附件 2:

浙江大学优秀博士学位论文申请表

论文题目	环太湖地区马家浜文化至马桥文化时期石制农具研究		
论文英文题目	A Study of StoneAgricultural Implements from the Majiabang Culture to the Maqiao Culture in the Taihu Lake Region		
作者学号	作者姓名	获得博士学位日期	论文涉及的研究方向
11904060	薛理平	2025.06.20	史前考古，石器分析
作者电话	作者邮箱	现工作或学习单位	
18867108584	1203533525@qq.com	浙大城市学院艺术与考古学院	
一级学科或专业学位类别代码	一级学科或专业学位类别名称	二级学科或专业学位领域代码	二级学科名称或专业学位领域名称
0601	考古学	060101	先秦考古
主导师姓名	陈虹	主导师研究方向	旧石器时代考古
导师组其他成员姓名①	唐锦琼，陈明辉	导师组其他成员研究方向	新石器时代考古，夏商周考古

申请学位时论文的总体评价	优秀（4）个	良好（1）个	其他（ ）个

作者攻博期间及获得博士学位后一年内与博士学位论文密切相关的浙大为第一单位的代表性成果②	序号	成果名称③	成果出处④	获得年月⑤	查询信息⑥
	1	A functional study of ground stone knives and sickles in the Lower Yangtze River Region during the Late Neolithic and Bronze Age	Journal of Archaeological Science: Reports	2024.11.29	https://doi.org/10.1016/j.jasrep.2024.104892
	2	An experimental investigation of the ground stone knives and sickles in the Lower Yangtze River Region during the Late Neolithic and Bronze Age	Journal of Archaeological Science: Reports	2023.09.23	https://doi.org/10.1016/j.jasrep.2023.104208
	3	A functional study of ground stone tools from the Bronze Age site of Dingjiacun in South China: based on use-wear evidence	Journal of Archaeological Science: Reports	2021.10.21	https://doi.org/10.1016/j.jasrep.2021.103215
	4				
	5				

论文主要创新点

本论文的创新点主要体现在以下三个方面：

1.思想创新：以往有关环太湖地区石制农具的研究重点始终默认落在对物质实用功能的讨论上，且主要关注单类工具，并没有清晰地认识到石制农具在精神象征层面的功能意义，也缺少一个将各类石制农具整体统一到其所处时代社会经济和文化背景下的综合研究视角。本研究突破了传统的工具功能分析视角，采用了综合的跨学科研究框架，将石制农具置于农业生产与社会信仰两个场域的交汇点，剖析其物质实用与精神象征双重价值的实践路径，揭示出不同类型石制农具的具体实用功能，以及它们如何在推动农业生产发展的进程中，与不同时期社会信仰体系的互动情况。

2.方法创新：研究从生命史的角度出发，考察工具从设计到原料获取、制作、使用、维护、

<table>
<tr><td></td><td>循环利用以及废弃和后埋藏过程的完整生命周期，解析其在各个环节所表现出的技术逻辑和文化意义。同时，基于物质实用功能和精神象征功能两个基本面，结合了实验考古、微痕分析、残留物分析、民族志类比以及力学和人体工学分析等方法，对石制农具的功能进行综合阐释，探讨其在农业生产与社会信仰体系中的双重价值。
3.观点创新：
（1）石制农具既可以是农业生产力的技术载体，也可以是精神信仰的象征符号，二者分别对应工具和礼器，前者强调物质实用功能，倾向实用型设计，后者强调精神象征功能，倾向象征型设计。
（2）石制农具的研究应以功能阐释为中心，只有结合形制、工艺、微痕和残留物、出土背景（使用情境）等多个要素进行微观-宏观情境的嵌套分析才能对功能进行准确把握与合理解释，需要警惕“实用为先”的功能预设，不能以针对（疑似）非实用器的观察结果直接肯定或否定其实用功能“合法”性。
（3）从崧泽文化晚期至马桥文化时期，石制农具体系始终在“农”与“祀”的双重场域中动态演进——前者指向稻作农业的物质生产需求，后者关联文化信仰的精神秩序建构。这一双重价值实践路径的构建，不仅反映了古代人类应对自然挑战的技术智慧，更揭示出社会组织形态变迁的文化逻辑。作为环太湖地区稻作文明的重要物化载体之一，石制农具折射出这一区域从平等社会到早期文明、再到成熟文明和早期国家、最终走向去中心化并融入中华文明整体发展进程的历史演变脉络，见证了社会经济和文化的变迁轨迹。
（4）论文的核心贡献在于重新全面审视了石制农具的功能和意义，并以之为窗口更深入地考察了古代社会的经济、文化和组织形态变迁历程。这一研究有望为环太湖地区乃至更广泛地区的物质文明研究带来新的视野和启发，推动对古代物质文明的理解走向更深层次的整合与创新。</td></tr>
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① 其他导师应与研究生管理系统一致，如有多位，可添加行，如没有，可填无。

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附件 3:

代表性成果证明材料

序号	论文题目	刊物名称	发表时间	本人排序/总人数/导师排序	浙大是否第一单位	备注(SSCI/一级、SCI/EI 收录、5 年平均影响因子等)	他引次数	学位论文对应章节
1	A functional study of ground stone knives and sickles in the Lower Yangtze River Region during the Late Neolithic and Bronze Age	Journal of Archaeological Science: Reports	2024.11.29	**1/8/8**	是	**A&HCI 收录，1.5**	**2**	第五、八章
2	An experimental investigation of the ground stone knives and sickles in the Lower Yangtze River Region during the Late Neolithic and Bronze Age	Journal of Archaeological Science: Reports	2023.09.23	**1/3/2**	是	**A&HCI 收录，1.5**	**0**	第五章
3	A functional study of ground stone tools from the Bronze Age site of Dingjiacun in South China: based on use-wear evidence	Journal of Archaeological Science: Reports	2021.10.21	**2/6/1**	是	**A&HCI 收录，1.5**	**1**	第五章
4								

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A functional study of ground stone knives and sickles in the Lower Yangtze River Region during the Late Neolithic and Bronze Age

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ARTICLE INFO

Keywords:
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ABSTRACT

Ground stone knives and sickles were important implements in the lower Yangtze River region during the Late Neolithic and Bronze Age, playing a pivotal role in understanding the technological behaviour and economic activities of prehistoric humans. In this study, twelve knives and seven sickles of the Liangzhu culture (ca. 3300BC–2300BC) and four knives of the Maqiao culture (ca. 1900BC–1200BC) were analysed, through an integrated approach that combined use-wear analysis, Py-GC/MS analysis, and replicative experimentation. The results show that three knives and one sickle of the Liangzhu culture and two knives of the Maqiao culture had been used for harvesting gramineous plants, probably rice. The knives of the Liangzhu culture were used with handles, exhibiting two different hafting techniques, one of which potentially involved the use of animal glue as binding agents. The half-moon-shaped knives of the Maqiao culture were used handheld with two working motions: upward picking and downward pinching. Besides harvesting tools, one hafted knife of Liangzhu culture used for scraping wood or bamboo was also identified. Notably, for the first time, evidence of polishing stone knives with gramineous plants has been found in both the Liangzhu and Maqiao cultures, which potentially signifies a special symbolic or ritual significance beyond their physical functions.

1. Introduction

The Lower Yangtze River Region, a fertile cradle of human civilization in East Asia, witnessed the emergence and flourishing of advanced rice farming agriculture during the Late Neolithic Age (Zheng et al, 2016; Zhao, 2010; Fuller et al., 2009, 2007), with the Liangzhu culture (ca. 3300BC–2300BC) marking the peak of this development (Zhang, 2023; Liu et al., 2017a; Zhao, 2018; Pan and Yuan, 2018; Zhuang et al., 2014). The discoveries of massive amount of carbonized rice remains (ZPICRA, 2019:179–181) and well-structured paddy fields (Zheng et al., 2014; Jin et al., 2019) indicateded the paramount significance of rice cultivation in the economic subsistence during the Liangzhu culture period. This period also witnessed a significant revolution in ground stone technology, leading to a new era where the most diverse and specialized ground stone tools for agriculture emerged, unparalleled throughout the Neolithic Age of China (Zhang, 2023; Liu, 2008:89–99). Following the Liangzhu culture, the Maqiao culture (ca. 1900–1200BC), recognized as the earliest Bronze Age culture in southeastern China, experienced some setbacks in rice agriculture economy (Yuan et al., 2020; SMCPAM, 2002:343–344), which was reportedly associated with climatic changes (Li et al., 2024; Zhang et al., 2021; Huang et al., 2019; Wang et al., 2018; Chen et al., 2005; Stanley et al., 1999). During this period, ground stone tools remained the primary implements in agricultural production (Cao, 2010). Therefore, the studies of these stone tools are of great importance, especially from a functional perspective.

Ground stone knives and sickles contributing to the ground stone assemblages as essential implements for daily life and agricultural production, which play a pivotal role in understanding the technological behaviour, economic activities and subsistence patterns of prehistoric human. These tools found in the Lower Yangtze River Region are often

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2352-409X/

Table 1
The information of knives and sickles analysed in this study.

No.	Specimen ID	Type	Lithology	Length, width, thickness (cm)	Weight (g)	Site/Locality
1	0077	knife	Argillaceous Silicalite	17.2, 7.8, 1.0	542.36	Tangqi
2	T103②:15	knife	Hornfels	10.5, 6.8, 0.8	59.04	Miaoqian
3	00LMT0506⑥:2	knife	Hornfels	8.9, 5.1, 0.6	25.35	Miaoqian
4	T401G1①:1	knife	Hornfels	11.5, 9.4, 0.4	64.18	Miaoqian
5	0056	knife	Hornfels	12.5, 4.3, 0.4	34.33	Liangzhu
6	T517②:22	knife	Hornfels	11.4, 4.6, 0.7	47.71	Miaoqian
7	0148	knife	Siltstone	10.4, 4.8, 0.4	31.82	Liangzhu
8	0073	knife	Hornfels	12.2, 4.7, 0.6	41.67	Jingshan
9	0074	knife	Hornfels	11.6, 5.6, 0.6	43.73	Pingyao
10	92LMT2⑤:4	knife	Hornfels	13.0, 4.0, 0.8	44.10	Mao'anli
11	T401G1②:1	knife	Hornfels	11.4, 4.0, 0.5	28.70	Miaoqian
12	00LMT0508G1:46	knife	Mudstone	9.6, 4.0, 0.8	43.59	Miaoqian
13	0064	Sickle	Hornfels	14.0, 4.5, 1.0	452.12	Linping
14	00LMT0608②:24	Sickle	Hornfels	14.9, 4.6, 0.9	92.71	Miaoqian
15	0183	Sickle	Hornfels	13.5, 4.3, 0.6	452.14	Renhe
16	00LMT0608②:7	Sickle	Hornfels	9.7, 2.8, 1.0	30.16	Miaoqian
17	00LMT0102③:21	Sickle	Hornfels	16.7, 4.6, 0.9	569.25	Miaoqian
18	0145	Sickle	Hornfels	17.0, 6.1, 0.6	358.69	Liangzhu
19	00LMT0408⑤:2	Sickle	Hornfels	17.3, 5.8, 0.8	125.58	Miaoqian
20	0093	knife	Hornfels	13.5, 4.6, 0.5	56.21	Pingyao
21	0147	knife	Silicalite	11.4, 3.7, 0.4	35.73	Liangzhu
22	0067	knife	Palimpsest argillaceous siltstone	13.3, 4.2, 0.4	52.26	Jingshan
23	0146	knife	Siltstone	13.2, 4.1, 0.3	52.01	Liangzhu

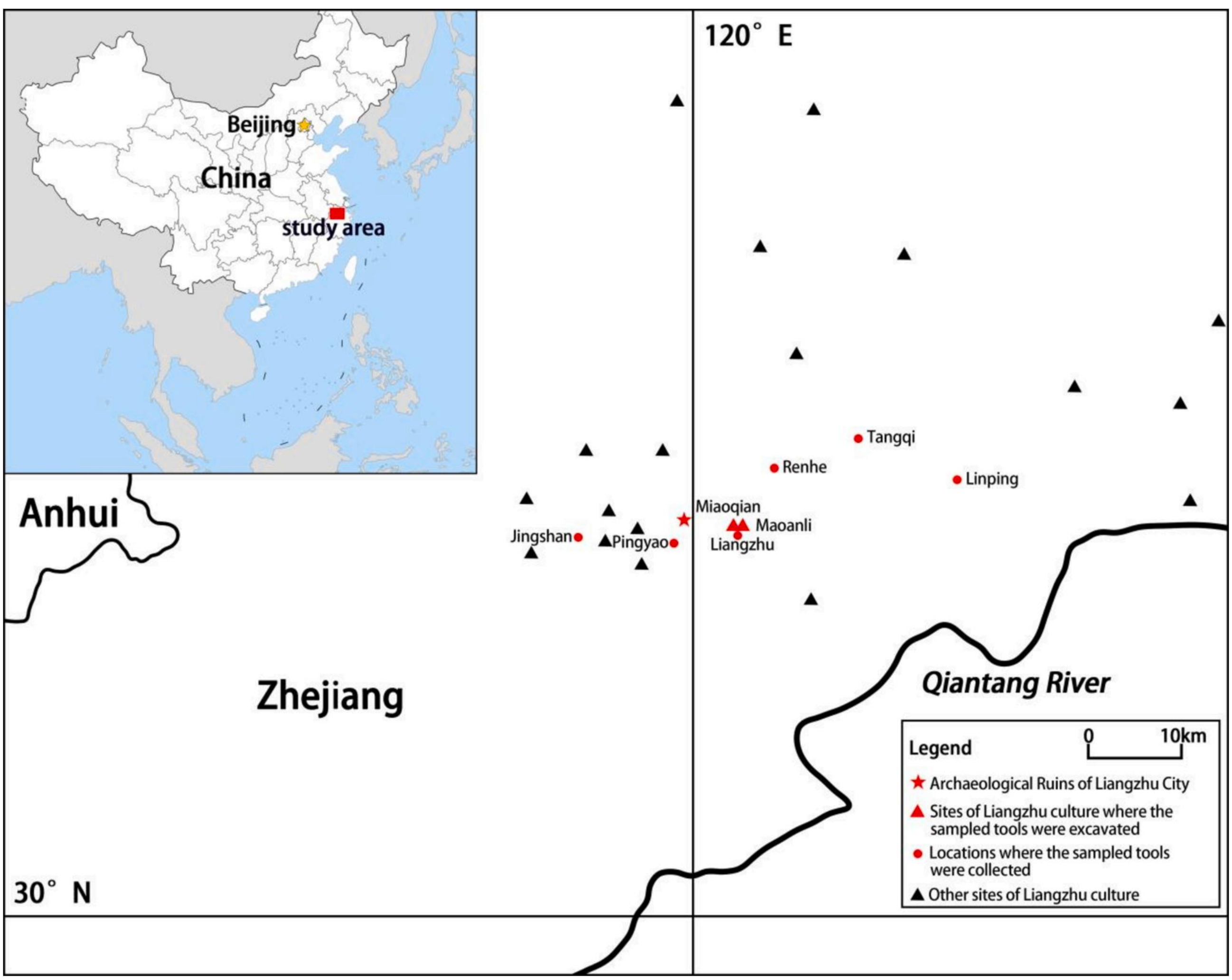

Fig. 1. Location map, showing the archaeological sites and collecting localities with knives and sickles analysed in this study.

Fig. 2. Overall pictures of knives and sickles analysed in this study. The blade edges are all facing downward.

considered to be used for harvesting gramineous plants, such as rice (Liangzhu Mus., 2020:74; Song, 1986; Li, 1980). Previous studies have provided some supportive evidence from the perspectives of archaeological context (Zheng et al., 2014) and use-wear analysis (Chen et al., 2021; Harada, 2011, 2013a, 2013b, 2014).

Building upon this established understanding, we have already conducted a systematic experimental project involving these tools in rice harvesting, resulting in a substantial accumulation of empirical data and an extensive collection of use-wear micrographs that offer profound insights into their functional capabilities (Xue et al., 2023). Now, leveraging the foundation laid by our previous research, we embark on a new phase of investigation to transcend the realm of experimental reconstructions and engage directly with the archaeological record.

The Lower Yangtze River Region holds a prominent position in the archaeological record due to its rich archaeological sites and extensive artifact assemblages (Liu and Chen, 2012:158–160, 200–207, 236–242). Archaeological excavations in this area have unearthed abundant examples of ground stone knives and sickles (Rao, 1958; Gao, 2014; Sun, 2016), offering a rich material basis for functional studies. The prestigious Liangzhu Museum preserves a wealth of stone artifacts, including ground stone knives and sickles with various designs, which facilitates this study. Using a combination of replicative experimentation, use-wear analysis and Py-GC/MS analysis, we thoroughly examined these tools. It is the first application of such an integrated analytical approach in the study of ground stone tools in the Lower Yangtze River Region. Our aim was to shed light on their manufacturing techniques, specific uses, and the socio-economic contexts in which they were employed.

2. Materials and methods

2.1. Materials

Twenty-three artifacts preserved at the Liangzhu Museum were sampled for functional study, including twelve knives and seven sickles from the Liangzhu culture (Fig. 2 and Table 1:1–19) and four knives from the Maqiao culture (Fig. 2 and Table 1:20–23). These specimens represent all available artifacts in the museum's collection that are suitable for research in this context. Most of the tools are complete, and two knives (T401G1①:1, T517②:22) are broken. Among them, eleven artifacts of the Liangzhu culture were retrieved from archaeological excavation, while eight were collected from open-air fields; all four stone knives of the Maqiao culture were also collected). Notably, both the excavated sites and collecting localities are located within the area of a group of archaeological sites of Liangzhu culture, and all in close proximity to the Archaeological Ruins of Liangzhu City, with the furthest locality being approximately 30 km in a straight-line distance (Fig. 1). The collected tools were fortuitously discovered by local residents during their labor activities, subsequently submitted to cultural relics authorities, and eventually preserved in the Liangzhu Museum, thereby ensuring their authenticity. The dating of these tools was primarily conducted by museum experts based on their typological styles and characteristics. Of the eleven excavated tools, ten unearthed from the Miaoqian site and one from the Mao'anli site, an archaeological excavation report on the two sites was published in 2005 (ZPICRA, 2005).

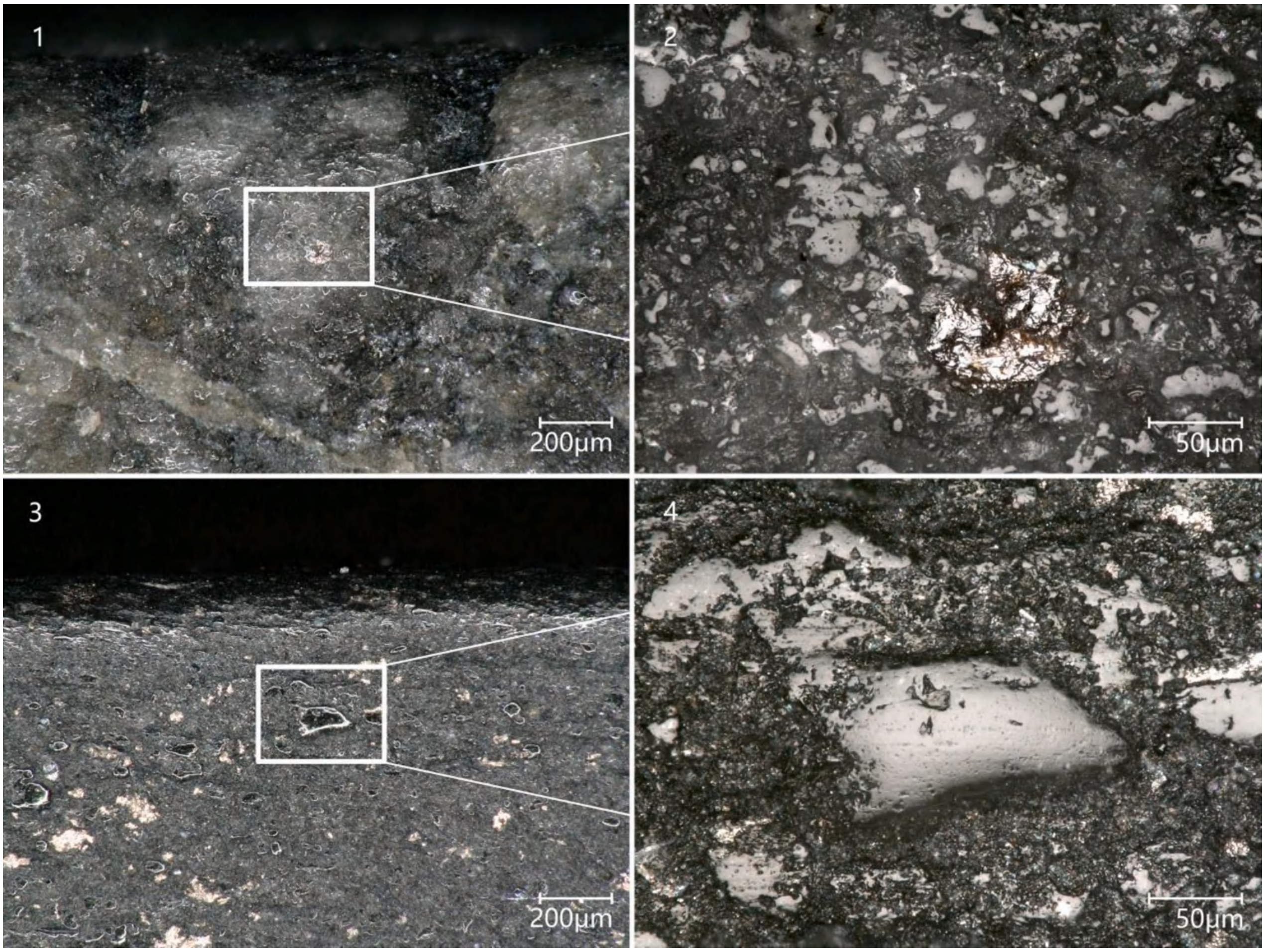

Fig. 3. Use-wear traces on two replicate knife and sickle produced by rice havesting: (1, 2) polish on the edge of knife SF-04 used for 677 min, 1 is 200×, 2 is 1000×; (3, 4) polish and fine striations on the edge of SK-03 used for 382 min, 3 is 200×, 4 is 1000×.

