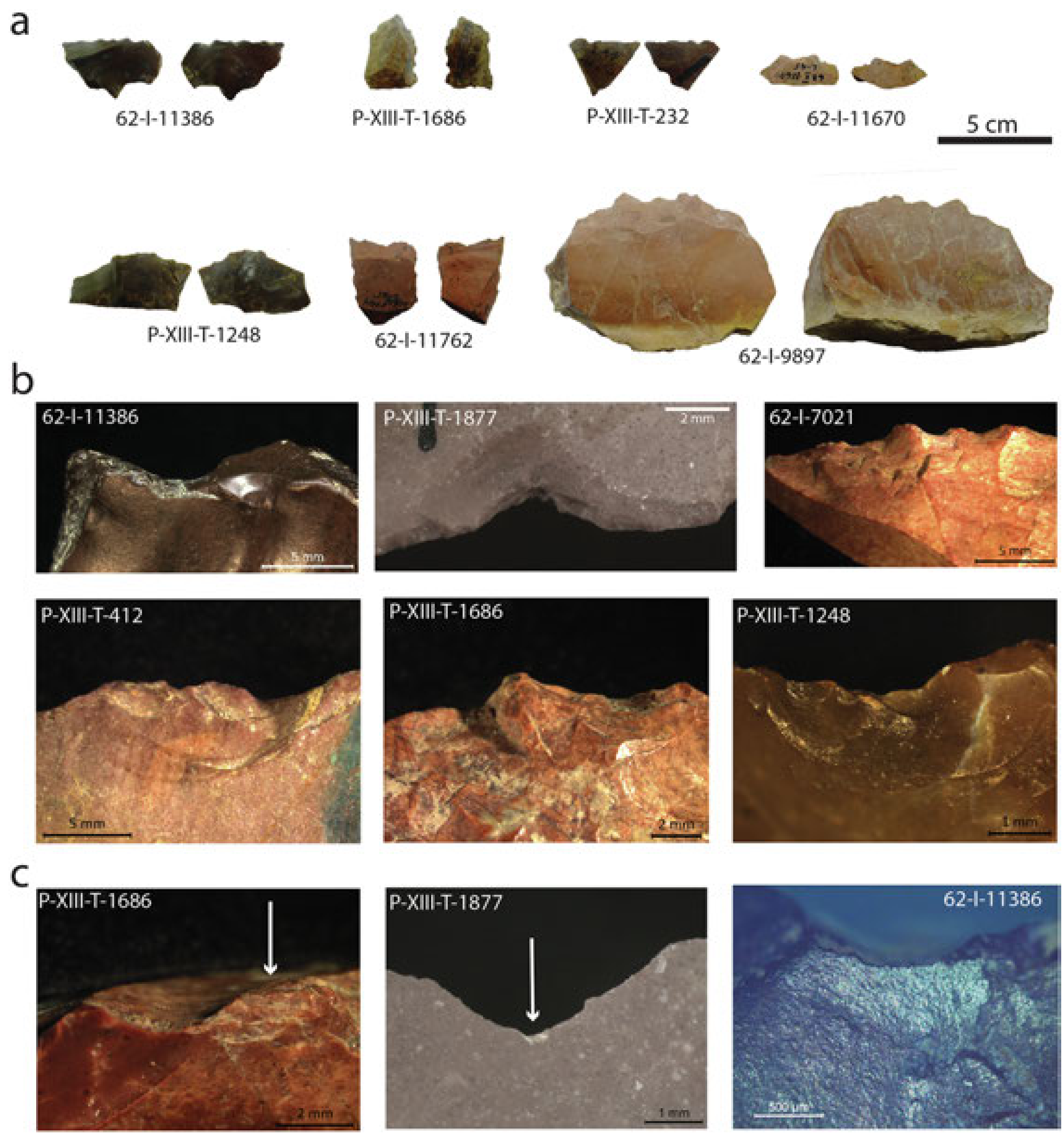


Fig. 14. **a)** Examples of tools from Tabon Cave whose notches result from intentional retouch. **b)** Details of notches whose morphology is characteristic of intentional retouch: irregular edges, uneven (accidented) inner surface, often steep initiations and presence of a counter bulb. **c)** Crushing, impact marks and striations testifying to the contact with a hard hammer.

microdenticulates and festooned denticulates with small to average degree of edge modification (See Fig. 1) (Bordes, 1961; Debenath and Dibble, 1994; Leroi-Gourhan, 2005 – 1st ed. 1998; Theodoropoulou, 2008; Thiébaut, 2005). This implies that some of the notches on archaeological artefacts might not be intentional retouches but use-related and suggests that the number of retouched artefacts amongst Island Southeast Asian assemblages could be even lower than previously considered (Reynolds, 1993, 2017; Pawlik, 2009; Patole-Edoumba et al., 2012; Marwick et al., 2016).

