Use-wear experimental studies for differentiating flint tools processing bamboo from wood

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ABSTRACT – *Bamboo is widespread in south China and is one of the major organic resources in daily use through history due to its similar potential use value as wood. Due to the unfavourable preservation conditions and taphonomic alteration, the rare discovery of well-preserved organic remains from Palaeolithic sites means there is a lack of direct studies on the technology and behaviour of early prehistoric humans. Use-wear analysis has been proved as a reliable method to detect evidence left by working wood and bamboo on stone artefacts. This study aims to provide an experimental reference of use-wear features and patterns to identify and interpret the exploration of bamboo and wood resources in prehistory. In this experiment, 12 flint flakes were selected for processing bamboo stems and pine branches with working motions of whittling, sawing, and chopping. The results show that the use-wear features, including edge scarring, edge rounding, and polish, of bamboo-working and wood-working are distinctive. Edge scarring is closely related to the working motion, and moderate bright to very bright polish is a significant feature associated with bamboo-working. It is possible to distinguish wear traces caused by bamboo-working from those by wood-processing through a combination of low-power and high-power techniques under a 3D digital microscope.*

KEY WORDS – *use-wear analysis; experimental study; flints; bamboo-working; wood-working*

Poskusne študije sledov uporabe za razločevanje kamnitih orodij, uporabljenih za obdelavo bambusa, od tistih, za obdelavo lesa

IZVLEČEK – *Bambus je široko razširjen na jugu Kitajske in je eden od poglavitnih organskih virov, ki je podobno kot les v dnevni rabi skozi celotno zgodovino. Zaradi neugodnih pogojev v depoziciji in tafonomskih sprememb so dobro ohranjeni organski ostanki na paleolitskih najdiščih redki, kar pomeni, da imamo na voljo malo neposrednih študij o tehnologiji in obnašanju zgodnjih ljudi. Analiza sledov uporabe na kamnitih orodjih se je izkazala za zanesljivo metodo pri prepoznavanju dokazov o obdelavi lesa in bambusa. V pričujoči študiji predstavljamo referenčne podatke, pridobljene s poskusi, o značilnih sledovih in vzorcih uporabe na orodjih, da bi lahko prepoznali in razlagali uporabo bambusa in lesa kot vira surovin v prazgodovini. Pri poskusu smo izbrali 12 kamnitih odbitkov za obdelavo bambusovih debla in vej, pri čemer smo orodje uporabljali za rezanje, žaganje in sekanje. Rezultati kažejo, da lahko jasno razločimo sledove uporabe, ki vključujejo poškodbe na robu, nastanek zaobljenega roba in poliranje površine, pri delu z bambusom, od tistih, nastalih pri delu z lesom. Poškodbe na robu orodij so tesno povezane z delovnimi gibi, medtem ko lahko srednje do zelo svetla polirana območja povezujemo z obdelavo bambusa. Ugotavljamo, da lahko na podlagi kombinacije različnih tehnik, ki jih opazujemo pod 3D digitalnim mikroskopom, jasno razločimo, ali je bilo kamnito orodje uporabljeno pri delu s bambusom ali lesom.*

KLJUČNE BESEDE – *analiza sledov uporabe; poskusne študije; kamnita orodja; obdelava bambusa; obdelava lesa*

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Introduction

Early in 1958, Grahame Clark mentioned Stanley R. Mitchell's (*1949*) ethnological observation of Australian aborigines and pointed out that the most important use of stone tools is most likely the making of wooden weapons and utensils. Archaeologists have discovered, though rare, a few preserved wooden implements from Palaeolithic sites, as far back as the Gesher Benot Ya'aqov assemblage with a date of 780 000 BP (*Belitzky* et al. *1991; Goren-Inbar* et al. *1992*) as well as at the Schöningen site (*Thieme 1997; Schoch* et al. *2015*) and Lehringen site (*Marshack 1998*) in Germany. Three pieces of pencil-shaped pointed wooden objects with smooth surfaces and longitudinal scars were uncovered from the Ohalo II site in Israel. The excavators speculated these were flaked and shaved by some sharp knives (*Nadel* et al. *2006*). Richard W. Yerkes *et al.* (*2012*) claimed that light stone tools might be used to plane, shave and clean branches rather than heavier tasks like felling trees or splitting large logs.

Stone tools are generally regarded as the best evidence of human technology in prehistory. The discoveries mentioned above have proved that implements and objects made of wooden or organic materials might have long coexisted with, or been even earlier than, stone tools as the main tools in prehistory. Due to the unfavourable preservation conditions and taphonomic alteration, well-preserved organic remains are rarely uncovered in Palaeolithic sites, resulting in a lack of direct studies on the technology and behaviour of early prehistoric humans. A functional study might thus be a good complementary path to understand this kind of information through use-wear and residue analyses.

Use-wear analysis, which refers to the study of wear traces on the edges and/or surfaces of archaeological artefacts caused by use (*e.g., Odell 2004; Fullagar, Matherson 2013*), is considered as one of the keys to the functional interpretation of archaeological records (*Sterud 1978*). Various working tasks and contact materials of the archaeological tools, as well as the economic, social and cultural implications for human behaviour, can be recognized based on the results of such analysis, and many use-wear studies have successfully identified use-traces in relation to wood-working on stone artefacts from Palaeolithic sites (*Keeley 1980; Odell 1996; Chen* et al. *2002; 2014; Lemorini* et al. *2014; Liu, Chen 2016*).