The knives of the Liangzhu culture exhibit considerable diversity in terms of their morphologies, distinguishing features including planimetric shape, handle, perforation and size. The sickles of the Liangzhu culture generally share similar morphological characteristics. Similarly, the knives from the Maqiao culture also demonstrate a relatively uniform shape, all being crescent-shaped, albeit varying in the concavity and convexity of their blade edges. However, the differences in morphological features raise the question of whether they signify distinct functional roles, which is always a pertinent issue that requires empirical study to address whether these tools were used and how.

2.2. Methods

2.2.1. Use-wear analysis

Use-wear analysis has emerged as an indispensable and vital approach in lithic functional study, and it has also been extensively applied in the field of ground stone tools (e.g., Adams, 2013; Dubreuil and Savage, 2014; Cunnar, 2007, 2013; Liu et al., 2017b; Chen et al., 2021; Fullagar et al. 2021; Xie, 2008; Cui, 2017; Cai, 2014). In this study, we have conducted in-situ microscopic examinations on all sampled specimens, thereby facilitating a thorough inspection of potential use traces across every part of the specimens. Such an approach allowed us to discern the overall distribution patterns of use-wear traces, reducing the risk of overlooking crucial information due to limited observing areas.

In this study, both low and high magnification techniques were employed. Firstly, we use a Nikon SMZ800 stereomicroscope with magnifications between 10× and 63× for preliminary examination. Subsequently, all the tools were carefully observed under a 3D digital Keyence VHX-5000 microscope with a zoom lens VH-Z20T with magnifications between 20× and 200× and ring illumination and a zoom lens VH-Z250R with magnifications between 250× and 2500× and both ring and coaxial illumination, micrographs were taken by the VHX-5100 microscope camera and processed in Photoshop. When using the low magnification lens with ring illumination, the observation effect resembles that of a stereomicroscope, making it suitable for examining scarring, edge rounding and the distribution patterns of all use-wear traces. And meanwhile, the application of the high magnification lens with coaxial illumination yields an effect similar to a metallographic microscope, which is ideal for observing the specific morphologies of use-wear traces, particularly polish and striation. It is noteworthy that the polish can also be detectable under low magnification with ring illumination (Fig. 3:1, 3), offering a rapid assessment of the distribution pattern across a wide range. While the high magnification with coaxial illumination ensures clarity in examining the morphological details of small areas (Fig. 3:2, 4). This integrated approach provides a comprehensive and balanced perspective for use-wear observation.

In previous study, we have established a use-wear reference collection resulting from harvesting rice with ground stone knives and sickles (Xue et al., 2023), and particularly determined the distinct features of cereal-reaping polish (Fig. 3). The raw materials of these replicative tools involved carbonaceous slate, silty mudstone, hornfels and hornfelsic silty mudstone, which exhibit a good correspondence with that of the archaeological specimens analyzed in this study. Thus, the experimental data obtained from our earlier work can serve as a valid reference for the current investigation.

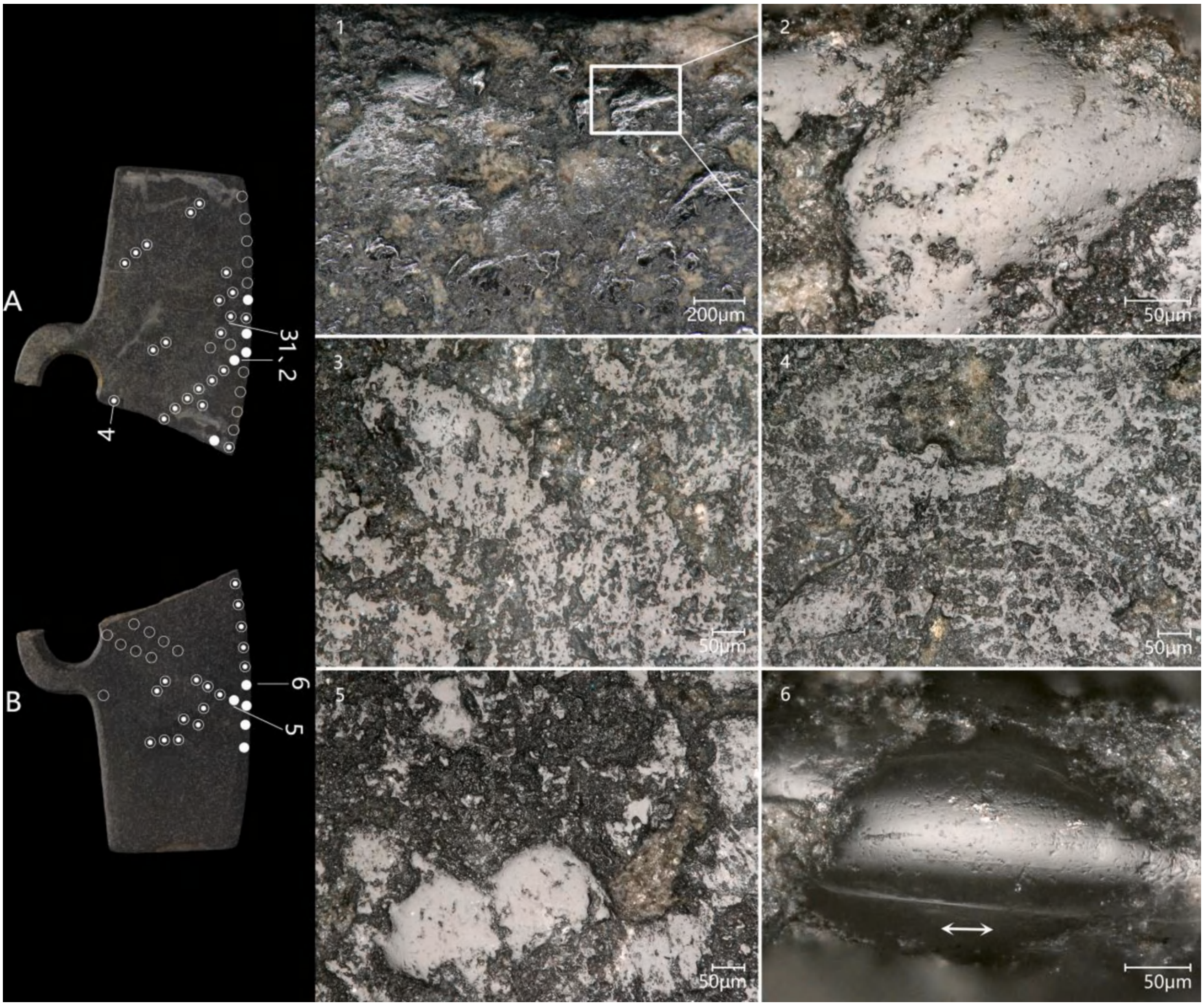

Fig. 4. Microwear traces observed on the broken knife T401G1①:1: (1–3) polish on the side A of the edge, 1 is 200×, 2 and 3 are 1000×; (4) polish on the side A near the perforation, 500×; (5) polish on the side B of the edge, 500×; (6) polish and fine striations on the ridge, 1000×. White symbols ○, ⨀, ● respectively represent weak, developing, and well-developed polish, with the same symbols carrying same meanings throughout this paper.

2.2.2. Py-GC/MS analysis

During the microscopic observation, tiny amounts of black organic residue were detected on the back of knife T401G1②:1 (Fig. 7:6). Pyrolysis–gas chromatography/mass spectrometry (Py-GC/MS) is an effective method for analyzing complex organic mixtures. Therefore, we employed the direct Py-GC/MS analysis to examine the black residue. This analysis was peformed using an EGA/PY-3030D thermal cracker (Frontier Company, Japan), combined with a 7890/5977 gas chromatograph/mass spectrometer (Agilent Company, United States), an HP-5 ms capillary column (30 m × 0.25 mm × 0.25 μm), a quadrupole mass spectrometer, and an electron bombardment source. The ionization source energy was set at 70 eV, and the sample (10 mg) was placed in a quartz tube directly. The pyrolysis temperature was set at 500 °C for 0.2 min, and a split injection was adopted with a 1:20 split ratio. Helium was used as the carrier gas with a flow rate of 1.0 ml/min. The temperature of the interface between the pyrolyzer and gas chromatographer was set at 300 °C, and the temperature of the GC sample inlet was set at 300 °C. The initial temperature of the chromatographic column was set at 50 °C for 2 min, followed by an increase in column temperature from 50 to 280 °C at a rate of 4 °C/min for 15 min. The temperature of the mass spectrum ion source was set at 230 °C while the temperature of the fourth pole was set at 150 °C. Full-scan mode was used for mass detection, with a mass detection range of 29–750 m/z, and the NIST library was used as the mass spectrum identification database.

3. Results

3.1. Results of use-wear analysis

During the preliminary examination stage, we evaluated the preservation status of the knives and sickles. Notably, ten specimens (00LMT0506⑥:2, 0148, 0074, 92LMT2⑤:4, 00LMT0508G1:46, 0064, 00LMT0608②:24, 00LMT0608②:7, 00LMT0102③:21, 00LMT0408⑤:2) presented pronounced surface weathering and erosion, leading to the deformation or loss of original use-wear traces. For these specimens, although no indicative use-wear traces, either scarring or polish, were observed in this study, it does not conclusively signify that they were never used. However, within the scope of this study, we are unable to definitively ascertain their actual usage history. In the following sections, we will describe the observed results of other twelve specimens.

3.1.1. Stone knives of the Liangzhu culture

The blade edges of specimen 0077 and specimen T103②:15 are both ground but unsharpened, with visible scars associated with the manufacturing process rather than usage. It is inferred that these two knives are probably unfinished semi-products that have not been used.

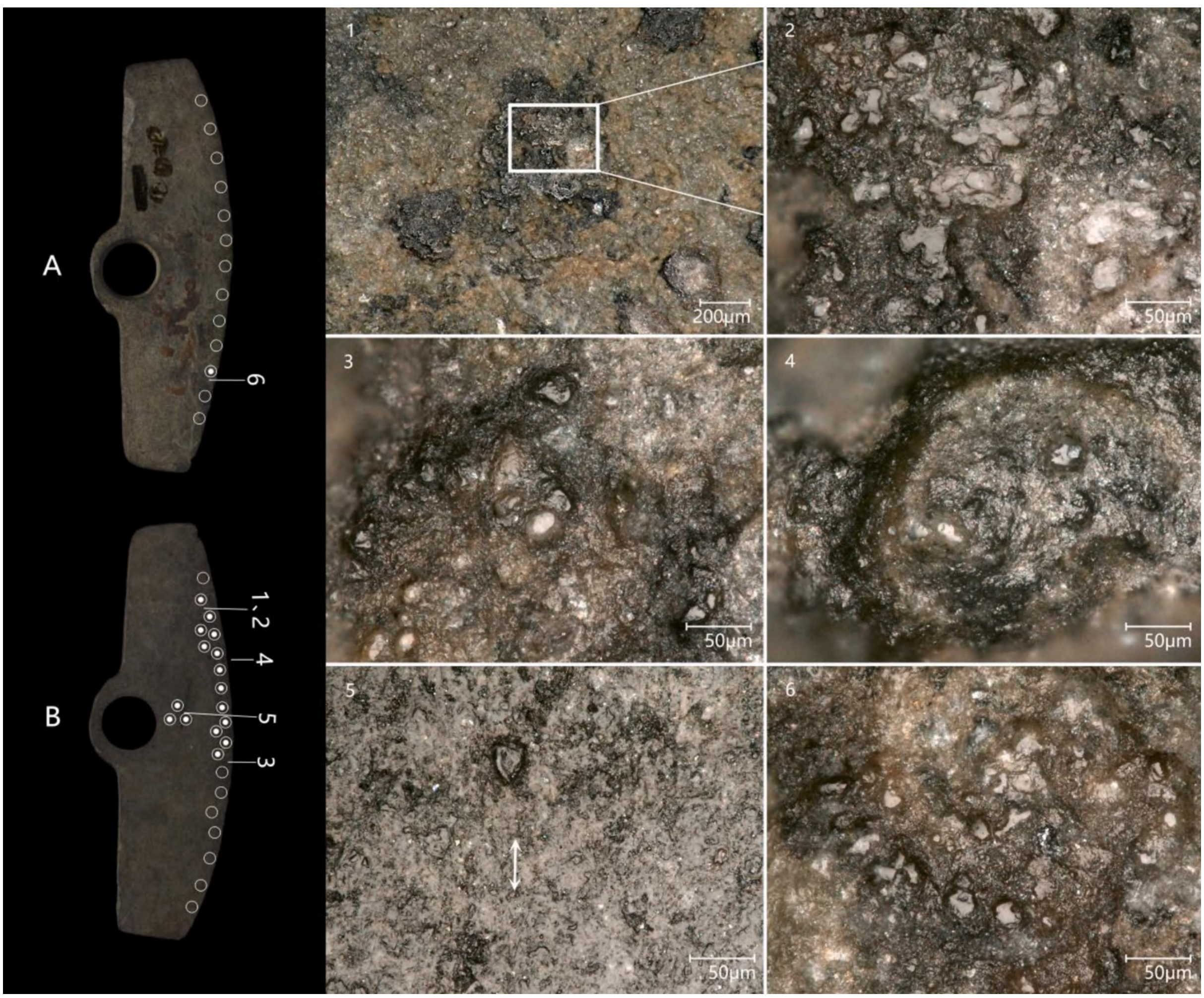

Fig. 5. Use-wear traces observed on knife 0056: (1–3) polish on the side B of the edge, 1 is 200×, 2 and 3 are 1000×; (4) polish on the ridge, 1000×; (5) polish on the side B near the perforation, 1000×; (6) polish on the side A of the edge, 1000×.

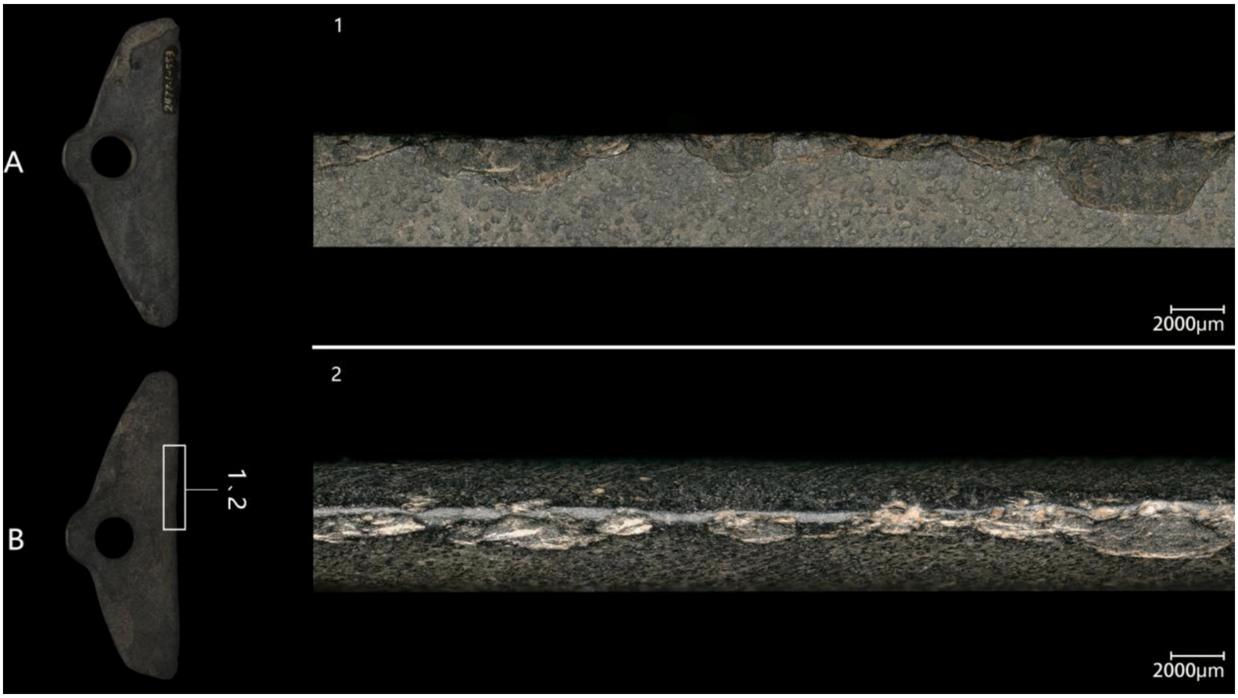

Fig. 6. Use-wear traces observed on knife 0073: (1, 2) Feather and step scars continuously distributed along the edge, 20×.

For specimen T401G1①:1, approximately half of it's body is broken, with no scars evident on the remained edge. The both sides of the edge exhibit bright domed polish in a banded distribution along the blade, linked in reticulated patches, generally smooth and interspersed with small pits. (Fig. 4:1, 2, 5). Several oblique strips of polish patches initiating from the edge were also observed on the both sides of the body, which were flatter and interspersed with more pits, less-developed compared to that near the edge (Fig. 4:3, 4). The ridge displays developed bright domed polsih, accompanied by fine striation parallel to the edge (Fig. 4:6). In terms of the morphology of individual patch, the polish observed on this stone knife resembles that of experimental cereal-reaping polish (Fig. 3:3, 4), yet the former demonstrates different overall characteristics. For instance, compared to the polish produced by rice harvesting, it tends to present a higher degree of linkage but is flatter. Additionally, the distribution of the polish is relatively symmetrical, with a notable presence extending beyond the immediate vicinity of the cutting edge, which deviates from the use-wear patterns attributed to harvesting activities. Based on the above, it can be inferred that this knife had been in contact with gramineous plants, although probably not during harvesting.

The side B of the edge of knife 0056 exhibits domed polish in a banded distribution along the blade, mostly separated in individual patches, some linked in reticulated patches, generally smooth and interspersed with tiny pits, most of the patches were less than 50 μm in size (Fig. 5:1, 2, 3). Polish on the left part of the edge were more developed than those on the right part. In the vicinity of the perforation, flat polish of low brightness, well-linked as a whole, accompanied by fine striations roughly perpendicular to the edge were observed (Fig. 5:5). The side A of the edge also displays a continuous band of domed polish, less-developed compared to that on the side B with a shorter intrusion distance into the body (Fig. 5:6). As for the ridge, domed polish patches similar to that on the edge were found (Fig. 5:4). In general, the domed polish observed on knife 0056 shows a similarity to the polish produced by rice harvesting (Fig. 3:1, 2), and the flat polish with striations is suspected to be traces resulting from contact with stalks (Xue et al., 2023:Fig. 7a). Furthermore, the distribution of the polish also aligns with the pattern expected from harvesting. It can be inferred that this knife had been used for harvesting gramineous plants, such as rice, with the cutting edge moving perpendicularly to the stalks, side B was the contact surface.