These results encourage a re-assessment of the origin of the notches on archaeological artefacts, especially in the case of assemblages containing a relatively high number of denticulates, such as in Song Keplek, Java, or in Gua Pandan, Sumatra (Forestier, 1999, 2007 – See Fig. 1). Although Fuentes and his colleagues (2020), showed that specific artefacts with a single large notch from Leang Sarru were retouched, pictures and drawings available in publications suggest that some stone tools with notches could be related to plant splitting activities: artefacts from Spirit Cave in Thailand, interpreted by Gorman (1970, p.100, plate III) as potentially used for wood working, or denticulates from Leang Sarru, Sulawesi (Ono et al, 2009; p.326, Fig. 4, top right), from Laurente Cave, Philippines (Patole-Edoumba, 2009, Fig. 6, n°3) or from Guanyindong Cave, Southwest China (Hu et al, 2018, ext. data Fig. 7), although a detailed microscopic analysis would be needed to confirm (or not) this hypothesis.

We showed that the micro-morphology of the notches varies according to their origin: plant splitting vs. intentional retouching with hard hammer. It would be interesting to also expand the experiments and test retouching with soft hammers (bamboo, wood, bone) and using techniques other than direct percussion (pressure, flexion). This will be the object of future research.

In the frame of this study, we already observed features similar to the ones present on the experimental tools used to split plants on artefacts from Tabon Cave. Although the number of stone tools exhibiting the diagnostic attributes is still limited (10), our use-wear analyses

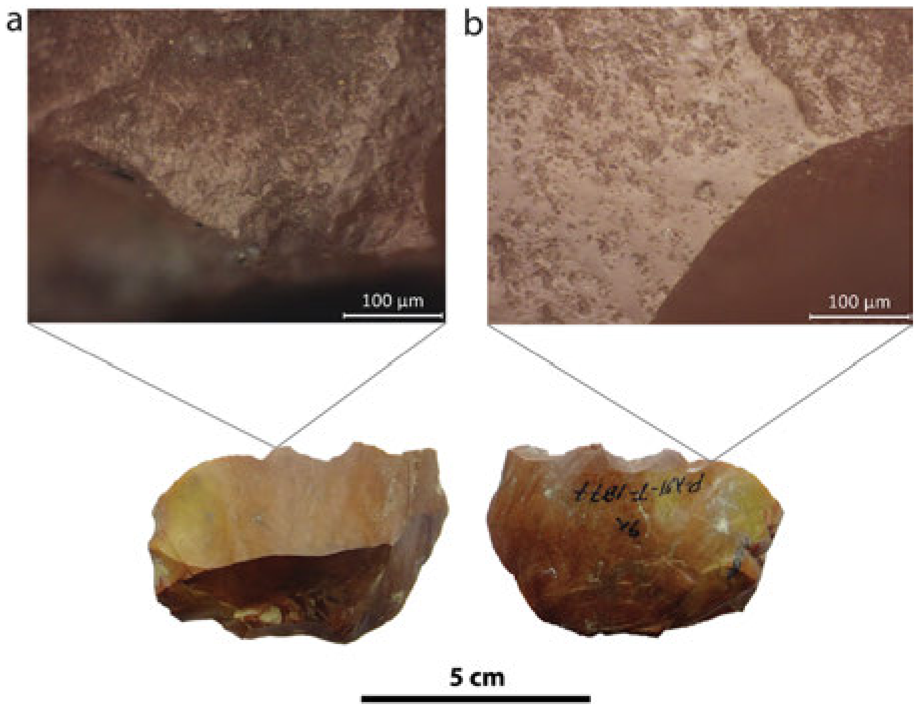


Fig. 15. 1st) This artefact from Tabon has been used first to process siliceous plants as indicated by the micro-polish (b). It enters in the variability of polishes created by the processing of bamboo, palm, rattan and *Donax cannaeformis* (Xhauflair et al., 2016). 2nd) The artefact has been retouched after that first use as the smooth, flat and shiny polish (b) is cut by the notches. 3rd) The tool has been used again to work a completely different material, as indicated by the rough and fluid polish observed on a dentil and inside the notches (a). This kind of polish is characteristic of softer materials such as skin or hide (Vaughan, 1985) but has also been observed on experimental tools we used to process tubers (*Manihot esculenta*).

show that the typological category of denticulates encompasses artefacts whose notches are in fact use-related. They also show that splitting plants has been performed in Southern Palawan around 40–30,000 years ago. These results allow us to dive into the deep history of plant use and give us a little insight into the technological behaviour of Southeast Asian prehistoric groups involving the use of ligneous perishable materials. The finality of their action remains unknown and could be the manufacturing of a wide range of objects or construction materials.