Bamboo is widespread in South Asia, Southeast Asia, and East Asia. Though classified into the grass family *Poaceae*, bamboo stems are usually woody and hollow and are light and durable, with a great potential for production and utilization in daily life. Some scholars have proposed a 'bamboo hypothesis' to explain the lithic industry in Prehistoric Southeast Asia, proposing that stone tools might coexist with light organic materials like bamboo (*Solheim 1972; Pope 1989; Reynolds 2007*). A few micro-wear studies showed evidence related to plant material processing, which is widely interpreted as a result of bamboo-working (*Teodosio 2006; Pawlik 2010; Xhauflair, Pawlik 2010*).

In ancient China bamboo had notable economic and cultural significance. According to ethnoecological data, bamboo stems have been used as important raw materials for numerous functions such as building houses and making crafts over a long period of time (*e.g., Wang* et al. *1990; Liao 1996*). The earliest archaeological evidence of bamboo objects in China to date was uncovered from the Qianshanyang Neolithic site, dating back to 4700 years ago, including bamboo pieces and implements such as bamboo mats (*Zhejiang 1960; 2010*).

Hermine Xhauflair *et al.* (*2016*) conducted a series of replicated experiments particularly adapted to the specific lithic materials and vegetation of Southeast Asia. They aimed to provide a reference for identifying bamboo-working traces on archaeological stone tools, but the characteristics and pattern of use-wear relevant to bamboo-working are not clear yet, especially in Chinese archaeological studies. This is probably due to the inadequate experimental interpretative criteria concerning various working tasks on bamboo. More importantly, it is difficult to distinguish bamboo-working traces from those caused by wood or other hard organic materials (*Mijares 2001; Blench 2013*).

The development of use-wear analysis is not only characterized by establishing a reference collection, but also by the effort of those who try to improve the accuracy in the identification and recording of wear traces. Low-power and high-power are two traditional approaches of use-wear analysis. The low-power method (5–100x), using a stereomicroscope, focuses on the identification and interpretation of the edge scarring and edge rounding as indicators of working activities and contact materials if possible (*e.g., Tringham* et al. *1974; Odell 1977*). The high-power or microscopic method (100–1000x), using a metallurgical microscope or scan electronic microscope, allows distinguishing and classifying different types of materials, in more detailed but limited areas, with the emphasis on the observation of polish and striations (*e.g., Keeley 1980; Vaughan 1985*). These two approaches are complementary, and each of them has strengths and limitations (*Odell 2001*).

During the last decades, researchers have gradually attempted to use both techniques to improve the methodology of use-wear analysis (*e.g., Grace 1996; Lombard 2005; Van Gijn 2010; Macdonald 2013*). A stereomicroscope is used to examine and ascertain the relationship between the distribution of wear traces on the overall tool, and an incident light microscope is mainly for the identification of the function. The combination of both magnifications allows a more comprehensive analysis. However, how to integrate those two techniques in a more effective way is still under exploration.

Controlled experiment is considered crucial to improve the standardization of use-wear analysis and the rationality of functional interpretation. This study carried out a set of experiments to better understand the use-wear resulting from bamboo-working, attempting to distinguish it from that by wood-working. Employing a 3D digital microscope, we wish to provide a set of experimental criteria of use-wear features and patterns for identifying, in a more practical way, possible organic resources exploration and interpreting the functions of stone tools in prehistory.

Experimental program

This study is first aimed at understanding the use-wear features and patterns on flint artefacts resulting from bamboo-working under a 3D ultra-depth microscope, and secondly to differentiate the bamboo-working use-wear from the wood-working use-wear.

Experimental aim and design

As defined by George H. Odell (*1981*), whittling/shaving is a motion transversal to the working edge at an acute angle, whereas cutting/sawing is a motion longitudinal to the working edge in a position approximately perpendicular to the contact materials. Wood whittling/shaving often results in contiguous feather-terminated scars mainly on one side, which sometimes have a conchoidal shape (*Hou 1992*). Wood cutting/sawing usually produces large and medium longitudinal scars directionally on both surfaces of a tool (*Chen* et al. *2008*), and the working edge displays regular denticulation.

Twelve flakes with unretouched edges were selected as specimens in this experimental program (Fig. 1). The raw material of the specimens is flint collected from Danjiang River (Henan Province) in the central part of China. Among these specimens, two smaller flakes with sharp straight edges were used for whittling, and those flakes with larger edge angles for chopping. The flakes for sawing have relatively long and sharp edges that are straight or almost straight.