The blade and perforation of the knife T517②:22 are partially broken, with weathering crust adhering to its surface. Within the areas accessible for microscopic examination, use-wear traces similar to those observed on knife 0056 were found, dominated by domed polish in a banded distribution along the blade. In conjunction with the morphological similarities, it can be inferred that this knife had been also used for harvesting gramineous plants, such as rice.

For knife 0073, no indicative polish was observed on the surface. While the left part of the edge on side B presents feather and step scars in a continuous distribution, with moderate edge rounding (Fig. 6:1, 2). These traces indicate the activity of scraping medium hard materials, possibly wood or bamboo. Given the straight profile of the blade edge, it is indeed well-suited for scraping tasks.

Bright domed polish linked in reticulated patches were almost symmetrically distributed on both sides of the edge of knife T401G1②:1 (Fig. 7:1–5), with fine striations showing an orientation parallel to the edge (Fig. 7:3–5). The degree of development of polish decreased with the distance from the edge, and the polish disappeared in areas near the back. While no scarring related to usage was observed. The morphology and distribution of polish suggest that this knife had been used intensively for cutting gramineous plants, such as rice.

3.1.2. *Stone sickles of the Liangzhu culture*

The scarring found on the edge of Sickle 0145 were left by manufacturing processes, with no evidence of use-wear traces being observed. It is speculated that this sickle had not been used.

For sickle 0183, despite significant weathering across its body, vestiges of the original surface remained in localized areas. On the original surfaces preserved along the edge on side B, bright domed polish in a banded distribution were found, linked in reticulated patches (Fig. 8:1–3). The degree of development of polish decreased with the distance from the edge and the tip (Fig. 8:4). However, fewer original surfaces were preserved on the side A, with only a few areas exhibiting domed polish, less-developed than that observed on side B (Fig. 8:6). Besides, the polish on the ridge demonstrates an orientation parallel to the edge (Fig. 8:5). Although heavily disrupted by weathering, it is still

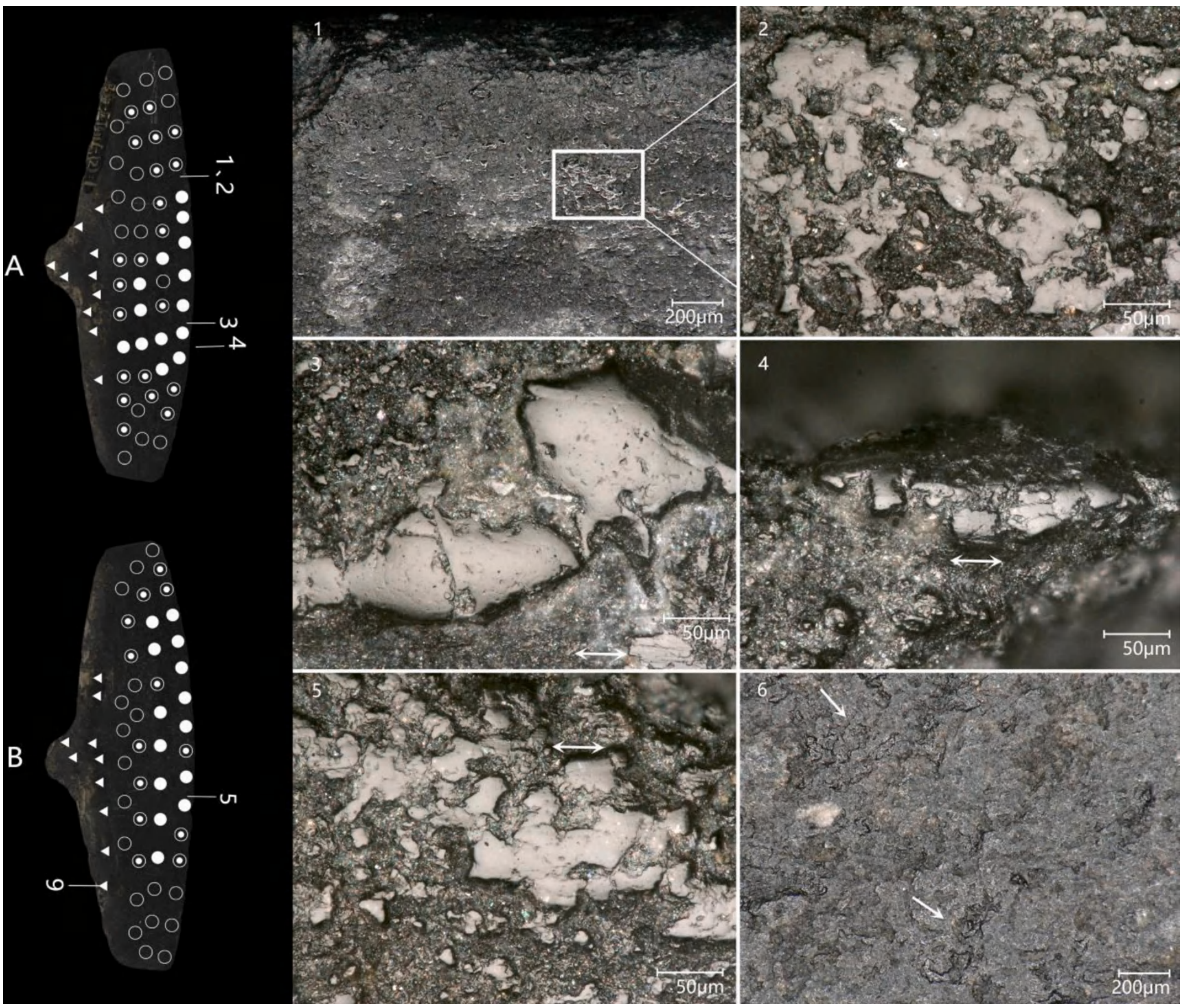

Fig. 7. Use-wear traces and black residue observed on knife T401G1②:1: (1–3) polish on the side A of the edge, 1 is 200×, 2 and 3 are 1000×; (4) polish on the ridge, 1000×; (5) polish on the side B of the edge, 1000×; (6) black organic residue on the side B near the back, 200×.

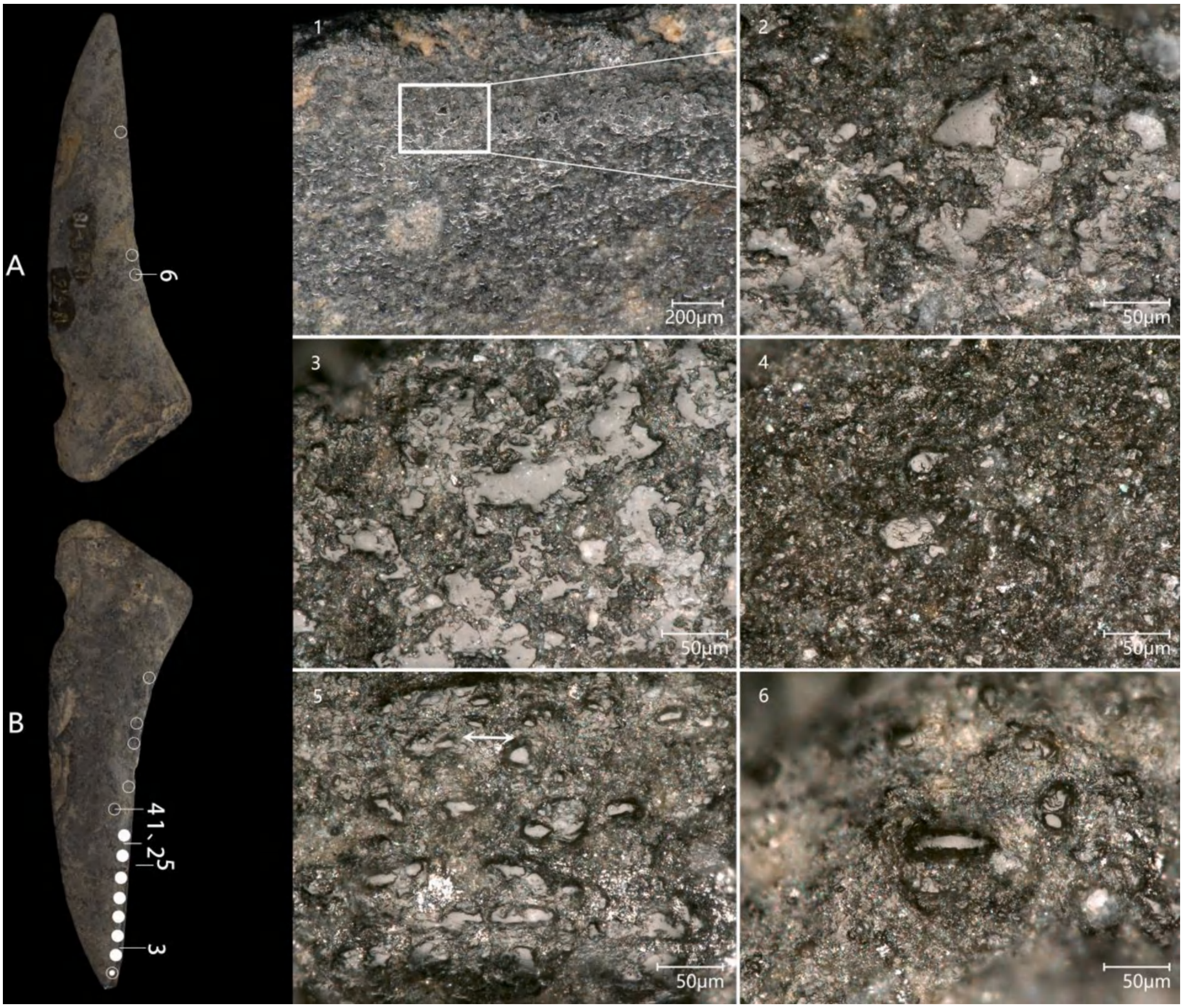

Fig. 8. Use-wear traces observed on sickle 0183: (1–4) polish on the side B of the edge, 1 is 200×, 2, 3 and 4 are 1000×; (5) polish on the ridge, 1000×; (6) polish on the side A of the edge, 1000×.

possible to deduce from the remaining use-wear traces that this sickle had been used for cutting gramineous plants, such as rice.

3.1.3. Stone knives of the Maqiao culture

The side A of the edge of knife 0093 exhibits bright domed polish in a banded distribution on the right part, with an orientation nearly perpendicular to the edge (Fig. 9:1–4). Two strips of polish patches initiating from the edge were also observed, the degree of development of polish decreased with the distance from the edge. The use-wear traces found on side B was similar to those on side A, but less-developed (Fig. 9:5). Deformed polish observed in localized areas was probably the result of post-depositional surface modification (Fig. 9:6), yet it fundamentally attributed to the domed polish produced by processing gramineous plants. Based on the above, it can be speculated that this knife had been used for harvesting gramineous plants, such as rice, both side A and B were contact surfaces.

For knife 0147, bright domed polish separated in individual patches were observed on the side A (Fig. 10:1–3, 5), most of which concentrated on the right part of the edge, except for a small area near the back (Fig. 10:4). The side B shows no discernible use-wear traces along the edge, while domed polish was observed on the area proximal to the back. According to the use-wear pattern, it is inferred that this knife had been used for harvesting gramineous plants, such as rice. Side A is the contact surface.

Knife 0067 displays no discernable scarring or polish related to usage on the edge, suggesting that it may have remained unused.

Bright domed polish separated in individual patches were observed on most parts of knife 0146 (Fig. 11:1–6). The extensive presence of domed polish across the whole body, without distinct difference in the degree of development between different regions, is inconsistent with use-wear pattern, as one would expect more pronounced use-wear traces on the edge compared to the middle part of the body and the back. This phenomenon suggests that these areas had almost uniform contact with gramineous plants, which is not likely to happen during harvesting activity.

3.2. Results of Py-GC/MS analysis

The polish on the surface of knife T401G1②:1 abruptly ceased near the back with a clear-cut boundary (Fig. 7). On the both sides of the back, some black organic residue in a banded distribution were observed (Fig. 7:6, where white triangles indicate the locations of the residue). It is speculated that this may represent a kind of binding agent, utilized to fix a handle to the back of this knife. About 10 mg of sample of these organic residue were extracted and analyzed by using Py-GC/MS. Table 2 presents the categories of pyrolysis products and their distribution. Among them, several notably indicative compounds were identified, including some stable amino acid, such as glycine, L-Leucine,

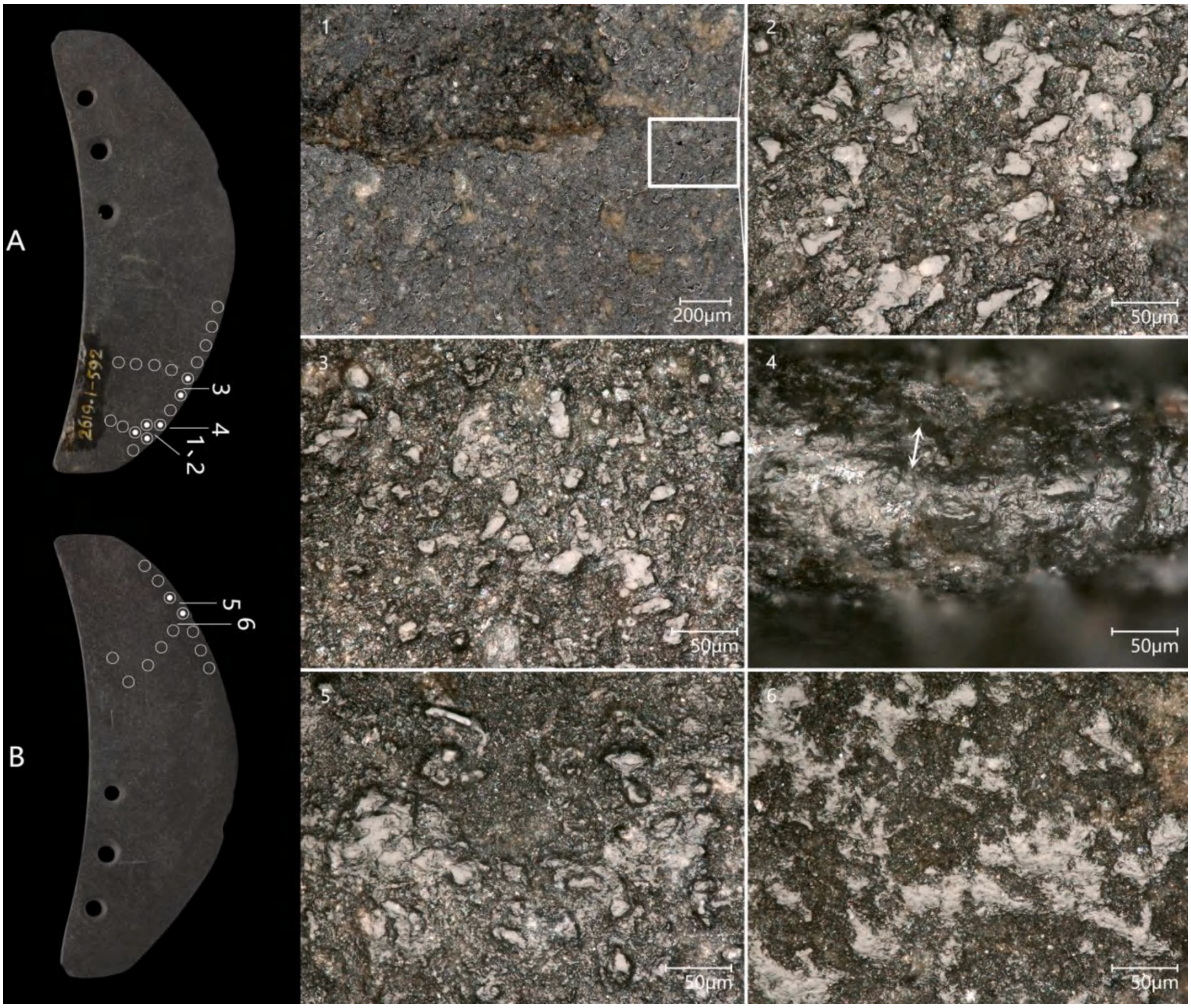

Fig. 9. Use-wear traces observed on knife 0093: (1–3) polish on the side A of the edge, 1 is 200×, 2 and 3 are 1000×; (4) polish on the ridge, 1000×; (5) polish on the side B of the edge, 1000×; (6) deformed polish on the side B of the edge, 1000×.

L-Serine, alanine, and also hexadecenoic acid and stearic acid, indicating the presence of proteinaceous materials. Collectively, these compounds point to the possibility of using animal glue as the binding agents (Colombini and Modugno, 2009:5–6; Schilling et al., 2016).

4. Discussion

4.1. The function of stone knives of Liangzhu culture

The certain type of stone knife represented by knife 0056 is unique to the Liangzhu culture, characterized by an arc raised on the middle of the back and a perforation below it. Their functional interpretations varied from scholar to scholar, including as tools for intertillage and weeding (ZPCRMC, 1960; Mou, 1984; Ren, 2000), harvesting (Ji, 1983), leather processing (Jiang, 1999), meat processing, bamboo and reed processing (ZPICRA and Huzhou Mus., 2006:451), and salt production (Cheng, 2009). Their morphological similarity to some crown-like jade ornaments has also led to suggestions of potential associations with ritual purposes (Liu, 1997). In this study, we obtained practical and valid information about the function of such tools. For knife 0056, by integrating morphological characteristics and use-wear patterns, we can reconstruct its use context: a handle made of wood or bamboo was attached to the back of the knife through the perforation, the operator gripped the knife, with the thumb and index fingers encircling the handle, the ring and little fingers placing below the knife, and the middle finger hooking the spike and pressing it against the blade edge, then to picked it upward (Fig. 12:1). The similar work motion is still employed by ethnic minorities in southwestern China when using bamboo or wood-handled knives to harvest rice (Yang and Wang, 2019). Given the high similarity of use-wear traces observed on archaeological specimens and that produced during rice harvesting experimentation, it is reasonable to infer that stone knives like 0056 and T517②:22 were indeed utilized as rice harvesting tools. On the other hand, knife 0073 provides evidence of scraping wood or bamboo, probably also mounted onto a handle through the perforation during use. This case underscores the significance of blade edge profile in indicating the function of tool, of course, the use-wear patterns should be evaluated first.