Splitting plants with the help of the twist-of-the-wrist process implies a constructive way of thinking and of approaching a technical problem that is more complex than only using one's muscles, as the strength is amplified by the lever (Leroi-Gourhan, 1971- 1st ed. 1943): in a fast motion, the wrist of the arm holding the tool is swivelled a quarter-turn to the right or to the left, the active part of the tool and the one opposite to it exerting a pressure on both parts of the plant, forcing it to diverge on either sides of the nick and making it grow longer. (see Fig. 17) Therefore, tracking the presence of this activity by the mean of use-wear analysis is also a way to address the question of the antiquity of the concept of lever and the evolution of cognitive abilities in our species and other ones, more ancient or contemporary (Détroit et al, 2019).

This method of splitting plants appears to be rather wide-spread nowadays. In Southeast Asia, we witnessed it in Luzon Island (Laguna) and in Java, Indonesia to split bamboo with machetes and Johan Kamminga recorded it among the Agta from the Sierra Madre, Northern Luzon in 1985–7 (Davenport, 2003). Huw Barton (2014) reported the use of an axe and a wooden stick to split a large segment of palm trunk with the twist-of-the-wrist in Borneo and Pétrequin and Pétrequin (1993) in Irian Jaya. Elsewhere in the world, De Stefanis (2018) reports the use of the same process in Southern France to split stems of the reed *Arundo donax* and young shoots of chestnut tree (*Castanea sativa*) by basket weavers. The twist-of-the-wrist process has also been documented to remove the bark from birch trees and split cedar wood to make canoes in North America (North of Montreal) (Gosselin, 1971). The fact that splitting with this process is practiced nowadays in very different regions of the world as part of traditional handicrafts raises the question whether this technical process was part of the common behavioural package that can be traced back to the first *Homo sapiens* groups who left Africa, or whether it rather was the fruit of local independent discoveries.

We hypothesise that bamboo splitting predates the invention of bamboo tools. Bamboo is turned nowadays into knives, spears, arrows and darts by traditional communities living in SE Asia (e.g. Forestier et al., 2008; Xhauflair et al., 2017a) and it has been suggested that a bamboo industry complemented stone tools in Southeast Asia during prehistory (e.g. Solheim, 1972; Pope, 1989; Forestier, 2003). Although we do not know when these organic knives and arrows appeared, it is clear that splitting bamboo leads to the discovery of the cutting properties of the plant which are due to the accumulation of silica in its epidermis (Ding et al., 2008). Beaune and her colleagues (2017), argue that humans innovate by analogy, and the discovery of the sharpness of bamboo segments would have led to the invention of bamboo tools. Tracking bamboo splitting could therefore be an indirect way of tracking the existence of bamboo knives.

We also showed that the notches of some of the denticulates from Tabon Cave were the fruit of intentional retouching, which testifies to the desire of prehistoric tool makers/users to control the properties of their instruments. In four cases, it turned out that the retouch took place after a first use of the tools, suggesting a functional reason for

Fig. 16. Denticulate from Tabon Cave whose notches seem to result from motions in the sediments or trampling: aside from the notches, the microwear distribution is completely random. The angle of the edge with the notches is quite low (22 to 25°), allowing notches to form easily. Yellow spots indicate the presence of micro-polish and black lines represent striations.

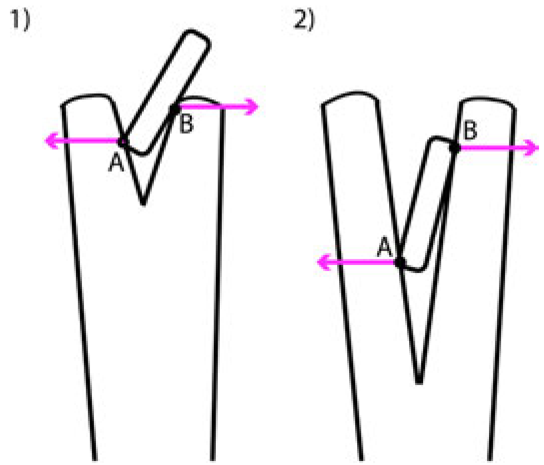


Fig. 17. During the twist-of-the-wrist process, the tool is used as a lever to amplify the strength. These two diagrams show the forces exerted (arrows) when the tool is partly (1) and completely (2) within the crack in the plant. The points A and B act simultaneously as active point and as resting point for the other one (Leroi-Gourhan, 1971). The pressure exerted to the edge of the tool (points A) leads to chipping and the creation of large crescent-break micro-scars.

retouching such as resharpening the edge or cleaning it. We also observed artefacts on which the notches seem to be completely independent of human intention: trampling or motions in the sediments (McBrearty et al., 1998; Vallin et al., 2001).