Bamboo and pine branches were chosen as the contact materials, as these are readily available in most parts of southern China. Considering the possible working tasks performed on bamboo and wood in the prehistoric period, three working motions were determined: chopping, sawing and whittling. To have

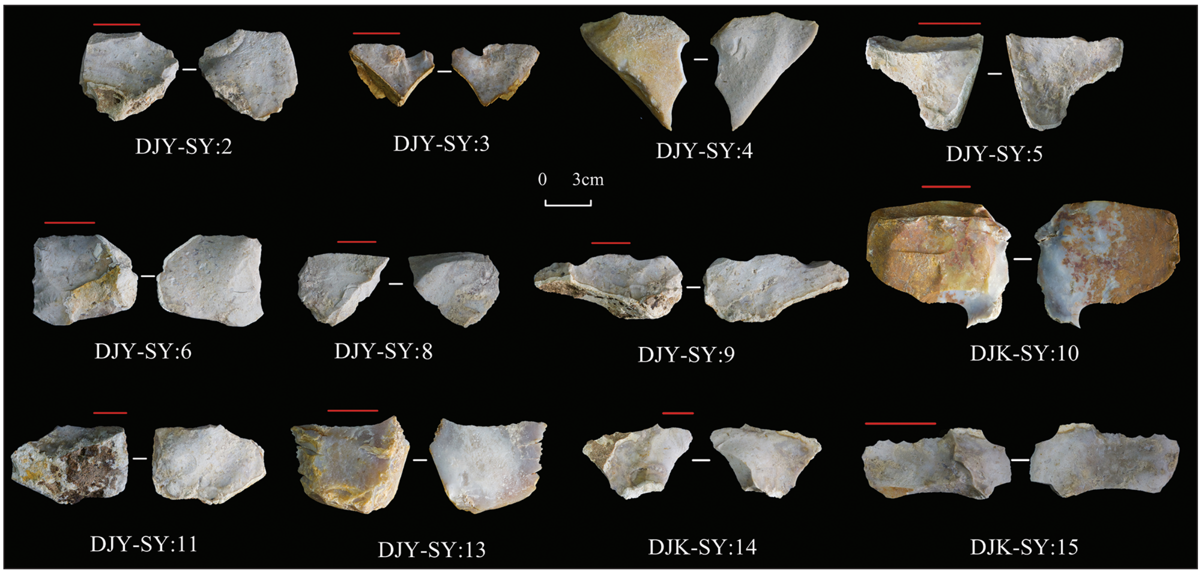

Fig. 1. Specimens in this experiment (used edge and location indicated by red line).

a better understanding of the formation of wear traces during usage, we also conducted multi-stage experiments (*Odell* et al. *1980; Chen* et al. *2013*) for every specimen. The duration of each experiment, the total time cost for processing the material with each specimen, was 30 minutes.

A group of students was invited to participate in the experiments in the laboratory. Given the detailed plan of the experimental program, they were shown how to perform the working tasks prior to the beginning of the experiments, and throughout the process their operations were closely monitored. One goal of our experiments is to understand the correlation between wear traces and contact materials and working motions, thus possible variables which would affect the wear traces were strictly controlled: every specimen had to be operated by a certain experimenter with the same supposed working motion and direction and with a steady force.

Analytical protocol

Two types of microscopes were employed in this experiment. The primary examination of specimens was carried out with a Nikon SMZ800 stereomicroscope with magnifications ranging from 10x to 63x, which allowed us to identify the overall distribution of the edge scarring, edge rounding and sometimes polish across the employable edge. All the experimental specimens were then observed and photographed under a 3D digital microscope Keyence VHX-5000 with magnifications between 20x and 200x. This is an optical microscope with the function of live depth composition, which integrates observation, image capture, and measurement capabilities, enabling detection of wear traces in a wider area with higher magnification at the same time. Compared to the approach of integrating two different kinds of microscopes, the automatic scanning and image stitching capacity of this equipment helps ease the workload considerably.

The recording criteria of use-wear patterns in this study consist of micro-fractural scarring, edge rounding, polish and striations. Scarring is documented and analysed by size (*Chen 2011*), termination (*Ho Ho Committee 1979*), distribution pattern (*Zhang* et al. *2010*) and location. Edge rounding, an indicator of the presence of abrasion, is divided into light, medium and heavy according to the extent of wear (*Odell 1996*). Polish is described mainly by brightness, the texture of the surface and the presence or absence of certain topographic features (*Keeley 1980*). Striations are often seen as linear traces indicating possible motions and directions of tool use. The presence of striations varies, and experimental specimens do not exhibit them in most cases (*Lombard 2005*).

Full-scale cleaning is necessary for each specimen after each periodic experimental operation and before observation under the microscope. The experimenter must wear powder-free gloves while handling the specimens during the whole experiment to avoid any possible contamination. First, each specimen was immersed in a warm detergent solution for 10–20 minutes. Then, JP-010T Sonic Cleanser was used to make each specimen sink in an ultrasonic bath of clean water for 10–20 minutes. The next step is cleaning each piece with an alcohol solution to remove finger grease. Finally, the specimens were placed in an ultrasonic tank with clean water for another 10–20 minutes and left to dry in the air. The residue that remained on several specimens after processing wood was difficult to remove, and thus additional cleaning was conducted before the final step, and this was immersion in warm NaOH (20–30%) for 10–20 minutes. According to Lawrence Keeley (*1980*), experimental tools are not required to remove the mineral deposits, and thus the 10% HCl solution was not used in our experiments. It is worth noting that special care must be taken to protect the employable edge of the specimen from contacting with the ultrasonic tank during the cleaning process.

Experimental procedure

The basic information of the specimens was documented in detail, including: (1) morphological features, technological characteristics, morphometric parameters and raw material colours of the experimental specimens; (2) working motions; (3) conditions of contact materials; and (4) the gender and grip strength of the operators.

Macroscopic photos were taken to record the original state of each specimen. Microscopic photos of the selected working edges before use were taken in several main magnifications of 20x, 50x or 100x, 200x. Meanwhile, the overall shapes of specimens were sketched to mark the employable locations.