The characteristics of the polish observed on knife T401G1②:1 demonstrate that it may have also been used for harvesting rice. However, it's shape is not suitable for direct holding with hand, and it is not possible to mount a handle through a perforation like knife 0056, which suggests an alternative method for fixing a handle. The distribution of polish indicates that the whole region proximal to the back was laterally covered by something, thereby preventing contact with the soft plant materials being processed. Precisely on these covered areas, we have identified organic residues that potentially represent animal glue. Take all the evidence together, it can be inferred that knife T401G1②:1 was also a composite tool, and the back was laterally embedded into a

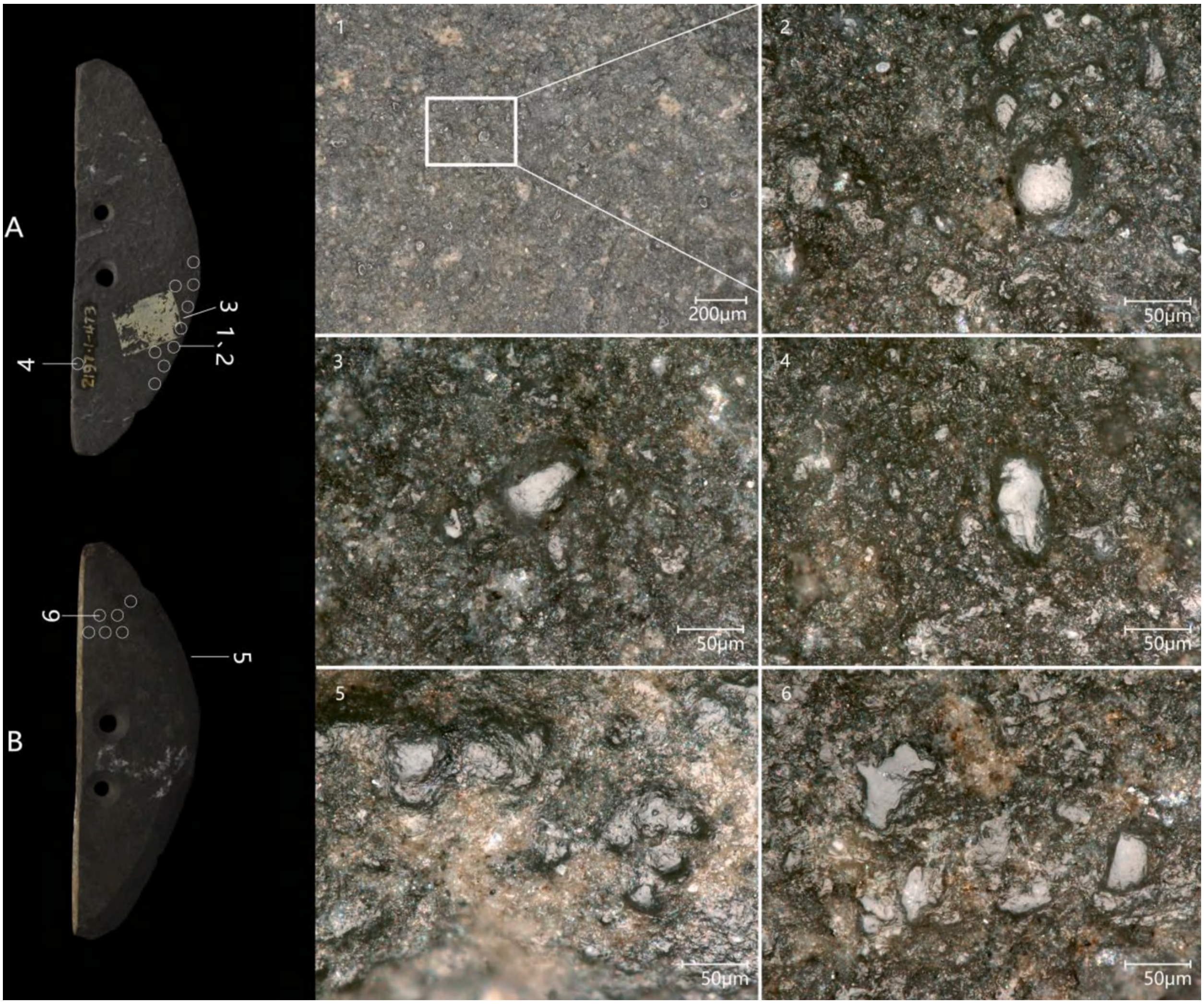

Fig. 10. Use-wear traces observed on knife 0147: (1–3) polish on the side A of the edge, 1 is 200×, 2 and 3 are 1000×; (4) polish on the side A near the back, 1000×; (5) polish on the ridge, 1000×; (6) polish on the side A near the back, 1000×.

handle. Animal glue was used as binding agents between the back and the handle. During use, the operator held the wooden handle with one hand, while the other grasped the spike, using the blade edge to cut the spike perpendicularly (Fig. 12:2). The cutting position likely targeted the ear rather than the root for two main reasons. Firstly, the relative small size and short blade would make it ineffective to harvest near the roots. Secondly, the striations observed on knife T401G1②:1 were less-developed compared to those on experimental stone sickles used for harvesting rice near the roots.

4.2. *The function of stone sickles of the Liangzhu culture*

Among the sickles analysed in this study, only Specimen 0183 exhibited indicative use-wear traces, similar to those observed on experimental sickles used for rice harvesting. Despite the severe weathering, from the development of the use-wear traces on the remained original surfaces, it seems that the contact between the worked material and side B was greater than that between the worked material and side A. Specifically, at approximately the same horizontal position, the polish observed on side B was more developed than that on side A (Fig. 13:1, 2). This phenomenon suggests that the cutting edge of this sickle was not perpendicularly to the stalks when it was used, but with an oblique angle. For modern metal sickles, when harvesting rice, are pressed against the stalks near the roots and pulled obliquely upward. However, the sharpness of the cutting edge of a stone sickle was inferior to that of a metal sickle, a pulling upward motion could lead to inefficiencies and a tendency to uproot plants along with soil, which has been suggested in our rice harvesting experiments. A more reasonable and effective way involves cutting downward with an oblique angle, wherein the upper side of the edge experiences greater contact with the stalks than the lower side. This engagement results in use-wear traces similar to that observed on the archaeological sickle 0183. In conjunction with the intentionally knapped concave notch on its back, which was designed for hafting, we can reconstruct its use context as shown in Fig. 13.

4.3. *The function of stone knives of the Maqiao culture*

In this study, four crescent-shaped stone knives of the Maqiao culture, offering an opportunity to investigate the change of harvesting methods across different periods. Use-wear traces indicative of harvesting gramineous plants, similar to those observed on experimental knives used for rice harvesting, were evident on the specimens 0093 and 0147. Based on the use-wear patterns identified on archaeological knives and the knowledge derived from our replicative experimentation, two potential use contexts for these half-moon-shaped stone knives were reconstructed: upward picking (Fig. 12:3) and downward pinching (Fig. 12:4). Knife 0147 primarily had been used in upward picking

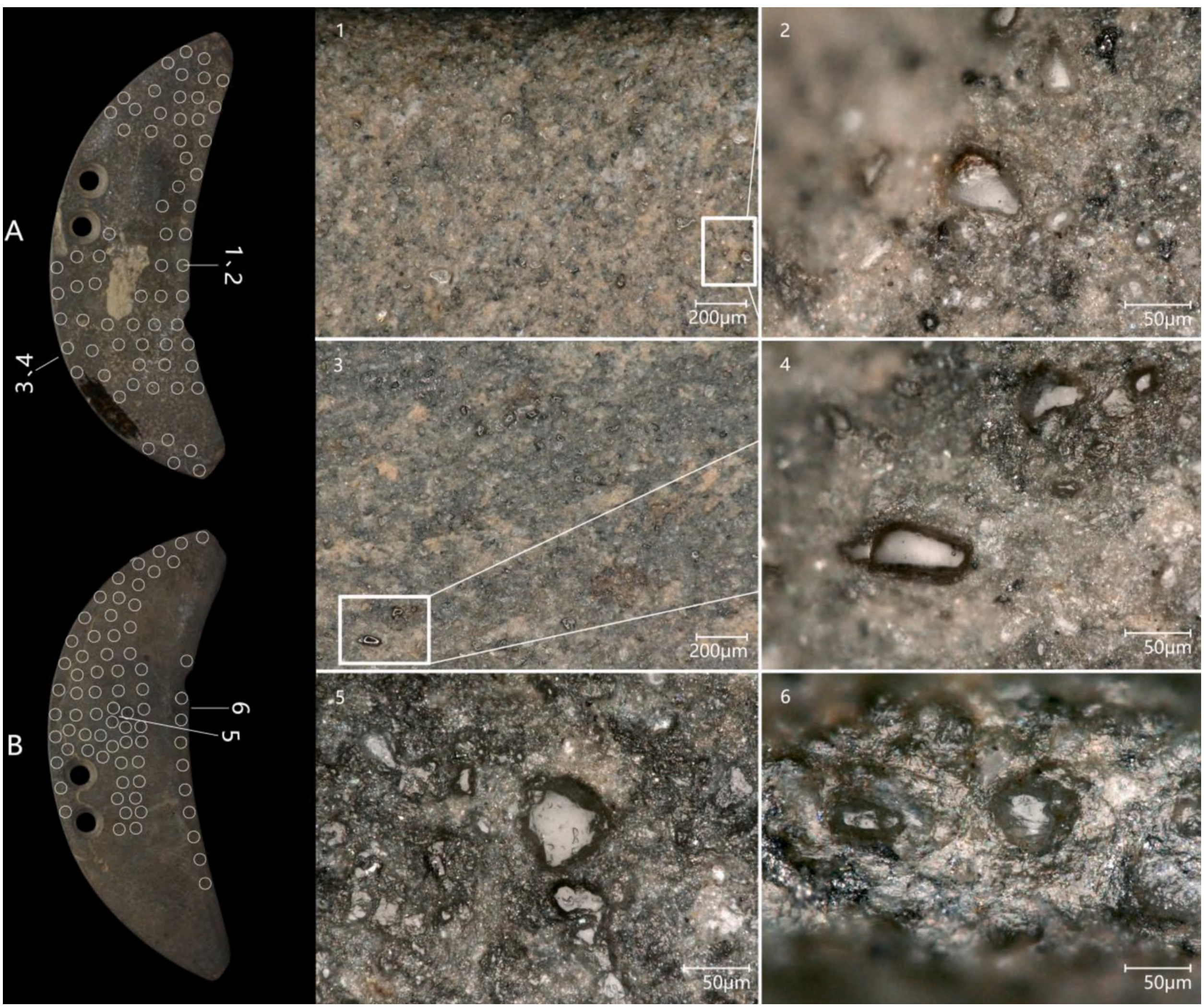

Fig. 11. Microwear traces observed on knife 0146: (1, 2) polish on the side A of the edge, 1 is 200×, 2 is 1000×; (3, 4) polish on the back, 3 is 200×, 4 is 1000×; (5) polish on the side B near the middle part of the body, 1000×; (6) polish on the ridge, 1000×.

Table 2
The pyrolysis products identified in knife LMT401G1②:1 by Py-GC/MS with the NIST library.*

RT	Name	Area %	RT	Name	Area %
3.545	Acetic acid, methoxy-, methyl ester	8.01	13.121	Benzoic acid, methyl ester	0.08
4.024	1-Butanol, 3-methoxy-	0.81	13.981	1,2-Ethanediamine, N, N,N',N'-tetramethyl-	9.28
4.611	Methyl dimethylcarbamate	2.23	15.514	Sarcosine, N-methoxycarbonyl-, methyl ester	0.34
4.956	Glycine, N,N-dimethyl-, methyl ester	26.07	17.702	Nonanoic acid, methyl ester	0.33
5.695	Methanediamine, N,N,N',N'-tetramethyl-	0.27	18.441	Hexanedioic acid, dimethyl ester	0.31
5.762	Ethanamine, 2-hydrazino-N,N-dimethyl-2-oxo-	0.41	18.517	(+)-N-Methylephedrine	0.33
6.234	2-Propanamine, N, N-dimethyl-	23.1	18.955	[2-(N,N-Dimethyl)]-1,2-propanediamine	0.21
6.569	2-[2,N,N-Trimethyl-2-aminoethyl] benzofuran	0.42	20.051	l-Valine, N-propoxycarbonyl-, pentyl ester	0.14
7.332	Hexanoic acid, methyl ester	0.48	20.462	alanine, N,N,2-trimethyl-, ethyl ester	0.22
8.132	Carbamic acid, 2-(dimethylamino) ethyl ester	0.05	21.08	Decanoic acid, methyl ester	0.1
8.640	Trimethyl phosphate	0.29	25.261	Dimethyl phthalate	0.09
10.635	Dimethyl fumarate	0.23	27.344	Dodecanoic acid, methyl ester	0.08
11.300	Hexanoic acid, 2-ethyl-, methyl ester	0.12	33.001	Methyl tetradecanoate	0.31
11.365	L-Leucine, N-methyl-, methyl ester	0.07	35.633	Pentadecanoic acid, methyl ester	0.17
12.256	Butanedioic acid, methyl-, dimethyl ester	0.06	38.141	Hexadecanoic acid, methyl ester	1.39
12.365	L-Serine, N,N,O-trimethyl-, methyl ester	0.14	42.835	Stearic acid, methyl ester	0.35

* Compounds with a match below 70 % are not included in the statistics.

motion, while knife 0093 may had been used in both upward picking and downward pinching motions. Regarding the perforations near the back, they allowed for a rope to be threaded through on the back of the knife and worn around the operator's wrist to prevent accidental drops. Notably, there are some similarities between the upward picking motion and the working motion employed by knife 0056 of the Liangzhu culture, with the primary difference lying in the hafting technique. This leads to the hypothesis that the former may had been influenced by the latter. And the downward pinching motion could represent a new emerged harvesting method during the Maqiao culture period.

4.4. The interpretation of unusual microwear traces on knife T401G1①:1 and knife 0146

As mentioned above, we have observed polish generated by contact with gramineous plants on knife T401G1①:1 of the Liangzhu culture and knife 0146 of the Maqiao culture. However, these traces deviate from the use-wear traces attributed to harvesting activities. Rather, they resemble the traces of polishing the stone surfaces with gramineous plants. possibly indicating a refinement during the manufacturing process. This is the first time such phenomenon has been found, suggesting that these tools might not have been designed for harvesting activities. Especially in the case of knife T401G1①:1, despite its similarity in shape to knife 0056, its immense size significantly exceeded the manageable grasp of an average human, making it impractical to harvest cereals in a motion employed by knife 0056, regardless of whether it was intended to be hafted or not. This tool may hold a special symbolic or ritual significance, transcending its utilitarian function to become a ritual object. The use of gramineous plants for polishing could carry dual implications. (1) refining its surface texture for aesthetic enhancement, and (2) if rice stalks were used, the act of polishing could symbolize reverence towards rice, thereby strengthening the connection between the implement and rice. During the Liangzhu period, ritual objects were usually crafted from jade (nephrite). Excavations of high ranking aristocratic tombs of the Liangzhu culture at Yaojiashan revealed several jade knives and sickles (Wang et al., 2005, 2006; Fig. 14), evidently intended for ritual purposes. These jade implements had fully completed the transition from physical functions to spiritual functions. Elaborately manufactured stone knives like knife T401G1①:1 might have preceded or served as lower-grade alternatives to these jade implements, also serving as ritual objects. This observation also offers insights into the significant role of rice farming agriculture in the Liangzhu society. Our findings provide the first traceological evidence supporting Liu's (1997) suggestion that some stone knives may have functioned as ritual objects. Regarding knife 0146, it was devoid of any exaggerated features in size and shape. Notably, knife 0067, which shared a similar shape with knife 0146, had not been found with any use-wear traces. Thus, it is currently infeasible to make a further speculation on the function of knife 0146.

5. Conclusion

Through an integrated analytical approach combining use-wear analysis, Py-GC/MS analysis, and replicative experimentation, we conducted a functional analysis on twenty-three ground stone knives and sickles preserved on the Liangzhu Museum, yielding profound insights into the functional patterns of these tools. Distinct use-wear traces align

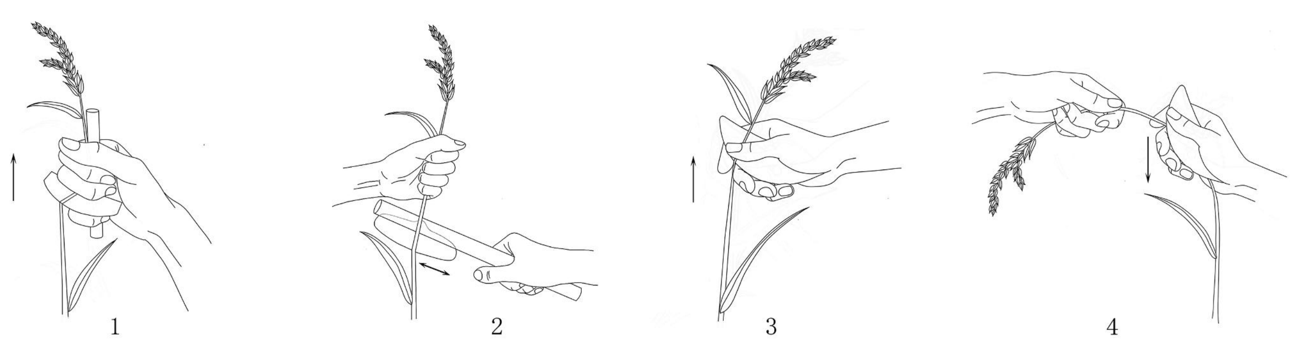

Fig. 12. Schematic representation of the use contexts of harvesting cereals near the ear with different kinds of knives.

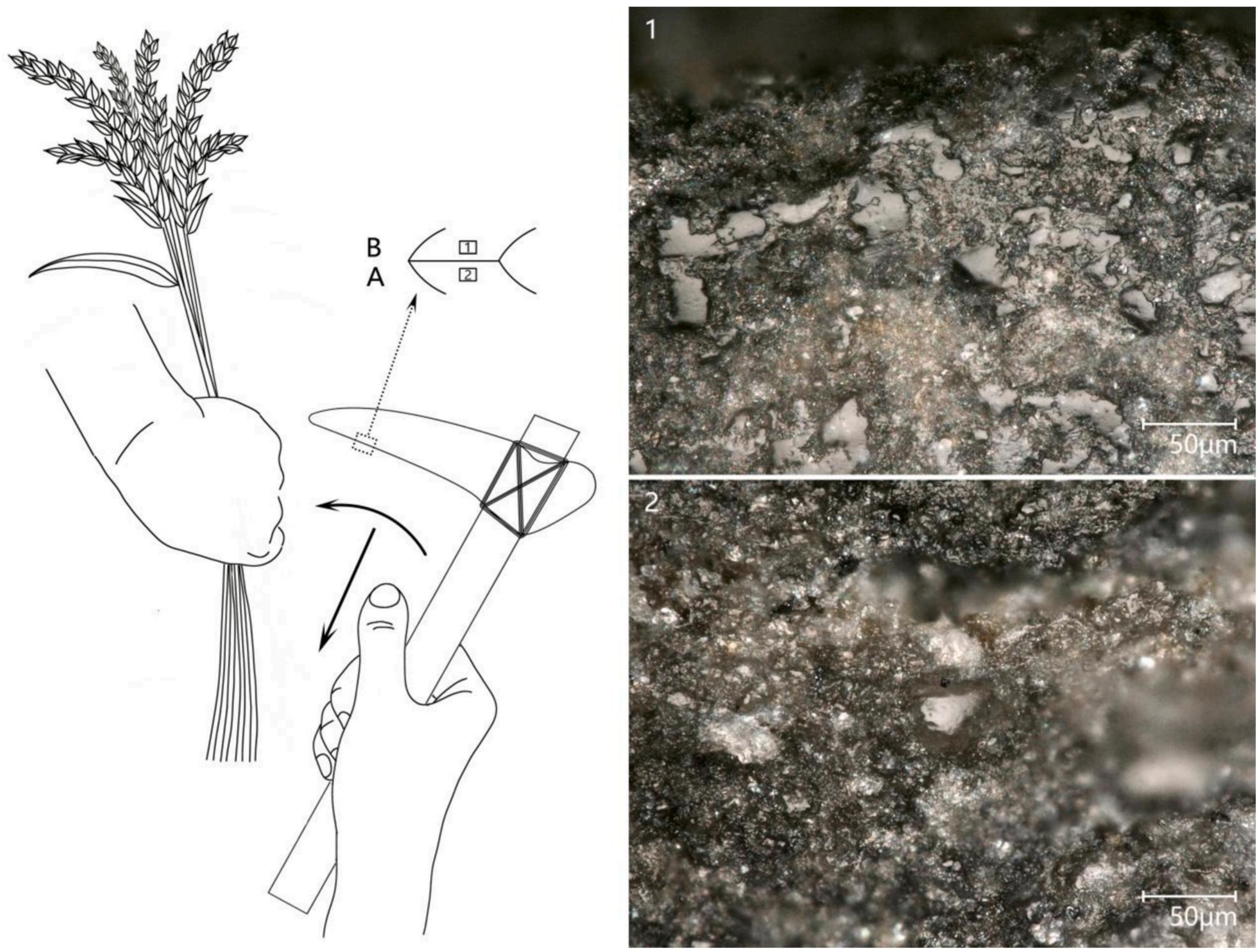

Fig. 13. Schematic representation of the use context and use-wear traces of harvesting cereals near the root with a sickle.

Fig. 14. Jade implements unearthed at the Yaojiashan site: jade knife M2:24 (left) and jade sickle M3:53 (right) (adapted from Wang et al. 2006).

with those produced by experimental replicas used for rice harvesting were observed on three knives and one sickle of the Liangzhu culture and two knives of the Maqiao culture, suggesting that they had been used for harvesting gramineous plants, probably rice. By combining the characteristics of use-wear patterns and tools' morphologies, four specific use contexts for the stone knives and one for the stone sickle were reconstructed. Notably, some stone knives of the Liangzhu culture were designed for hafting, and two distinct hafting techniques were adopted according to different morphology designs. The first involved attaching a handle made of wood or bamboo to the back of the knife through a big perforation, while the second involved embedding the back into a handle laterally, possibly facilitated by the use of animal glue as binding agents. The sickle was also used with a handle attached to its end. The half-moon-shaped knives of the Maqiao culture were used handheld with two working motions: upward picking and downward pinching. Besides cereal harvesting tools, we identified one hafted knife of Liangzhu culture used for scraping wood or bamboo, thereby broadening the functional interpretation of such tools. Notably, the polishing of stone knives with gramineous plants has been determined in both the Liangzhu culture and the Maqiao culture, which underscores not only a novel understanding of ground stone polishing techniques but also potentially signifies a special symbolic or ritual significance beyond their physical functions. These findings shed new light on the functional diversity and technological sophistication of ground stone tool manufacture and utilization in the Lower Yangtze River Region during the Late Neolithic and Bronze Age.