Altogether, the observations reported here raise the following question: should the term denticulates be restricted to tools intentionally retouched or encompass all tools with adjacent notches whatever the origin of the latter is?

9. Conclusion

Denticulates are stone tools whose one or more edges present a series of adjacent notches. These notches are usually considered as the products of intentional retouching performed by the tool makers in order to control the shape and the properties of the cutting edge. The results of our experiments, however, question the validity of this interpretation and suggest that some of the notches present on archaeological artefacts might in reality be the involuntary by-products of plant splitting. In the frame the experiments presented here, we were able to split four different plant taxa with the help of experimental lithic flake tools made of red jasper, using the twist-of-the-wrist process: the erect bamboo *Schizostachyum* cf. *lima*, the bamboo vine *Dinochloa luconiae*, the palm *Arenga pinnata* and the shrub *Donax cannaeformis*. We were unable to split rattan *Calamus merrillii*, which could be explained by the width of the stems (3,5 to 4,5 cm) or by the structure of rattan whose fibres are very strongly bound together. The process used (twist-of-the-wrist) is based on the way local Pala'wan communities split plants to manufacture utilitarian objects with the segments (e.g. flooring, tools, darts, baskets, musical instruments, traps, tying materials), as recorded during extensive fieldwork in Southern Palawan, Philippines. It implies making a first nick in a plant segment and then, inserting the tool in it, swivelling one's wrist to the left or to the right, using the tool as a lever to make the crack grow longer, until the plant is eventually split.

Splitting plants with the twist-of-the-wrist process resulted in a series of diagnostic use traces that are described above. Among them are large crescent-break micro-scars. In some cases, these large micro-scars were adjacent, making unretouched flakes look like denticulates after utilisation. We observed traces similar to the ones present on the experimental tools used to split plants on denticulated artefacts from Tabon Cave, suggesting that their notches resulted in fact from plant processing instead of intentional retouch.

This study adds another possible cause for the notches observed on archaeological artefacts, besides taphonomic causes like trampling and mobility in the sediments: plant splitting.

Consequently, the number of intentionally retouched artefacts among Southeast Asian assemblages seems to be even lower than previously thought. Splitting plants using the twist-of-the-wrist process has been reported in ethnographic context from various regions around the globe. This suggests that the question of the intentional character of the notches on prehistoric artefacts could be raised for other regions of the world as well, and that some might be related to plant processing activities.

These questions can be addressed by functional analyses of archaeological denticulates or other stone tools with notches, to determine if the use-wear pattern reported here and characteristic of plant splitting is present or not. This could also provide information about the antiquity of the concept of lever and possibly about the emergence of a bamboo industry in Southeast Asia, as being able to split bamboo is a necessary condition prior to the invention of bamboo knives and darts. Eventually, we can stress that there is a technological parallel between splitting plants and knapping stones, both producing blanks that can be used as such or shaped further.

CRediT authorship contribution statement

Hermine Xhauflair: Project administration, Funding acquisition, Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Alfred Pawlik:** Supervision, Validation, Funding acquisition, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Sheldon Jago-on:** Project administration, Resources, Data curation, Investigation, Writing - original draft, Writing - review & editing. **Timothy Vitales:** Project administration, Investigation, Writing - original draft, Writing - review & editing. **John Rey Callado:** Investigation, Methodology, Resources. **Danilo Tandang:** Investigation, Methodology, Resources. **Trishia Palconit:** Investigation, Methodology, Resources. **Dante Manipon:** Investigation, Methodology, Resources. **Claire Gaillard:** Supervision, Validation, Investigation, Writing - original draft, Writing - review & editing. **Angeliki Theodoropoulou:** Visualization, Writing - original draft. **Nicole Revel:** Supervision, Resources, Validation. **Hubert Forestier:** Supervision, Validation, Investigation, Funding acquisition, Formal analysis, Visualization, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2020.102334.

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