The whole process of every task was divided into six 5-min sections to ensure the working efficiency of each operator. Details concerning operation times, processing efficiency and alteration of the employable edges, modification of the contact materials were recorded during each interval. Based on this information, each specimen was assigned to be observed under the microscope after every 15 minutes to record the wear traces.

After cleaning, each specimen was examined under the stereomicroscope (Nikon SMZ800), and then under the 3D digital microscope (Keyence VHX-5000) from low to high magnifications, in order to compare the results with their former conditions and be photographed. The characteristics of scarring, edge rounding, polish and striations were also described.

Results

A total of twelve specimens developed wear traces after use, and the results of microscopic observation are presented in the following (Tab. 1).

Use-wear resulting from bamboo-working

Sawing bamboo

Three specimens were selected for sawing bamboo stems and show recognizable use-wear after 30 minutes of use (Fig. 2.a1, a2, b1, b2). The medium and small scars, associated with a few large ones, distribute continuously along the edge bifacially. Most are oblique to the transversal axis of the edge, showing feathered and snapped terminations. Some rolled-over scars (*Odell 1996; Chen* et al. *2008*), which refer to the scars observed on dorsal or ventral surfaces, initiate from the opposite surface. The edge for sawing dry bamboo exhibits relatively more scars than the one for sawing fresh bamboo stems.

The moderate to highly bright polish is observed on both surfaces, mainly displaying on the elevated parts of the edge. Some polish links together as small zones. The most developed and extensive polish, characterized as very bright and smooth, was discovered on the flakes for sawing fresh bamboo. In such cases, the well-linked polish extends over the bulged parts of the edge and less bright polish is present inside some scars. Heavy rounding was observed on the employable edges of these three specimens. Except for some short striations parallel to the working edge found occasionally on the specimen for sawing fresh bamboo stems, no apparent striations were recognized.

Chopping bamboo

Two specimens were selected for chopping bamboo stems over 30 minutes. The use-wear is described as follows, including resulting from chopping dry and fresh bamboo stems (Fig. 2.c1, c2, d1, d2).

Stepped scars mainly of medium and large size distribute unevenly either on the dorsal or ventral surfaces, a few are overlapped. Small feathered scars scatter along the very edge.

Heavy rounding developed on both surfaces, which makes the edge ridge become dull. The specimen for chopping fresh bamboo displays bright polish in a relatively limited area. The polish seems not well-linked but forms a domed shape, and most scatters near the small scars. No apparent striations were identified.

Whittling fresh bamboo

Specimen No. DJK-SY:3 was used for whittling fresh bamboo stems over 30 minutes. Small and medium feathered scars are continuously distributed mainly on the dorsal surface – the non-contact surface – of the working edge. Several scars are oblique to the transversal axis of the edge. Inside the large and intrusive feathered and hinged scars, small feathered scars were observed. There are also a few medium stepped scars with rolled-over appearance. The overall margin of the contact edge appears denticulated. The employable edge on the non-contact surface shows light and medium rounding, with heavier rounding on the elevated part. Polish and striations were not recognized (Fig. 2.e1, e2).

Use-wear resulting from wood-working

Sawing wood

After 30 minutes of use, use-wear was observed on the three experimental specimens for sawing pine (Fig. 3.a1, a2, b1, b2). Both surfaces of the employable edge are dominated by feathered and snapped

Specimen No.	Contact material	Working motion	Duration (min)	Action (strikes)
DJK-SY:2	Dry bamboo stem	sawing	30	3357
DJK-SY:6	Dry bamboo stem	chopping	30	2515
DJK-SY:3	Fresh bamboo stem	whittling	30	1695
DJK-SY:4	Fresh bamboo stem	sawing	30	2249
DJK-SY:5	Fresh bamboo stem	sawing	30	3013
DJK-SY:13	Fresh bamboo stem	chopping	30	2549
DJK-SY:14	Dry pine branch	whittling	30	2129
DJK-SY:9	Dry pine branch	sawing	30	2789
DJK-SY:8	Dry pine branch	chopping	30	2651
DJK-SY:10	Fresh pine branch	sawing	30	2253
DJK-SY:15	Fresh pine branch	sawing	30	2948
DJK-SY:11	Fresh pine branch	chopping	30	2586

Tab. 1. Basic information of the experiments undertaken.