Further study is needed to advance our understanding in this field. Residue analysis, particularly on starch grain and phytolith, is crucial for conclusively identifying the specific worked materials. Furthermore, expanding the sample size of archaeological specimens to ensure current conclusions are more representative of the broad context. Lastly, enhancing the evaluation of post-depositional surface modification to mitigate their potential impact on microscopic observation and interpretations.

CRediT authorship contribution statement

Liping Xue: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yong Xia:** Writing – review & editing, Validation, Resources, Investigation. **Yao Jin:** Writing – review & editing, Methodology, Investigation. **Jiadian Wang:** Validation, Resources, Investigation. **Shuang Wu:** Writing – review & editing, Visualization. **Ling Shen:** Writing – review & editing, Investigation. **Ningyuan Wang:** Visualization, Writing – review & editing. **Hong Chen:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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An experimental investigation of the ground stone knives and sickles in the Lower Yangtze River Region during the Late Neolithic and Bronze Age

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ABSTRACT

Ground stone knives and sickles were important implements in the Lower Yangtze River Region during the Late Neolithic and Bronze Age. Previous studies had suggested that harvesting gramineous plants such as rice was probably one of their functions, but there is very few empirical evidence of whether these tools were used and how. In this study, a set of replicative experiments were carried out to examine their effectiveness as harvesting tools and use-wear analysis was adopted to determine the multi-stage formation process of the use-wear traces on tool's surface. The results showed that the knives and sickles were efficient for rice harvesting when used in proper working motions. The use-wear patterns generated by rice harvesting are dominated by bright domed polish linked in reticulated patches often accompanied by fine striations. The distribution of the polish and its morphological characteristics are influenced by working motion, use intensity, and the nature of the stone raw material in varying degrees. The results of our study provide significant reference data and images for deciphering the functions of stone knives and sickles in archaeological records, which are crucial for investigating the development of rice farming agriculture in the Lower Yangtze River Region during the Late Neolithic and Bronze Age.

1. Introduction

Ground stone knives and sickles were important implements that appeared in the Neolithic Age, which were widely unearthed in the Neolithic and Bronze Age sites all over China (An, 1955). The rice farming agricultural economy was well-developed in the Lower Yangtze River Region during the Late Neolithic Age (Zheng et al, 2016; Zhao, 2010; Fuller et al., 2009; Fuller et al., 2007), and the ground stone knives and sickles found from the archaeological sites in this area during this period are often considered to be agricultural tools used for harvesting gramineous plants (Li, 1980; Liangzhu Mus., 2020:74), such as rice. Yet, most of these assumptions are based on morphological analogies with metal tools or ethnographic records (Luo, 2004; Yang and Wang, 2019), and lack empirical evidence directly from the archaeological materials. Only a few studies have speculated on the function of tool from the archaeological context, such as the ground stone knives found in Neolithic paddy fields (Zheng, 2014), indicating the possibility of harvesting rice. For most ground stone knives and sickles, there is still no explicit answer to the questions about whether they have been used and how.

In Chinese archaeology, early studies have often suggested that form can define function. Many scholars considered stone tools from a typological perspective, and derived their design and function from their forms, as if the answer was visually evident. Ground stone knives were considered to be versatile, being used for agricultural harvesting activities, as well as for other cutting and scraping actions, processing a wide range of materials such as gramineous plants, meat, bone, and leather (An, 1947; An, 1995; Rao, 1958). As for the ground stone sickles, they were mostly regarded as agricultural harvesting tools, hafted with a handle for use, due to the high consistency of their form with metal tools (Li, 1980; Song, 1986). Tong (1982) was the first to study the Neolithic stone knives and sickles from a use-wear perspective, but his research did not integrate replicative experimentation and used only a stereo microscope with a magnification of less than 10 × to observe scar, striation and rounding.

Since then, more scholars have taken use-wear analysis as an essential approach to investigate the functions of stone knives and sickles, combined with replicative experimentation, involving the

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Daxinzhuang site (Qian, 2005), the Xinglongwa site (Wang, 2008), the Erlitou site (Xie, 2008), and the Taosi site (Cai, 2014). More recently, some scholars have combined both use-wear analysis and residue analysis to carry out functional studies of ground stone tools. Their results on stone knives and sickles from the Jiahu site (Cui et al., 2017; Fullagar et al., 2021), the Huizui site (Liu et al., 2018), the Liangchengzhen site (Cunnar, 2007, 2013) and the Jiangzhai site (Jiang, 2020) indicate that stone knives and sickles were mainly used for harvesting, but also for cutting and scraping other plant materials. However, most of these studies on the function of stone knives and sickles focused on the archaeological records from the North China, only a few attempts have been made to explore these issues in South China (Harada, 2013; Chen et al., 2021).

So far there have been no experimental studies on ground stone knives and sickles in the Lower Yangtze River Region during the Late Neolithic and Bronze Age, which brings uncertainty and ambiguity to the study of archaeological records. Our study aims to address this research dilemma, in order to investigate and confirm the relationship between stone knives and sickles and the rice farming agriculture in the Lower Yangtze River Region during the Late Neolithic and Bronze Age, thus helping to better understand the technological behaviour and economic patterns of prehistoric people.

2. Materials and methods

2.1. Materials

The replicative experimentation involved eight replicate specimens (Fig. 1), corresponding to eight sets of rice harvesting experiments, all of which were conducted in the rice fields within the Park of Archaeological Ruins of Liangzhu City. The stone raw materials used to make the specimens were all metamorphic rocks, including carbonaceous slate (3

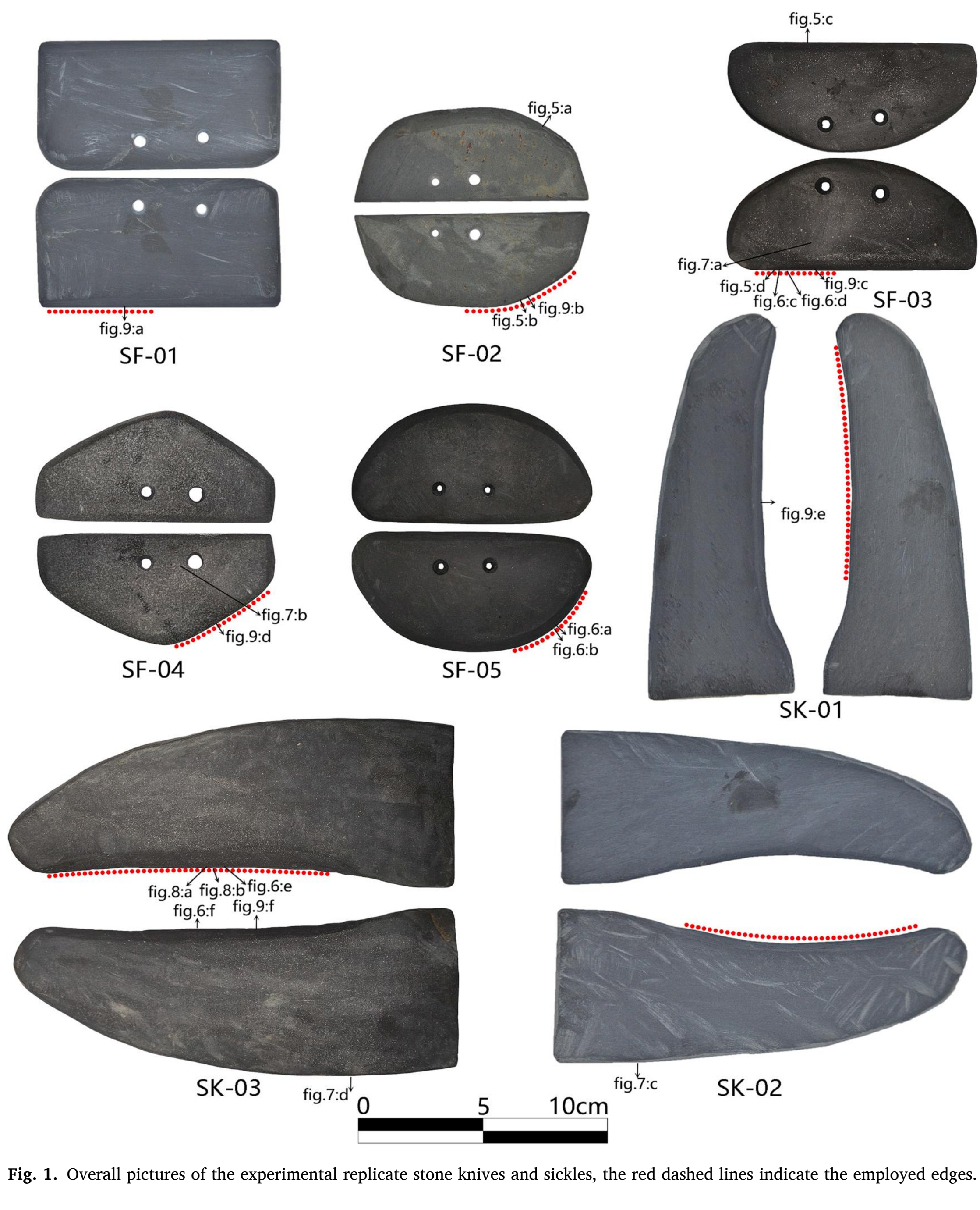

Fig. 1. Overall pictures of the experimental replicate stone knives and sickles, the red dashed lines indicate the employed edges.

specimens), silty mudstone (1 specimen), hornfelsic silty mudstone (3 specimens) and hornfels (1 specimen), of which the carbonaceous slate was purchased from the market and the others were acquired from the mountain valleys surrounding the Liangzhu Ancient City site. The slate, hornfelsic silty mudstone and hornfels were all common raw materials used for ground stone tools during the Late Neolithic and Bronze age in the lower Yangtze River Region (Huang, 1978; Ji et al., 2019: 83-100; Tang et al. 2020).

The replicate tools were made by the first author of this paper, according to the reference of archaeological specimens from the LiangZhu Museum (Table 1). Among them, SF-03, SF-04 (Fig. 2) and SF-05 were all handmade throughout the whole manufacture process, while the other tools were obtained from large raw materials using a cutting machine in the initial blank making stage, and then handmade.

2.2. Methods

The experimental project consists of two parts. The first part is the replicative experimentation, in which the operators used the replicate stone knives and sickles to harvest rice in the possible ways of prehistoric human, so as to obtain the knowledge of tools' effectiveness and the use-wear traces on the tools. The second part is the microscopic observation and use-wear analysis to determine the patterns of the use-wear traces produced by rice harvesting. Seven specimens have undergone multi-stage use and observation to record the use-wear patterns at different stages, in order to understand the trajectory of use-wear formation (Chen et al., 2013).

2.2.1. Replicative experimentation

In the replicative experimentation, four working motions were designed. The stone knife is used handheld by tying hemp rope to the perforations near the back and holding it with the palm through the rope loop. There are three working motions of using the knife (assuming the user is right-handed):

a. Upward picking (Luo, 2004)(Fig. 3: a): holding the stone knife with the edge of the blade against the spike about 10 cm below the ears, pressing the spike upon the surface of the knife with the thumb, turning it slightly and lifting the wrist upwards to cut the spike.
b. Downward pinching (Xie, 2008)(Fig. 3: b): hold the stone knife with the edge of the blade against the spike about 10 cm below the ears, hook the spike below upon the surface of the knife with the index and middle fingers, lift the spike up with the left hand and press the stone knife downwards with the right thumb to cut the spike.
c. Lateral cutting (Fig. 3: c): hold the stone knife with the ridge of the blade against the spike horizontally, hold the spike with the left hand, and cut the spike with the right hand.

The stone sickle is a composite tool with a wooden handle made of camphor stick and a hemp rope binding material. The user can hold the wooden handle and cut downwards to harvest the rice near the roots (Fig. 3: d).

Generally, in such experiments, individual differences in operators need to be assessed. Our experimental project has involved 23 stages with eight operators. Only one operator was involved in each stage, the first author of this paper participated in 14 stages, while one operator participated in three stages, and each of the remaining six operators participated in one stage. Considering that each operator had performed the task following a uniform working motion, under our attentive control, the effect of individual differences on the formation of use-wear traces is limited and will not be the focus of this study.

2.2.2. Use-wear analysis

At the end of each stage of the experiment, the specimens were rinsed and then cleaned for 5 min using an ultrasonic cleaner. The employed locations of each tool were examined under a 3D digital Keyence VHX-5000 microscope with magnifications between 20× to 2500×, micrographs were taken by the VHX-5100 microscope camera and processed in Photoshop.

As the soft texture of rice stalks makes it difficult to cause scars to the edge of the stone tool, the use-wear variables we considered in this study are polish, striation and edge rounding. Polish produced by processing the gramineous plants, which corresponds to the term "sickle gloss" (Curwen 1930) or "corn gloss" (Witthoft 1967), is the main use-wear indicator used to identify an artifact as an harvesting tool. In the second half of the 19th century (Evans 1872, Spurrel 1892), scholars began to focus on traces of this polish on prehistoric tools, suggesting that it was associated with the processing of soft plants. Curwen's experimentation with flint sickles had suggested that this polish was produced by the processing of plants, particularly harvesting grain (Curwen 1930). Since then, scholars have explored issues related to the description of polish morphology, the mechanism of its formation, and the relationship between the formation rate and use intensity and worked material (Semenov, 1964; Witthoft, 1967; Kamminga, 1979; Keeley, 1980; Anderson, 1980, 1999; Unger-Hamilton, 1984; Fullagar, 1991; Kaminska-Szymaczak, 2002). In English literature, most studies on the polish produced by the processing of gramineous plants have been based on cryptocrystalline rock such as flint and obsidian, except for Cunnar's work (2007, 2013) involving rhyolite and sandstone. However, the lithic materials for ground stone knives and sickles in the Lower Yangtze River Region differed considerably. It is therefore needed to provide new use-wear reference based on local stone raw materials to facilitate further research. On the basis of previous studies (Witthoft, 1967; Fullagar, 2006; Gao and Shen, 2008; Chen, 2011; Dubreuil, 2015; Li, 2020), it is appropriate to characterize the polish from several perspectives, including morphology, texture, degree of linkage, distribution, directionality, size of the maximum patch.

It should be noted that the use-wear traces on the tool's surface vary depending on the degree of contact with the worked material. This is reflected in the distribution pattern and the degree of development of use-wear traces in different areas on the tool's surface. Therefore, during the microscopic observation, we have selected typical use-wear traces from different locations for examination and photography, and constantly recorded them at each stage of the experiment to obtain a dynamic trajectory of the formation of use-wear traces.

Table 1
Statistics of replicate stone knives and sickles.

Specimen ID	Lithology	Edge profile	Edge angle (°)	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)
SF-01	Carbonaceous slate	Straight	49.6	99.2	53.3	5.3	61.7
SF-02	Silty mudstone	Convex curved	56.4	95.0	37.9	6.3	39.3
SF-03	Hornfelsic silty mudstone	Straight	53.9	100.8	44.9	7.0	60.5
SF-04	Hornfels	V-shaped	53.2	96.5	45.4	6.4	52.3
SF-05	Hornfelsic silty mudstone	Convex curved	60.5	96.9	48.8	6.6	62.4
SK-01	Carbonaceous slate	Concave curved	51.5	156.4	60.7	6.5	111.4
SK-02	Carbonaceous slate	Concave curved	63.9	168.7	64.9	5.7	120.8
SK-03	Hornfelsic silty mudstone	Concave curved	54.5	179.2	66.7	8.3	171.5

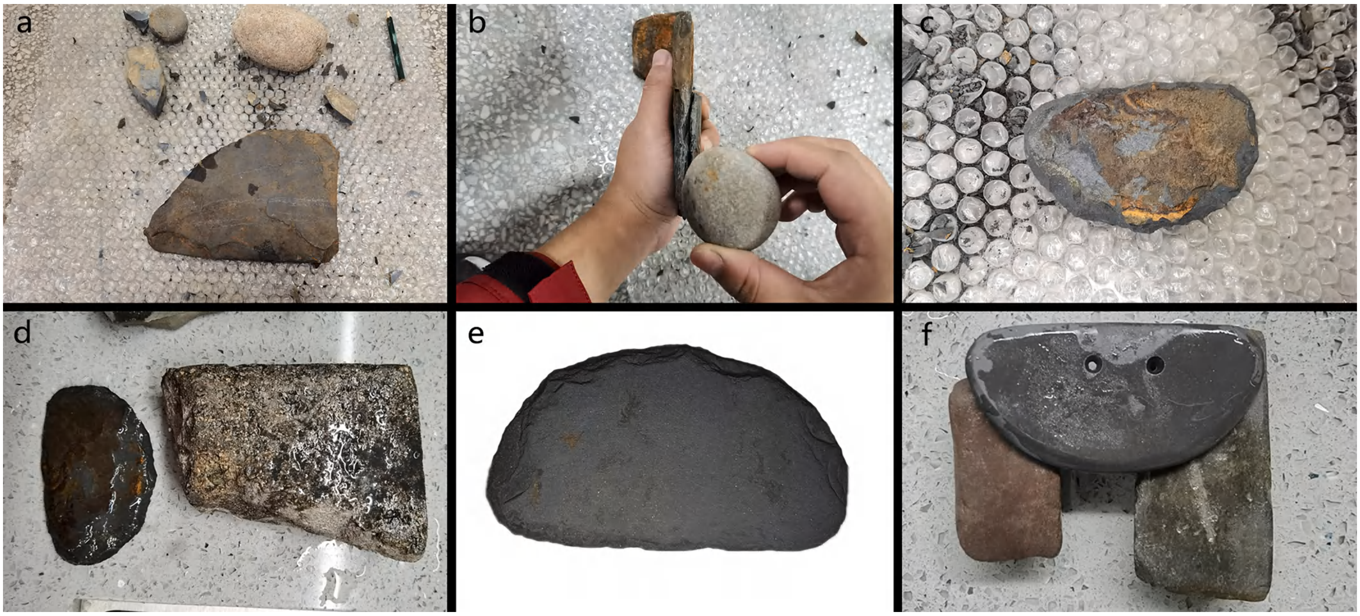

Fig. 2. Manufacturing process of a replicate stone knife: (a) A tabular raw material and the tool kit; (b) Flaking with a hammerstone; (c) A preform of the knife; (d) Grinding with granite; (e) A semi-manufactured knife; (f) Grinding with fine-grain sandstone and getting the finished knife.

Fig. 3. Four working motions used in the replicative experiments: (a) Upward picking; (b) Downward pinching; (c) Lateral cutting; (d) Downward cutting.

3. Results

3.1. Tools' effectiveness

According to the results of the replicative experiments (Table 2), both the upward picking (SF-01, SF-03) and downward pinching (SF-02, SF-04) motions were more effective, while the lateral cutting motion was inefficient and the specimen SF-05 was only used for one stage. Based on the operator's personal feedback, the hemp rope attached to the perforations on the knife had improved comfort and saved effort, and the wrist would become sore after prolonged upward picking and the lower back after downward pinching. But there is no absolute difference between these two motions in terms of effectiveness.

To a certain extent, the size and weight of the sickle affect its effectiveness and harvesting efficiency. The relatively large size of the specimen SK-02 combined with its comparatively light weight makes it the most comfortable and efficient of the three sickles. Occasionally, during the harvesting process, the hemp rope would break and the sickle would fall off the wooden handle, but it had little effect on the continuity and efficiency of the work.

3.2. Use-wear patterns resulting from different working motions

The different working motions determine differences in the contact

Table 2
Recording form of the multi-stage replicative experiments.

Specimen ID	Working motion	Durationof each stage (min)	Number of spikes harvested in each stage	Total time-consuming (min)	Total number of spikes	Number of spike harvested per hour
SF-01	Upward picking	98	956	361	5065	841
		88	780			
		175	3329			
SF-02	Downward pinching	88	1396	538	7604	848
		73	758			
		242	2872			
		135	2578			
SF-03	Upward picking	90	953	605	10,440	1035
		205	3887			
		310	5600			
SF-04	Downward pinching	88	1098	677	10,651	943
		354	5135			
		235	4418			
SF-05	Lateral cutting	210	1914	210	1914	546
SK-01	Downward cutting	112	~3000*	294	~9000*	~1836
		95	~3200*			
		87	~2800*			
SK-02	Downward cutting	118	~7500*	311	~19200*	~3704
		88	~5200*			
		105	~6500*			
SK-03	Downward cutting	127	~5600*	382	~19100*	~3000
		135	~7000*			
		120	~6500*			

* :When harvesting rice using the stone sickle, the stalks are stacked on the ground directly and it is hard to count them accurately.

areas and the degree of contact between the tool and the worked material. This is perceptible in the distribution of polish on the tool's surface and in the degree of development of the polish in different locations (Fig. 4), which can often be revealed at low magnification observation.

The two working motions of the stone knife, upward picking (SF-01, SF-03) and downward pinching (SF-02, SF-04), can be seen as somewhat of a mirror image of each other. Thereby, the use-wear patterns resulting from these two motions are similar: the polish is more widely distributed and more developed on the contact surface (Fig. 4), which is often smoother, brighter and has a higher degree of linkage than that on the non-contact surface(Fig. 5). Furthermore, the polish on the non-contact surface is restricted to the edge, and its intrusion distance is significantly smaller than that on the contact surface (Fig. 4). However, the use-wear traces on SF-05 used in a lateral cutting motion were almost symmetrically distributed on both sides of the edge.

With regards to the stone sickle, both sides of the blade are in direct contact with rice stalks and the polish patterns are basically similar, except a slight difference in the polish intrusion distance: SK-01: 6.5 mm, 4 mm; SK-02: 5 mm, 3.5 mm; SK-03: 5 mm, 4 mm.

Different working motions determine different directions of relative movements between the tool and the worked material, which are clearly reflected in the use-wear patterns. The knife SF-05 was used in a lateral cutting motion, which produced domed polish and fine striations parallel to the blade on the edge (Fig. 6: a) and relatively small polish patches in a horizontal distribution along the edge ridge (Fig. 6: b). The use-wear traces on the knife SF-03 used in an upward picking motion presented a distinctively different orientation, with domed polish and fine striations almost perpendicular to the edge of the contact surface

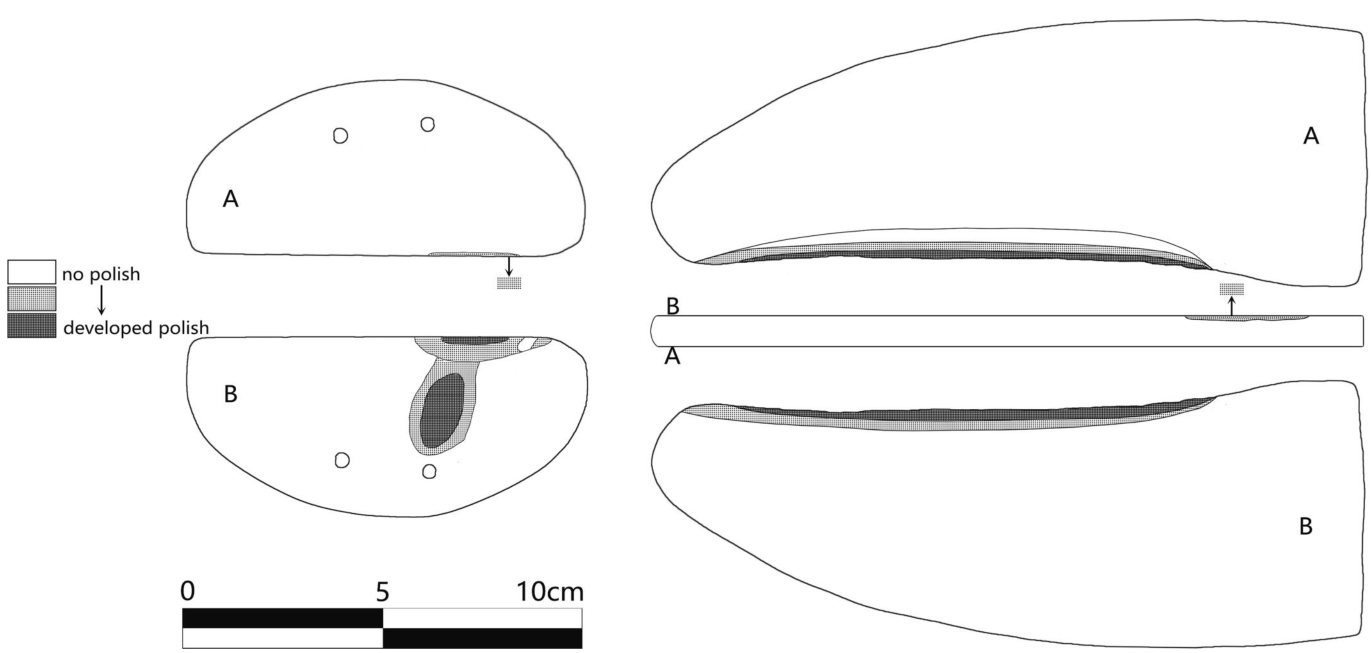

Fig. 4. Schematic drawing of the use-wear traces distribution on experimental replicas: left. SF-03; right. SK-03.

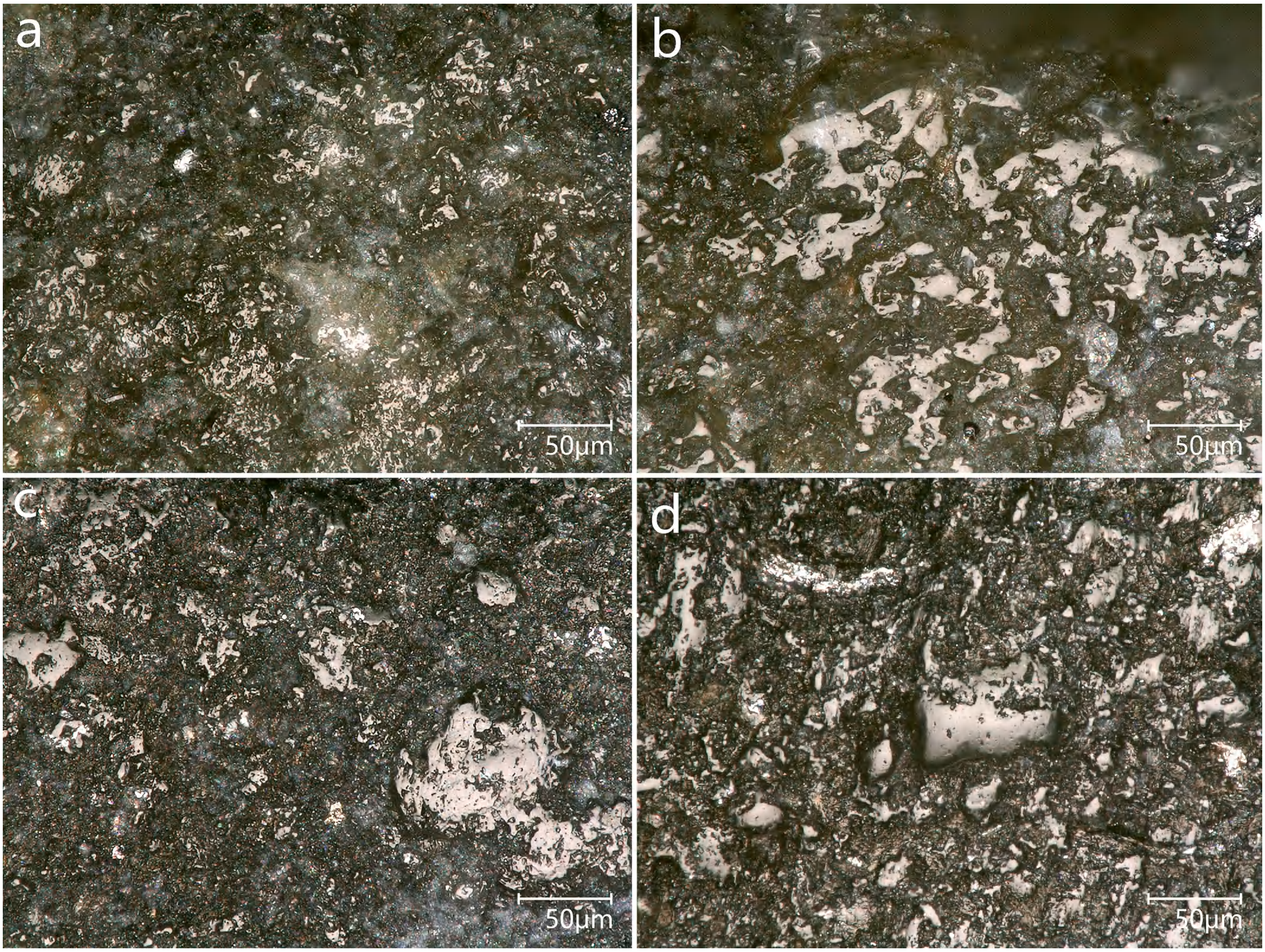

Fig. 5. Polish on non-contact surfaces and contact surfaces of the replicate stone knives: (a) polish on non-contact surface of SF-02, 1000×; (b) polish on contact surface of SF-02, 1000×, used for 538 min; (c) polish on non-contact surface of SF-03, 1000×; (d) polish on contact surface of SF-03, 1000×, used for 605 min.

(Fig. 6: c, d). The sickle SK-03 was observed with domed polish and fine striations parallel to the edge (Fig. 6: e, f), the polish patches were relatively larger with a higher degree of linkage. Fine striations corresponding to the direction of movement of the tool were observed on most experimental specimens, except for SF-01 and SF-02. In addition, striations on the sickle's edge were more numerous and more obvious than those on the knife's edge, which may be related to the higher soil contents on the stalks near the ground (Anderson, 1999; Unger-Hamilton, 1989, 1999).

In addition to the contact between the working edge and the worked material, other parts of the tool also come into contact with the worked material, the hafting material and the skin of the operator. When the stone knife used in both the upward picking and downward pinching motions, the stalk was pressed against the body of the tool. This action produced the corresponding use-wear traces, which appeared as flat polish of low brightness, well-linked as a whole, accompanied by fine and relatively deep striations in roughly the same direction indicating the direction of movement of the stalk (Fig. 7: a, b). These traces were observed on four knives (except SF-05), in this paper we referred to these as "impressions of rice stalk". Hafting-wear traces were also found in the contact areas between the backs of all three stone sickles and the wooden handles, which appeared as sinuous polish of low brightness, with rough texture, linked in small patches, some were accompanied by fine striations almost perpendicular to the long axis of the tool (Fig. 7: c, d). It is noted that the hafting-wear traces observed here were less developed, this is probably related to the hafting stability. All the three sickles experienced instances of rope breakage during their use, but only SK-01 had detached from the handle twice. There was no excessive friction between the sickles and the handles caused by detachment, except for that required for microscopic observation. No obvious prehensile wear traces were detected on any of the stone knives in the replicative experimentation, which may be related to use intensity and the fact that the specimens were all cleaned prior to observation.

3.3. Use-wear patterns resulting from different use intensities

The use intensity can be divided into relative and absolute use intensity. The relative use intensity varies according to the working motion. Harvesting rice near the ear with a stone knife can be considered as a light-duty task, while harvesting rice near the root with a stone sickle can be considered as a heavy-duty task. The latter would have a greater contact area with the worked material, the movement would be more forceful, and therefore a wider distribution of polish with a higher level of its development for the same or even less duration of use (Fig. 6). When the tool was used in a uniform working motion, without involving maintenance, the absolute use intensity was mostly subject to the duration of use. Different intensities/durations of use produced different use-wear patterns, and these patterns of different stages were put together to constitute a dynamic trajectory of the formation of use-wear traces. Here we have chosen the sickle SK-03 to describe its use-wear

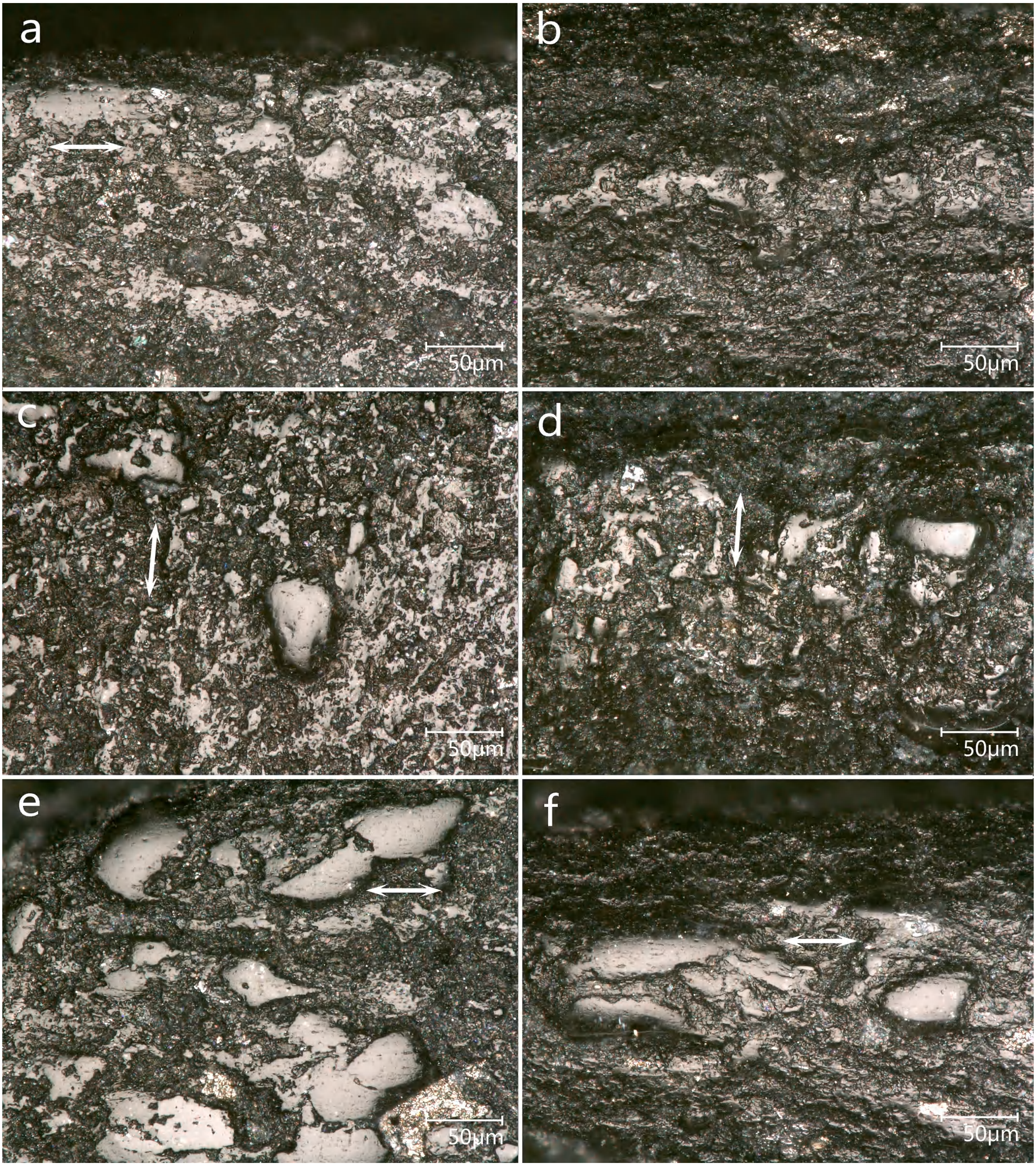

Fig. 6. Use-wear patterns on replicate knives and sickles used in different working motions: (a) polish on the edge of SF-05, 1000×; (b) polish on the ridge of SF-05, 1000×, used for 210 min; (c) polish on the edge of SF-03, 1000×; (d) polish on the ridge of SF-03, 1000×, used for 605bminutes; (e) polish on the edge of Sk-03, 1000×; (f) polish on the ridge of Sk-03, 1000×, used for 382 min.

patterns observed after each of its three experimental stages (Fig. 8).

Stage 1: The tool was used for 127 min and about 5,600 spikes were harvested. The working edge was observed with bright polish in a banded distribution parallel to the blade, mostly domed, a few flatter. The length of the maximum patchy was about 110 μm, comet-like pits were often found inside the patchy, most patches were not well-linked. The polish intrusion distance on the both sides of the blade was about 3 cm and 4 cm respectively. As for the ridge, the polish was similar to that on the edge, and the maximum patch was about 130 μm long.

Stage 2: The tool was used for 262 min and about 12,600 spikes were harvested. The number of domed polish was increased, mostly smooth, some with fine striations parallel to the blade and comet-like pits, linked

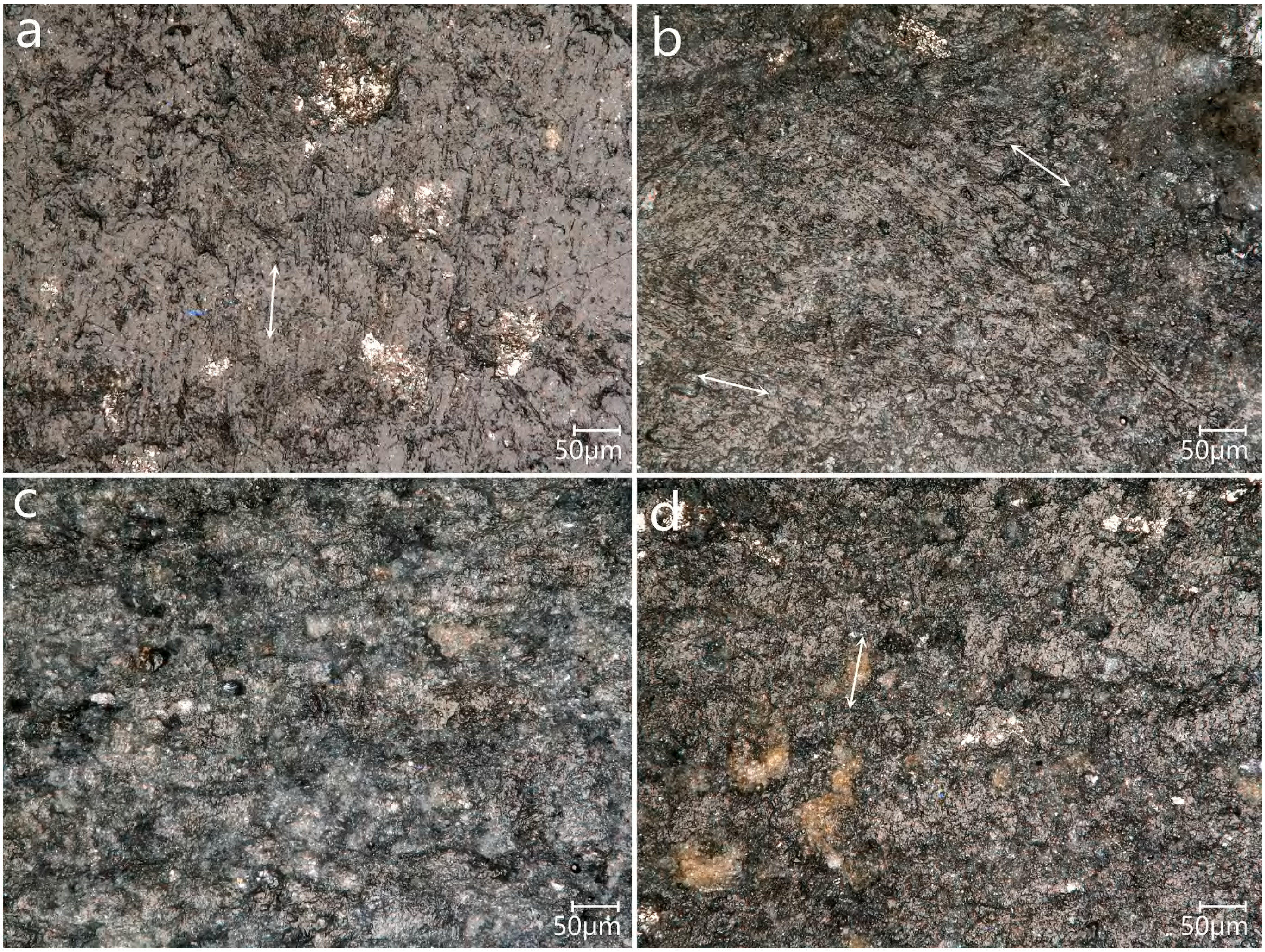

Fig. 7. Use-wear traces left by rice stalk and hafting material: (a) impressions left by rice stalks on the body of SF-03, 500×, used for 605 min; (b) impressions left by rice stalks on the body of SF-04, 500×, used for 677 min; (c) hafting-wear left by the wooden handle on the back of SK-02, 500×, used for 311 min; (d) hafting-wear left by the wooden handle on the back of SK-03, 500×, used for 382 min.

in small patches, and the maximum patch grew to about 150 μm long. The polish intrusion distance on the both sides of the blade was approximately 4 cm and 5 cm respectively. The maximum polish patch on the ridge was about 160 μm long.