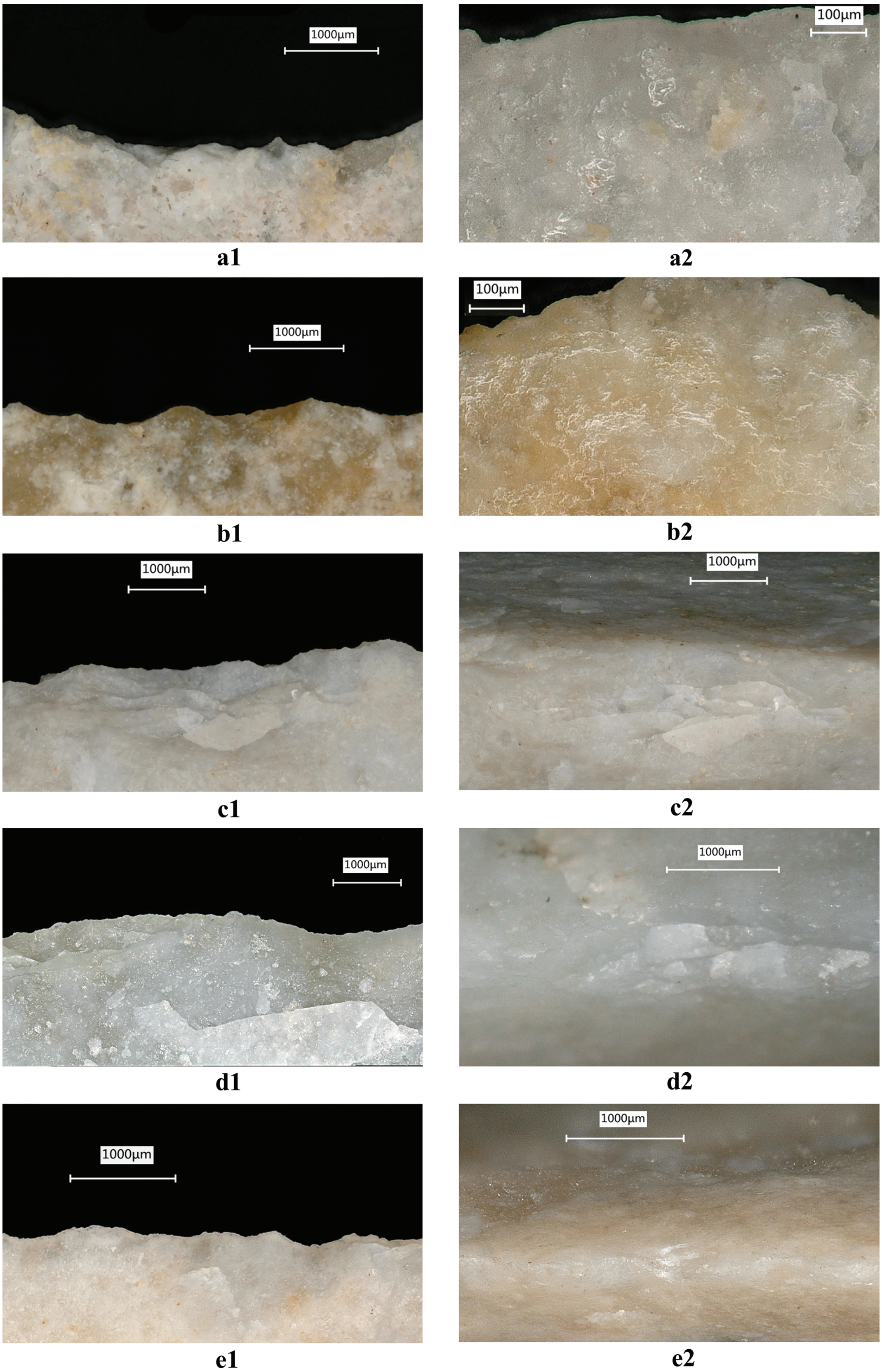

Fig. 2. Use-wear resulting from bamboo-working. **a1** ***sawing dry bamboo (No. DJK-SY:2), scarring D40x;*** **a2** ***polish, 30min, V400x;*** **b1** ***sawing fresh bamboo (No. DJK-SY:4), scarring D40x;*** **b2** ***polish, 30min D400x;*** **c1** ***chopping dry bamboo (No. DJK-SY:6), scarring D30x;*** **c2** ***rounding, 30min, R30x;*** **d1** ***chopping fresh bamboo (No. DJK-SY:13), scarring V30x;*** **d2** ***rounding, 30min, R50x;*** **e1** ***whittling fresh bamboo (No. DJK-SY:3), scarring D40x;*** **e2** ***rounding, 30min, R50x.***

scars in large, medium and small sizes. A few large scars occur in rolled-over appearance. The small scars distribute more closely to the edge margin. Some unevenly distributed scars in association with hinged terminations were also found on the specimen used for sawing dry pine. For the specimen sawing fresh pine, scars with occasional stepped terminations are distributed continuously.

The specimen for sawing dry pine (No. DJK-SY:9) shows heavy rounding, while the one for sawing fresh pine (No. DJK-SY:10) presents medium rounding. Moderate bright to bright polish was observed on both surfaces of the edge, of which some developed polishes with the occurrence of short lines. More developed polish appears on the specimen for sawing fresh pine, and very bright and smooth polish is only observed on the elevated part of the edge. In this case, no obvious striations were observed.

Chopping wood

The specimens No. DJK-SY:8 and No. DJK-SY:11 were used for experimentally chopping dry and fresh pine branches for about 30 minutes (Fig. 3.c1, c2, d1, d2).

Small feathered scars, and medium scars with stepped and snapped terminations, distribute unevenly on these two specimens. Scars on the specimen for chopping dry pine are mainly on the dorsal surface, while several notches of different sizes distribute on the ventral surface.

Both specimens exhibit medium and heavy rounding on the used edges, and the specimen for chopping fresh pine shows heavier rounding. Moderate bright and dull polish were identified on both specimens, with few striations.

Whittling dry wood

One flake (No. DJK-SY:14) was used for whittling dry pine for around 30 minutes and presents obvious use-wear (Fig. 3.e1, e2).

Scars were mainly observed on the non-contact side of the working edge, the dorsal surface, and these are medium and small scars with feathered and stepped terminations in relatively continuous distribution with few overlapping. There are also several hinged scars scattering along the dorsal side. The overall shape of the edge margin of the ventral contact surface appears denticulated.

Most part of the working edge shows medium rounding, while the elevated part of edge ridge displays heavy rounding. Only the contact surface of the working edge presents moderate bright and rough polish. Striations were not identified.

Discussion

The experimental results suggest that wear traces caused by bamboo-working and wood-working are distinctive. According to multi-stage experiments, the formation of scarring and polish appears differently. For the working motions of sawing and chopping, most scars were produced within the first 15 minutes, allowing the easy identification of working tasks. In the latter 15-min stage, only some small feathered scars were produced along the edge margin. On the other hand, the polish becomes more and more developed over the whole 30 minutes.

Use-wear features and patterns of bamboo-working

The bamboo-working experiments by Armand S. B. Mijares (*2001*), as well as Xhauflair and his colleagues (*2016*), show that medium to very large microfractural scarring, mainly in stepped terminations, would occur; the polish created by bamboo-working is well-developed, which is smooth and bright, very domed and often well-linked; and numerous brushstroke striations were also produced, though not on every specimen.

According to our results from the bamboo-working experiments, besides the stepped scars, feathered and snapped scars were also recognized on every specimen. The small scars in feathered termination tend to distribute continuously along the edge margin. The features of scarring are complex, which might be affected by working motions. Continuously distributed scars often occur during whittling and sawing, while uneven and overlapped scars appear with chopping. Rolled-over scars (*Odell 1996; Chen* et al. *2008*), also described as hinged cross-section scars (*Xhauflair* et al. *2016*), appear frequently. Processing dry bamboo stem tends to produce hinged-terminated scars. Medium to heavy rounding usually occurs on the edges of tools used for bamboo-working.

Moderate to very bright polish is a significant feature of use-wear in connection with bamboo-working (Fig. 4). The extent of polish expands when it is well-developed; the polish on the elevated part of the edge appears linked together, but the linkage of polish caused by chopping is much poorer. Polish produced by processing fresh bamboo is generally