Stage 3: The tool was used for 382 min and about 19,100 spikes were harvested. The working edge was dominated by bright domed polish, linked in reticulated patches, some with subtle striations and comet-like pits, the maximum patch reached to about 160 μm long. The polish intrusion distance on the both sides of the blade was almost unchanged. The polish on the ridge was relatively well-linked in large patches, and the maximum patch was about 210 μm long.

3.4. Use-wear patterns resulting from different stone raw materials

Differences in the mineral composition, grain size, asperity, hardness and degree of cementation of different stone raw materials can affect the use-wear patterns (Liu, 2017; Zhai, 2018). In this study, the most significant effects were in the two attributes of the linkage of polish and the size of the maximum polish patch (Fig. 9), which of course were also influenced by the working motion and the use intensity. A comparison of the polishes observed on different replicate tools made of various stone raw materials showed that they were generally similar in terms of morphology, texture, and brightness (Fig. 9). However, these results of the replicative experimentation and microscopic observation suggested that the differences in the attributes of polish resulting from differences in the nature of stone raw materials were less significant for identification at the microscopic level than the commonality.

4. Discussion

The results of the replicative experiments have suggested that both ground stone knives and sickles are effective in harvesting rice when used in proper working motions, which provides empirical evidence for deciphering the functions of archaeological specimens. Our definition of the use-wear patterns of rice harvesting will help determine whether or not the tools were used and how.

4.1. The use-wear patterns of rice harvesting

Harvesting rice would produce bright domed polish linked in reticulated patches on the working edges of ground stone knives and sickles, close to the “sickle gloss” observed on the flint tools. In this study, we would like to use the term “cereal-reaping polish” (Linton et al, 2016), which had already been detected on the stone knife we used to harvest wheat (Chen, 2021). Fine striations in the same direction of tool movement and comet-like pits were often observed on the surfaces of polish patches. For the stone knives, the degree of polish development and polish intrusion distance were significantly higher on the contact

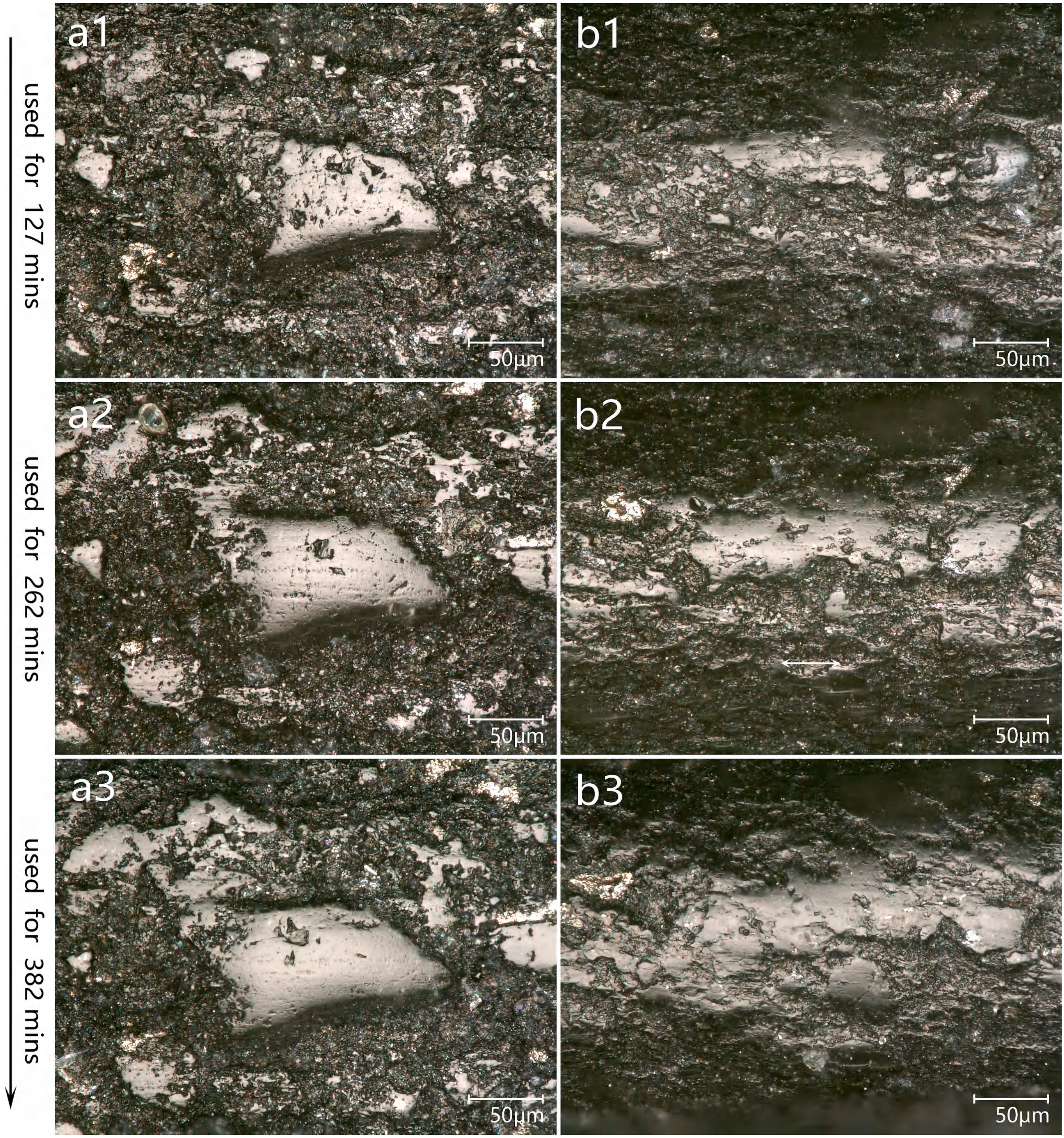

Fig. 8. Multi-stage use-wear patterns observed on the sickle Sk-03: the polish on the edge of the blade at each stage (a1, a2, a3) and that on the ridge of the blade at each stage (b1, b2, b3), 1000×.

surface than on the non-contact surface. Here it should be noted that the non-contact surface refers to the surface that does not have direct contact with the worked material at a macro level. However, rice stalk is soft, and during the harvesting, it will slightly pass over the ridge of the blade and leave traces on the other side, which is the less developed polish on the non-contact surface. As for the stone sickles, the use-wear features were similar on both sides of the blade, and the polish intrusion distance could up to 5–6.5 mm. The two motions of upward picking and downward pinching would produce flat polish of low brightness accompanied by fine and relatively deep striations on the body of the stone knife that were undetectable on the used edge. While the wooden handle also produced, on the back of the stone sickle, a sinuous polish of low brightness accompanied by fine striations. These traces reflected the working motions in which the tools were used. These traceological features of cereal-reaping polish, impressions of rice stalk and hafting-wear traces can be applied for the functional analysis of ground stone knives and sickles from the archaeological records.

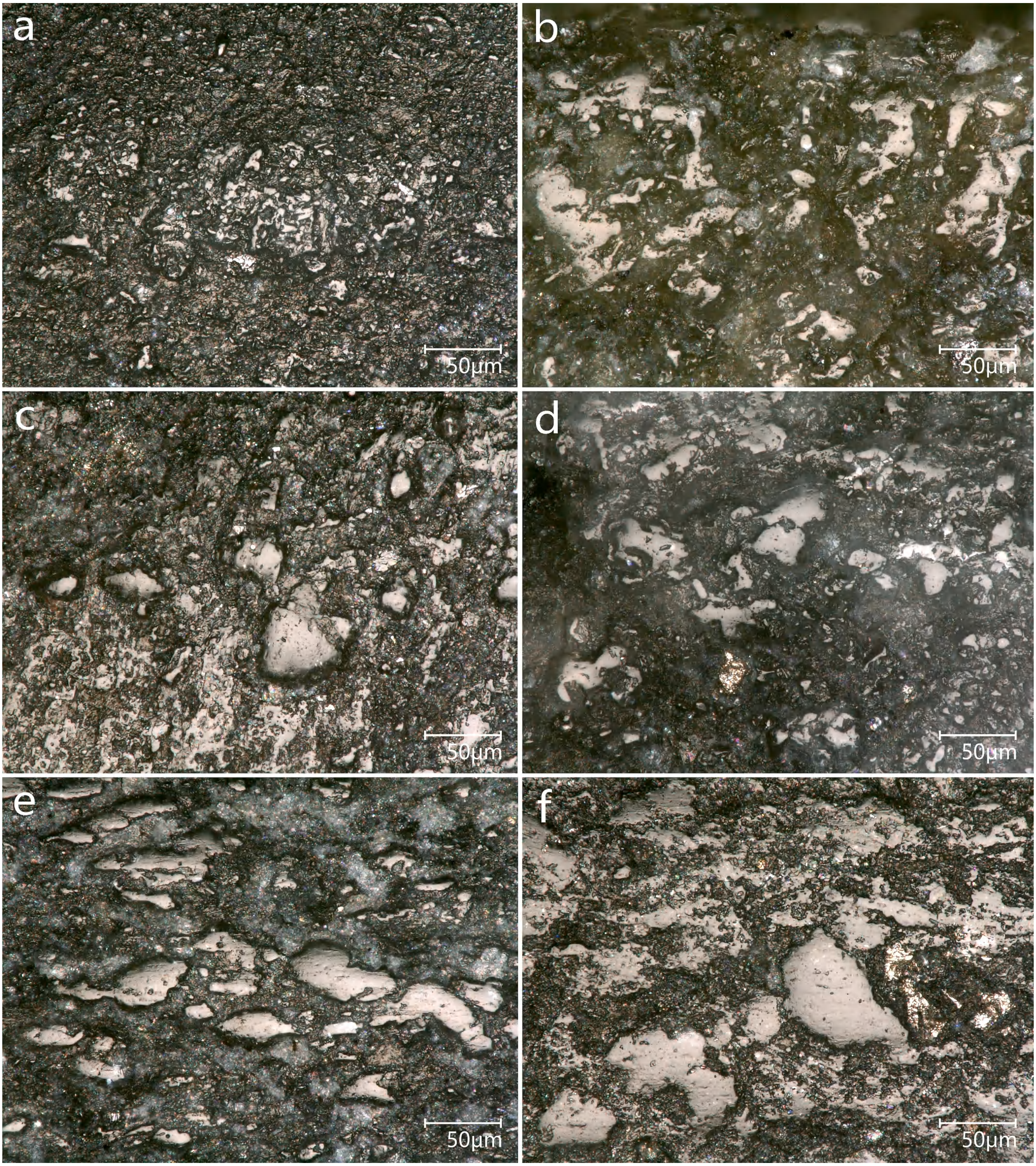

Fig. 9. Use-wear patterns on replicate knives and sickles made of different stone raw materials. (a) polish on the edge of SF-01 used for 361 min, 1000×; (b) polish on the edge of SF-02 used for 538 min, 1000×; (c) polish on the edge of SF-03 used for 605 min, 1000×; (d) polish on the edge of SF-04 used for 677 min, 1000×; (e) polish and fine striations on the edge of SK-01 used for 294 min, 1000×; (f) polish and fine striations on the edge of SK-03 used for 382 min, 1000×.

4.2. The dynamic trajectory of the formation of cereal-reaping polish

The cereal-reaping polish observed on the working edge changed as the intensity of tool used increased, and its dynamic trajectory was characterized by the followings:

(1) The polish morphology developed from flat to domed;
(2) The polish texture was initially heavily pitted, then the pits gradually diminished, and the polish became smoother;
(3) The polish was relatively bright in the early stages of its formation and did not change significantly after reaching the peak of its reflectance;

(4) The polish was in a banded distribution along with the working edge, the polish patches were initially separated and gradually linked into larger patches;
(5) The maximum polish patch size increased with the intensity of use, for developed polish, the maximum patch size was generally greater than 100 μm, but the growth rate would become progressively slower;
(6) The polish would intrude into the edge of the tool over time, but stopped after a certain distance, as the area of contact between the edge and the worked material is essentially limited.

By combining the various attributes of polish, it is possible to determine the degree of polish development and thus inferring the specific position of the tool in its life history. From the experimental results, the polish produced by rice harvesting developed in a fast to slow rate that was positively correlated with the intensity of use. Such a pattern of polish development is consistent, to some extent, with previous studies (Fullagar, 1991; Ibáñez and Mazzucco, 2021). Here, the correspondence between use-wear features and use intensity has mainly been qualitatively described, with only a simple quantitative distinction for the size of the maximum patch. Although the quantitative research on determining use intensity through use-wear traces has been a significant issue (Vardi et al., 2010; Goodale et al., 2010; Stemp et al., 2012), the field of rice harvesting polish discussed in this paper is currently in a stage of data accumulation, requiring a more cautious approach. In the future, it can be expected to further in-depth quantitative analysis.

4.3. A comparison of cereal-reaping polish under different circumstances

Some scholars have carried out experiments on processing soft plants with ground stone tools, and there are some aspects worth comparing and discussing. Harada (2011) used stone knives made of crystalline schist to harvest rice, Cai (2014) used stone knives made of metamorphic tuff to cut dry rice straw, and Cui (2017) used stone knives made of schist to cut dry rice straw, all of which resulted in cereal-reaping polish on the tools, similar to that on our study, but with different degrees of development. This further demonstrates that, under the condition where the tool type and the worked material are basically similar, the difference in stone raw materials has a limited impact on the polish.

As for different worked materials, the situation seems to be somewhat complex. Fullagar et al. (2012) have used experimental denticulate slate sickles to harvest Quercus acorns, Poaceae grass and Typha reeds, and the results demonstrate that small patches of polish in the three harvesting experiments is strikingly similar. Considering the similar texture of Poaceae grass and Typha reeds, it is reasonable that harvesting them produces a similar polish. To some extent, the same situation applies to Quercus acorns as well. It is worth noting that in our experiments, the polish produced by harvesting rice appears to be very similar to that produced by harvesting wheat (Chen et al., 2021). However, the polish addressed in Fullagar et al.'s (2012) experiments differs significantly from that in our experiments, which could be related to factors such as tool type, working motion and even observation equipment. What needs to be pointed out is that when the tool type, the stone raw material and the working motion are basically similar, the polish produced by processing different kind of gramineous plants has a strong similarity, and it is not easy to directly distinguish them. Therefore, it is necessary to combine the archaeological context and the residue analysis to achieve a more precise interpretation.

5. Conclusion

The ground stone knives and sickles were an essential group among the stone tool assemblages in the Lower Yangtze River Region during the Late Neolithic and Bronze Age, the link between them and rice farming agriculture has always been of great interest to scholars. It has long been assumed that these tools were used for harvesting, based on morphological analogy with metal tools of later ages. However, this view is purely speculative and has no empirical evidence to corroborate and enrich the details.

In this study, we have conducted a systematic experimental project on the ground stone knives and sickles, and have successfully evaluated their effectiveness as harvesting tools. The results of the replicative experiments have confirmed that the ground stone knives and sickle could be used for rice harvesting. The use-wear patterns of rice harvesting were dominated by a specific cereal-reaping polish, impressions of rice stalk and hafting-wear traces, which appeared on different parts of the tool, suggesting the necessity and importance of a throughout in-situ examination of the tool.

This study expands the use-wear reference collection for identifying ground stone harvesting tools, particularly stone knives and sickles, which are crucial for investigating the development of rice farming agriculture in the Lower Yangtze River Region. The data and images acquired in this study will certainly be used in the functional interpretation of archaeological specimens in future studies, and will need to be combined with other methods, such as residue analysis, to construct a complete chain of evidences for deciphering the functions of ground stone tools.

CRediT authorship contribution statement

Liping Xue: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Data curation, Visualization. **Hong Chen:** Methodology, Investigation, Writing – review & editing. **Minghui Chen:** Resources, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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A functional study of ground stone tools from the Bronze Age site of Dingjiacun in South China: Based on use-wear evidence

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ABSTRACT

Ground stone tools were a revolutionary technology that appeared during the Late Pleistocene and Early Holocene periods and played a key role in the economic and ritual activities of many prehistoric and early historic societies. Previous functional analyses of ground stone tools in China have focused primarily on Neolithic materials and had a regional preference for northern China. This article reports on the results of a functional study of an assemblage of ground stone tools found at the Dingjiacun site in southern China. Use-wear analysis was adopted to interpret the tools' function through observing and identifying the wear patterns that corresponded to different substantial activities. Our results showed that the site once contained a settled agricultural community where a large array of activities such as wood-working, harvesting, earth-working, and hunting were carried out. The results of our study should provide a better understanding of human behaviors and subsistence strategies in the Lower Yangtze River region during the Bronze Age.

1. Introduction

Ground stone tools are clearly distinguishable from chipped stone in having been modified through abrasive, as opposed to only percussive, forces (Odell, 2004: 74). The term "ground" actually refers to two different processes, namely manufacture-ground and use-ground. Manufacture-ground is a technological perspective, which means that stone tools are primarily manufactured through abrasion, polish, or necessary impaction, like an axe. Use-ground is a functional perspective used to describe tools that are used to grind, abrade, polish, pound or impact, such as metates and mortars (Odell, 2004: 75-80; Adams, 2013: 3). Large scale studies have previously been conducted by Wright (1992) in Southwest Asia, Adams (2002) in the American Southwest, and de Beaune (2000) in Europe, which have all laid the groundwork for typological and use-wear analysis research. It is clear that ground stone tool assemblage composition often varies according to geographic areas, meaning that scholars from different areas will put their focuses on different ground stone tool types. There have been several investigations of use-ground stone tools (Dubreuil, 2004; Dubreuil and Grosman, 2013; Dubreuil et al., 2015; Fullagar et al., 2006; Nadel et al., 2009; Nadel et al., 2012) Hamon, 2008; Liu et al., 2010; Liu et al., 2011), while the manufacture-ground stone tools have received less attention (Latorre et al., 2017; Liu et al., 2017, Fullagar et al., 2021). In the context of Chinese archaeology, ground stone tools refer primarily to the manufacture-ground tool types, such as cutting (axes and adzes), harvesting (knives and sickles), earth-working (spades), and hunting (arrowhead) implements. This study focuses primarily on the manufacture-ground stone tools.

Although grinding and polishing require a higher cost in terms of time and labor, and although ground stone tools may not be more efficient for short-time use comparing to chipped tools, they do have some specific advantages. Each grinding and polishing process creates a newly available edge, which can greatly improve the lithic raw material utilization (Hayden, 1987). Most ground tools are made from materials with less silicon content, which makes them tough and hard to break. Moreover, material strength is improved by edge-grinding, meaning that ground tools are a better choice for long-term use compared to chipped tools as they will have greater durability and efficiency (Boydson, 1989). This means that fewer raw materials are ultimately needed to accomplish the same amount of tasks, which would have reduced the time and

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labor needed for ancient humans to obtain raw materials for stone tools manufacture.

The earliest known evidence of manufacture-ground stone tool reported up till now all over the world is a fragment of a ground-edge axe found in northern Australia, which dates back to 44,000–49,000 years ago (Hiscock et al., 2016). In China, stone tools with partially ground edges have also been found at Upper Paleolithic sites, for example, archaeologists discovered a partially polished spade, dating back to 25000 cal BP at the Longwanchan site in Shaanxi Province, China (Yin and Wang, 2007; Zhang et al., 2011). In the Neolithic Age, ground stone tools became one of the most significant tool kinds and were still being used in China until iron tools gradually replaced stone tools in the Qin and Han dynasties (Wang, 2004).

Archaeological studies of ground stone tools in China began in the 1920 s. From 1917, Anderson had discovered prehistoric Neolithic remains in central China while he was collecting fossils. He collected a lot of stone artifacts, such as axes, adzes, chisels, knives, and arrowheads, and published several works based on them (Anderson, 1920, 1923). In 1926, Li conducted archaeological excavations of Xiyincun ruins in Xia County, Shanxi Province-the first Neolithic site excavated by Chinese archaeologists. Ground stone tools such as axes, adzes, and knives were recovered in this excavation (Li, 1927).