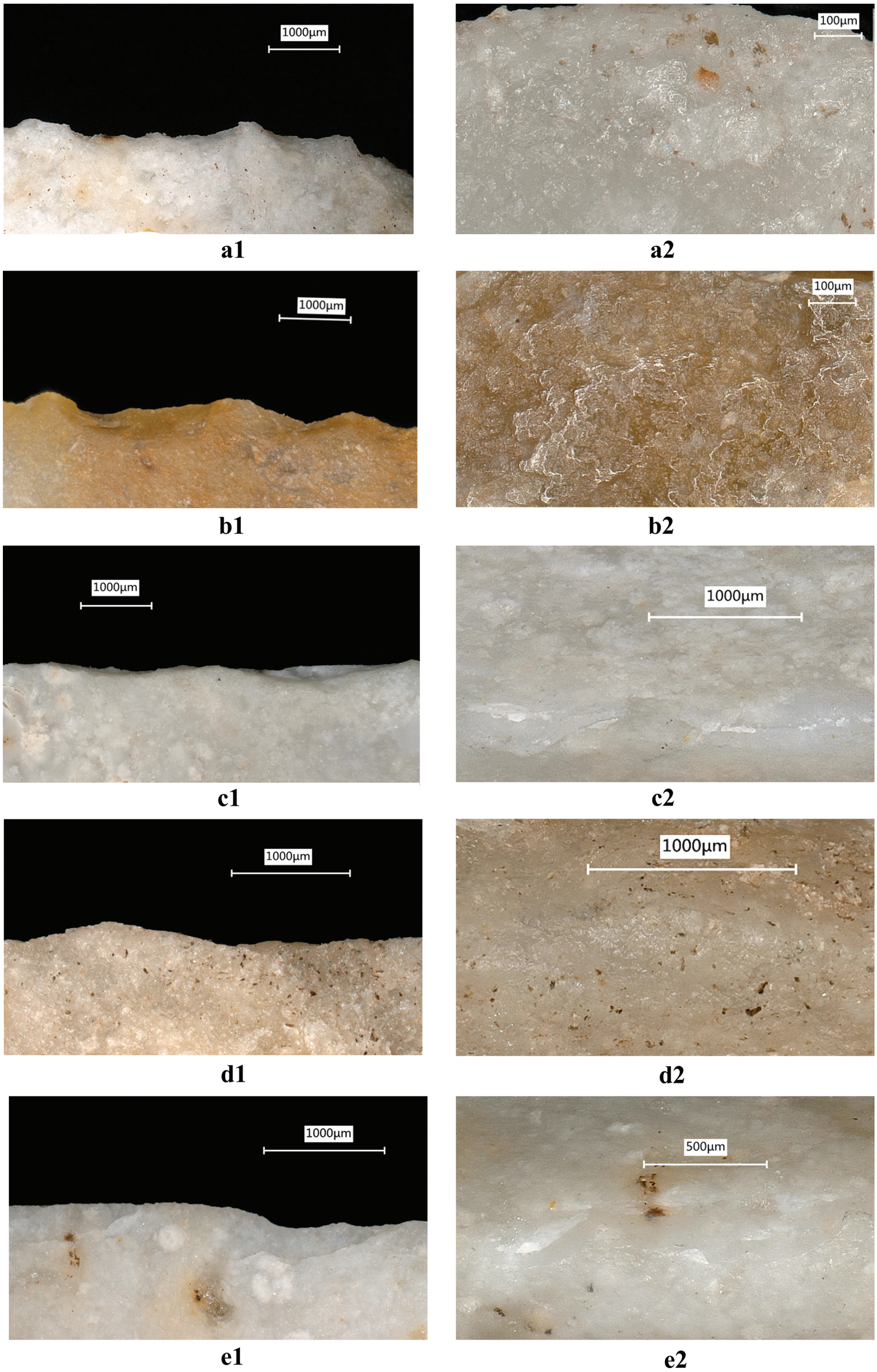

Fig. 3. Use-wear resulting from wood-working. a1 *sawing dry pine (No. DJK-SY:9), scarring V30x;* a2 *polish, 30min, V400x;* b1 *sawing fresh pine (No. DJK-SY:10), scarring V30x;* b2 *polish, 30min D400x;* c1 *chopping dry pine (No. DJK-SY:8), scarring D30x;* c2 *rounding, 30min, R50x;* d1 *chopping fresh pine (No. DJK-SY:11), scarring D50x;* d2 *rounding, 30min, R60x;* e1 *whittling dry wood (No. DJK-SY:14), scarring;* e2 *rounding, 30min, R100x.*

more developed than that by dry bamboo, but an exception is found on one specimen for sawing fresh bamboo, which develops polish less bright than that resulting from sawing dry bamboo. Based on the dynamic observation of the multi-stage experiments, it can be suggested that the development of use-wear is more probably affected by working intensity.

No apparent striations were observed under the optical microscope in our experiment. The development and appearance of the striations might be influenced by various factors, which needs to be further explored in the future.

Use-wear features and patterns of wood-working

Many experimental and archaeological studies have been conducted to explore the characteristics of wood-working traces. It is summarized that the use-wear resulting from working on woody materials of medium hardness mainly consists of two categories: first, the more common smooth, bright and domed polish with occasional flat striations (*Shea 1992; Yerkes* et al. *2003; 2012*); second, the continuous distribution of shallow feathered scars of large and/or medium size, and especially with the typical marks of rolled-over shaped scars along the working edges (see *Chen* et al. *2008.Fig. 3.8; Odell 1981; 1996; Shen 2001*).

Comparison of use-wear patterns between bamboo-working and wood-working

Our experiments show that there are some similarities and differences between the use-wear resulting from bamboo-working and wood-working on flints (Fig. 5).

Rolled-over scars are commonly produced by processing both bamboo and wood, and are indicative of working with other woody materials, as suggested in previous experiments (*e.g., Odell 1996; Shen 2001; Chen* et al. *2008*). The characteristics of micro-fractural scarring, especially its distribution patterns, are in close relation to the working motion. The patterns of scars caused by whittling and sawing these two materials are similar. More differences can be observed on the specimens for chopping activity: bamboo-chopping tends to produce more scars with stepped termination and overlapped distribution, while scars produced by chopping wood are relatively smaller, presenting some medium and small notches on the edge ridge. Hinged scars often exist in association with processing dry wood and bamboo.

It has been demonstrated by a large number of experiments that a distinctive polish can be formed by different types of wood and various working motions. Usually bright or very bright with a smooth texture, the surface of the polish is rarely flat but appears to have a fluted or domed morphology (*e.g., Keeley 1980; Shen 2001; Wang 2008*). Similar features correspond to the polish produced on specimens for bamboo-sawing and bamboo-chopping. More similarities exist on the edge rounding, which is characterized by medium and heavy rounding.

In addition, rough and moderate bright polish was observed in the wood-working experiments. However, under approximately the same conditions the range and distribution of polish resulting from bamboo-working are more extensive and well-linked. In the sawing task, bamboo polish tends to link together and seems like a net in a zone, but wood polish tends to form numerous short lines. Bamboo polish is brighter than wood polish caused by chopping. Generally, soft and fresh wood or bamboo produces

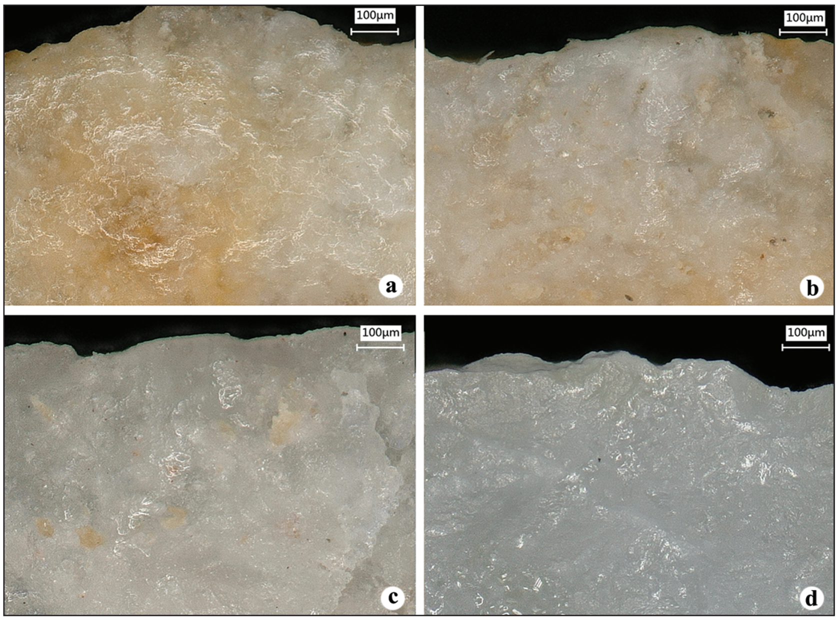

Fig. 4. Polish resulting from different bamboo-working activities: **a** ***sawing fresh bamboo (No. DJK-SY:4), 30min, D400x;*** **b** ***sawing fresh bamboo (No. DJK-SY:5), 30min, D400x;*** **c** ***sawing dry bamboo (No. DJK-SY:2), 30min, V400x;*** **d** ***chopping fresh bamboo (No. DJK-SY:13), 30min, V400x.***

more polish on the tool surface than hard and dry wood or bamboo after the same use duration (also see *Keeley 1980; Vaughan 1985*).

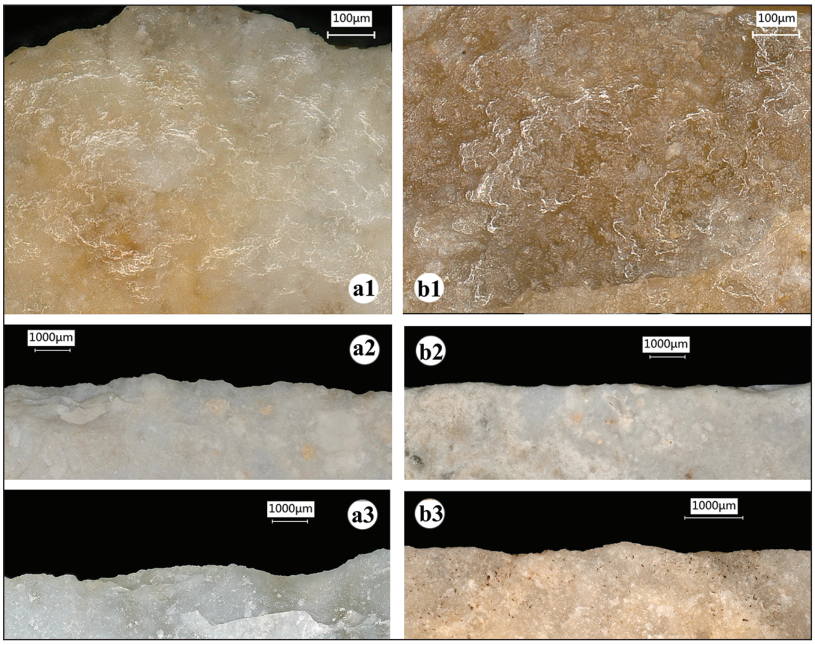

Fig. 5. Comparison between the use-wear resulting from bamboo-working and wood-working. **a1** ***sawing fresh bamboo (No. DJK-SY:4), 30min, well-linked brighter polish, D400x;*** **a2** ***chopping dry bamboo (No. DJK-SY:6), stepped and overlapped scarring, 30min, D30x;*** **a3** ***chopping fresh bamboo (No. DJK-SY:13), 30min, stepped scarring, V30x;*** **b1** ***sawing fresh pine (No. DJK-SY:10), 30min, bright polish, D400x;*** **b2** ***chopping dry pine (No. DJK- SY:8), 30min, scarring, D30x;*** **b3** ***chopping fresh pine (No. DJK-SY:11), 30min, scarring, D50x.***

Conclusion

The experiments and results described above indicate that the features and patterns of micro-fractural scarring, edge rounding and polish caused by bamboo-working and wood-working could be identified under the 3D digital microscope.

Based on our experiment and other similar studies, it is demonstrated that more similarities exist between the use-wear resulting from bamboo-working and wood-working on flints, including the pattern and distribution of scarring, as well as edge rounding. The distinction and connection to working motions appear stronger than that to the contact materials. The characteristics of scarring can be used to understand the movement of tools, the brightness, morphology, and distribution of polish are also useful to identify the specific working motion.

Notably, there are a few differences allowing us to distinguish the use-wear caused by bamboo-working from that by wood-working, which should be considered in terms of a set of features rather than a single element. The most obvious distinction is that more stepped and overlapped scars and brighter polish are produced by bamboo-working than wood-working. Moreover, the range and distribution of polish resulting from bamboo-working are more extensive and well-linked. In the case of sawing activity, bamboo polish tends to link together and seems like a net in a zone, but wood polish tends to form numerous short lines. Although the resulting bamboo-working polish seems like that from reed processing (see *Vaughan 1985; Jensen 1994*), it is distinguishable when the light edge rounding and small feathered scarring are taken into consideration.

It is worth noting that striations are often seen as linear indicators of working motion in the high-power analysis. However, our experimental results show that the distribution of scarring and polish is closely related to the specific movement of the tools, which could be used to infer the working motion. The absence of striations on most specimens might be attributed to the raw material or other factors.

This study also proves that the optical 3D digital microscope used in this work has great potential to conduct integrative use-wear analysis. The capabilities of live depth composition and advanced imaging enable observation and documentation of wear traces and their formation with more details and in more extensive areas on tools. The presentation and description of traces can be more readily perceived and easily understood, which could be helpful for analysing a large sample of stone tools. Since numerous variables might influence the development of use-wear, more experiments and use-wear analyses on archaeological stone tools are needed in the future.

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