Typological studies have always been the main research approach for examining ground stone tools (Li, 1952; An, 1955; Lin, 1958), and classification and designation have been conducted for decades (Li, 1981; Ji, 1983; Fu, 1985, 1988; Yang, 1996; Qian, 2010). With more archaeological materials being discovered and more studies being conducted, researchers have realized that tool function, manufacturing method (Tong, 1978; Shuo and Yang, 2003; Huang, 2004; Zhang and Lin, 2008; Liu et al., 2013; Zhai, 2015) and raw material procurement and distribution (Tao, 1991; Qian et al., 2006; Zhuang, 2008; Jia, 2013; Zhai, 2014) are all key issues in ground stone tool analysis.

Functional studies have often been used for interpreting human behaviors and subsistence strategies and have been used in China since the 1980s. Chinese researchers initially tried to combine morphological comparisons and ethnographic observations based on typology (Li, 1980; Mou and Song, 1981). Additionally, functional analyses were attempted from the viewpoint of mechanics (Yang, 1982; Ji, 1987, 1993). More recently, scientific methods such as experimental archaeology, microwear analysis, and residue analysis were gradually introduced to China, which provided more objective evidence for the functional study of ground stone. Based on this, more comprehensive studies of ground stone tools have been conducted in China (Tong, 1982; Fu, 1993; Zhu, 1997; Qian, 2005; Wang, 2008; Xie, 2008; Cai, 2014; Cui, 2018; Gao, 2018), which demonstrated the great potential of functional study to interpret subsistence strategies and economic patterns of prehistoric cultures and early states. Some studies integrated multiple methods for an entire assemblage of ground stone tools, including plough-shape tools, knives, and sickles (Liu et al., 2015; Liu et al., 2018). Although some results are still under debate, multi-disciplinary studies have generated important data for archaeological interpretation.

With the development of research theory and method, and based on typological, technological, and functional studies, ground stone tool analysis has become an important research topic. However, only limited research regarding ground stone tool analysis in China has been published in the international literature. Therefore, more theories and practices of ground stone tool analysis in China needed to be present.

Previous functional studies of ground stone tools in China have mainly been conducted on Neolithic materials and have a regional preference in North China (Xie, 2008; Wang, 2008; Cai, 2014; Cui, 2018; Liu et al., 2018; Fullagar et al., 2021). There have been few comparable studies in southern China (Liu et al., 2015), particularly during the historical period with written records which was opened by the Oracle Bone Inscriptions from approximately 1300 BCE.

In this study, we applied use-wear analysis on the ground stone tool assemblages from the Dingjiacun site to reveal their function. Based on our analysis, we will then discuss the human lifestyle and socio-economic patterns of the people who lived in the Lower Yangtze River region during the Bronze Age.

The Dingjiacun site (32°06′23 ~ 54″N, 119°19′45 ~ 28″E) in Zhenjiang City, Jiangsu Province (Fig. 1), is located in the valley between Mount Gaoli and Mount Shilichang. The site is a typical platform mound on the bedrock, occupying approximately three hectares. Pottery styles suggest that this site dates back approximately to the West Zhou Dynasty. The AMS dating of the charcoal is 2830 ± 30 cal BP, while the charred wheat seeds have been dated to 2820 ± 30 cal BP. Therefore, the site itself can be carbon-dated to 2790–2860 cal BP (Fig. 2). The chronological framework of the studied area is arranged in the order of Dingshadi Culture (7000–6300 cal BP), Beiyinyangying Culture (6000–5000 cal BP), Dianjiangtai Culture (4100–3700 cal BP), and Hushu Culture (3600–2850 cal BP, corresponds approximately to the Shang Dynasty and the early West Zhou Dynasty in the Central Plain, Zhang, 2003: 242). Based on the chronological evidence, the Dingjiacun site was probably occupied by the Hushu Culture.

A team from Zhenjiang Museum have conducted an excavation on this site in 2014 and have uncovered many different features, including pillar holes, ash pits, burials as well as remnants of pottery, stone tools, bronze objects, animal bones, and plant remains (Si et al., 2018) (Fig. 3).

Large quantities of carbonized plant remains, predominantly crop seeds, were identified in plant flotation samples from cultural layers. These included wheat (*Triticum aestivum*), rice (*Oryza sativa*), foxtail millet (*Setaria italica*), broomcorn millet (*Panicum miliaceum*), and soybean (*Glycine*), implying that the food production at the Dingjiacun site was primarily based on agriculture, characterized by the distinct "five grains" crop planting structure, and supplemented by foraged wild plants. Rice was the local crop in the Lower Yangtze River region, while

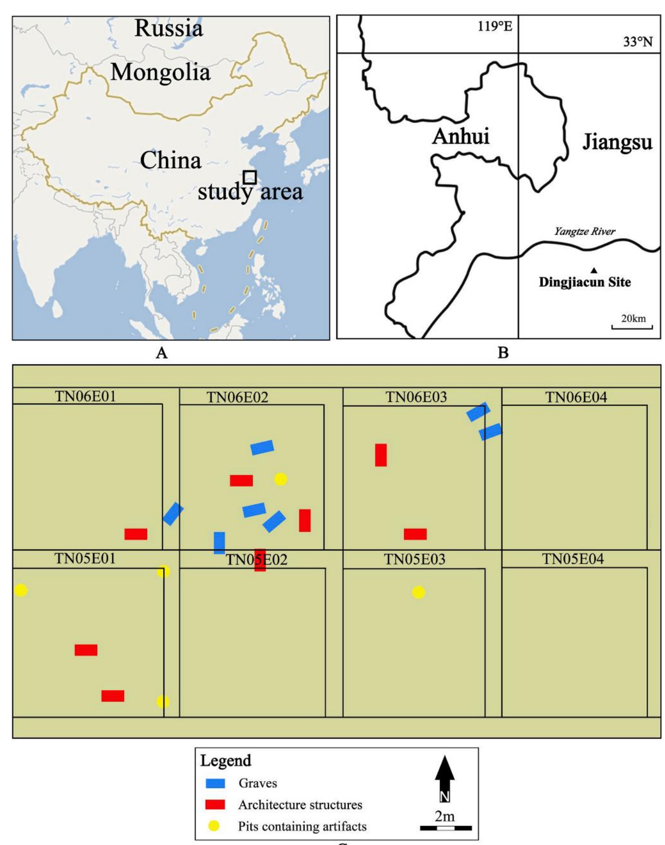

Fig. 1. A, B. Geographic location of the Dingjiacun site studied in this work. C. The distribution of archaeological features at the site in the eastern part of the excavated trenches.

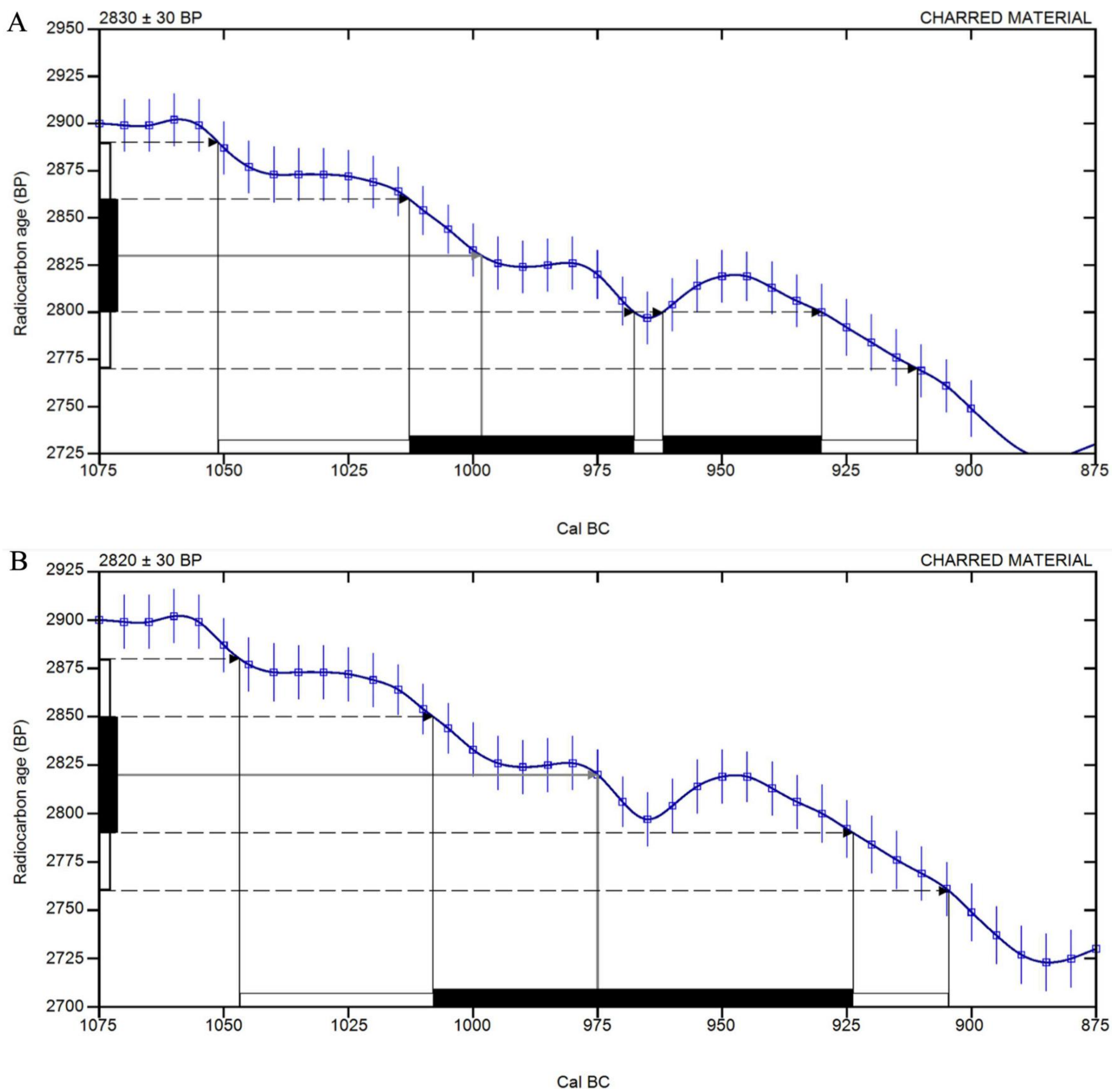

Fig. 2. C14-AMS dating results of the charred materials from the Dingjiacun site. A. Charcoal sample (Beta-443999). B. Charred wheat seed sample (Beta-4434000).

millet and wheat were foreign upland crops that prevailed in the north arid agriculture. This indicates that people at the Dingjiacun site practiced a mixed rice and millet agricultural system and were probably influenced by cultural exchanges and population migration between the Lower Yangtze River Basin and the Yellow River Basin (Wu et al., 2017).

The faunal remains recovered at the Dingjiacun site were mammalian. Seven species were found, including dog (*Canidae*), pig (*Sus scrofa domesticus*), elk (*Elaphurus davidiaus*), sika deer (*Cervus Nippon*), cattle (*Bos* sp.), and horse (*Equus caballus*). According to the behaviors of C*ervidae*, the Dingjiacun site was once in a temperate grassland zone with some marshland and a relatively warm and humid climate (Chen and Si, 2017). Moreover, the identification of cattle and horse remains provides important early evidence that people in the Yangtze River Basin had begun domesticating these animals.

The remains also indicated that with the spread of cultures from North to South China, domesticated animals such as cattle and horses had been spread to South China and were being domesticated there. The aforementioned evidence shows the possibility of communication and exchanges between cultures in the Lower Yangtze River region and the Yellow River region during the Bronze Age.

Carbon and Nitrogen stable isotopic analysis was conducted on two pieces of human bones recovered from the Dingjiacun site, with the results showing that ancient people at the Dingjiacun site mainly consumed C_3 plants with a small number of C_4 plants. Combining the results of archaeobotanical analysis together, it is very likely that rice and wheat were the dominant plant resources exploited by the Dingjiacun people, although they also consumed small proportions of millet. The results from the nitrogen isotope suggest that a certain number of terrestrial herbivores, and a lot of marine fish were exploited as animal resources, as the Zhenjiang area was close to the paleocoastal line during the late Neolithic Age and the early Bronze Age (Zheng et al. 2018).

2. Materials and methods

2.1. Materials

A total of 258 stone artifacts were recovered from the Dingjiacun site, including 62 adzes (including ten broken ones), 60 knives (including 47 broken ones), eight sickles (including six broken ones), 14 chisels (including eight broken ones), 32 spades (including 21 broken ones), nine arrowheads (including seven broken ones), 29 grinding stones, 16 other types of tools, and 28 semi-manufactured or unknown tools. Among these artifacts, 120 relatively well-preserved tools (57.4%) with identifiable working edges were selected for use-wear analysis.

All adzes and chisels were classified as “adzes” when they were unearthed, although some of the tools involved in this study were

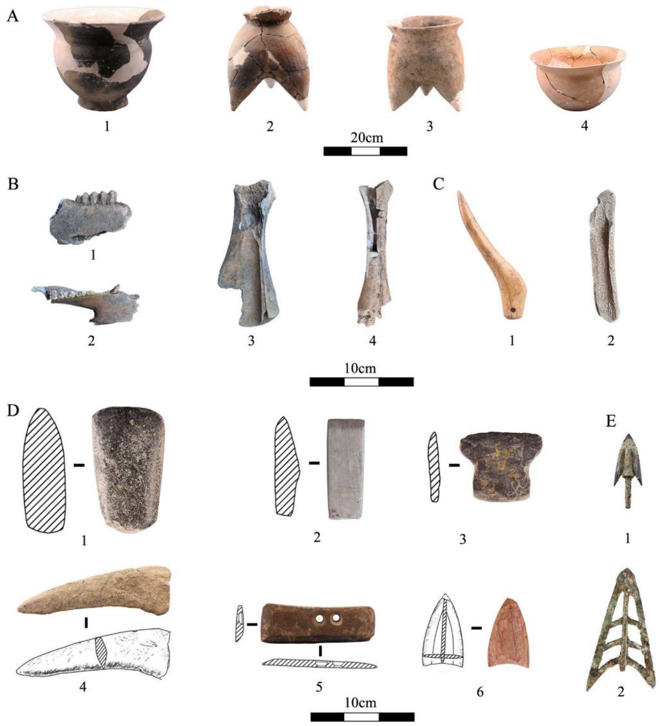

Fig. 3. The archaeological record retrieved from the Dingjiacun site. A. Pottery vessels. 1. Gui (a round-mouthed food vessel); 2. Yan (an ancient cooking utensil for steaming rice); 3. Li (an ancient cooking tripod with hollow legs); 4. Pot. B. Animal bones. 1. Right mandible of *Bos* sp.; 2. Mandible of *Sus scrofa domesticus*; 3. Right scapula of *Bos* sp.; 4. Right metacarpal of *Elaphurus davidiaus*. C. Bone tools. 1. Antler tool with a drilled hole; 2. Bone dagger. D. Ground stone tools. 1. Axe; 2. Stepped adze; 3. Shouldered spade; 4. Sickle; 5. Knife; 6. Arrowhead. E. Bronze arrowheads. 1. Tanged arrowhead; 2. Hollowed-out arrowhead.

distinguished separately and renamed as "chisels". We propose the following criteria to distinguish adzes and chisels based on morphological and technological features.

The adze usually bears the following characteristics: a. the width is greater than the thickness; b. most artifacts are unifacial on edge; and c. knapping traces or a step for hafting are often present on the tool surface. In contrast, a chisel has the following characteristics: a. its width is nearly equivalent to or slightly greater than its thickness; b. most artifacts are bifacial on edge; and c. knapping traces for hafting are rare.

Both axe (which only account for a small proportion of the Dingjiacun ground stone tool assemblage) and adze are generally considered to be composite tools; the relatively small, rounded base (relative to the edge) of the axe and the knapping traces or a step of the adze are suitable for hafting, which are probably intentionally designed. However, the chisel is often more evenly shaped, seemingly for ease of grip. However, although these three kinds of tools (Fig. 4) were likely to have been used to process the same materials (e.g., wood), the working postures were probably different.

2.2. Use-wear analysis

Because of its ability to efficiently observe large samples and to revealing the general distribution of use-wear traces, the low-magnification method of use-wear analysis, which follows the widely accepted analytical protocol, was determined to be the primary approach for identifying the functions of the ground stone tools. Before the microscopic observations were made, all the samples were cleaned using an ultrasonic bath. Then the artifacts were examined under a 3D digital Keyence VHX-5000 microscope with magnifications between 20 × and 200 × . Micrographs were taken by the VHX-5100 microscope camera and processed in Photoshop.

The references we applied in this study for use-wear identification are the experimental data from the collection of the Institute of Cultural Heritage and Museology, Zhejiang University, which will be further discussed in another paper. However, we will be publishing some of the research results here for the first time (Figs. 5 & 6). Moreover, we also refer to published data for comparison, including references for both of chipped stone (Gao et al., 2008; Liu and Chen, 2016; Wang and Jiang, 2016; Chen et al., 2017; Liu et al., 2019) and ground stone tools (Xie, 2008; Harada, 2013; Cai, 2014; Latorre et al. 2017; Liu et al., 2017). Various features of different actions and contact materials were summarized based on the characteristics of artifact edge scarring and rounding (Ho Ho Committee, 1979; Odell, 1981; Chen, 2011). There is also a particularly rich data set about ground stone tools from PhD dissertations published in China (Qian, 2005; Cui, 2018; Gao, 2018), which also contributes to our observation and identification. The identification of the arrowheads was based on "Diagnostic Impact Fractures" as well as the overall morphology of the tools. A large number of published experimental studies replicating prehistoric projectiles have shown that step-terminating bending fractures, burinations, unifacial spin-off fractures, and bifacial spin-off fractures are the four most commonly recognizable impact fractures (Fischer et al. 1984; Lombard

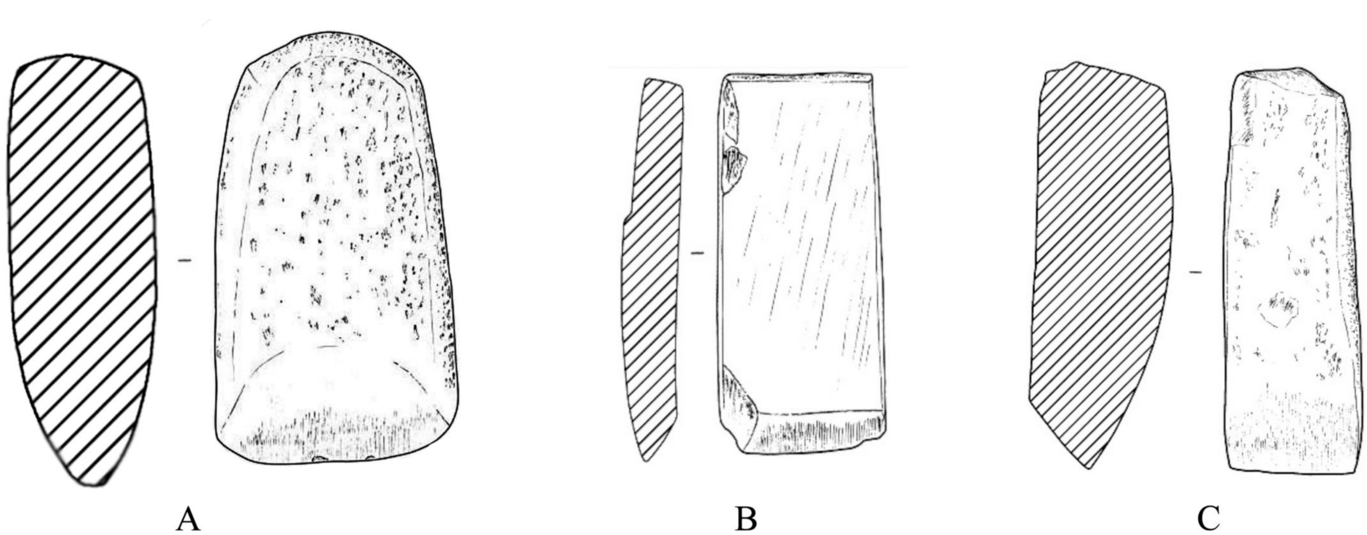

Fig. 4. The schematic drawings of an axe, adze, and chisel from the Dingjiacun site: A. Axe TN05W01⑥:1; B. Stepped adze TN06E03⑦C:13; C. Chisel TN05E01C:1.

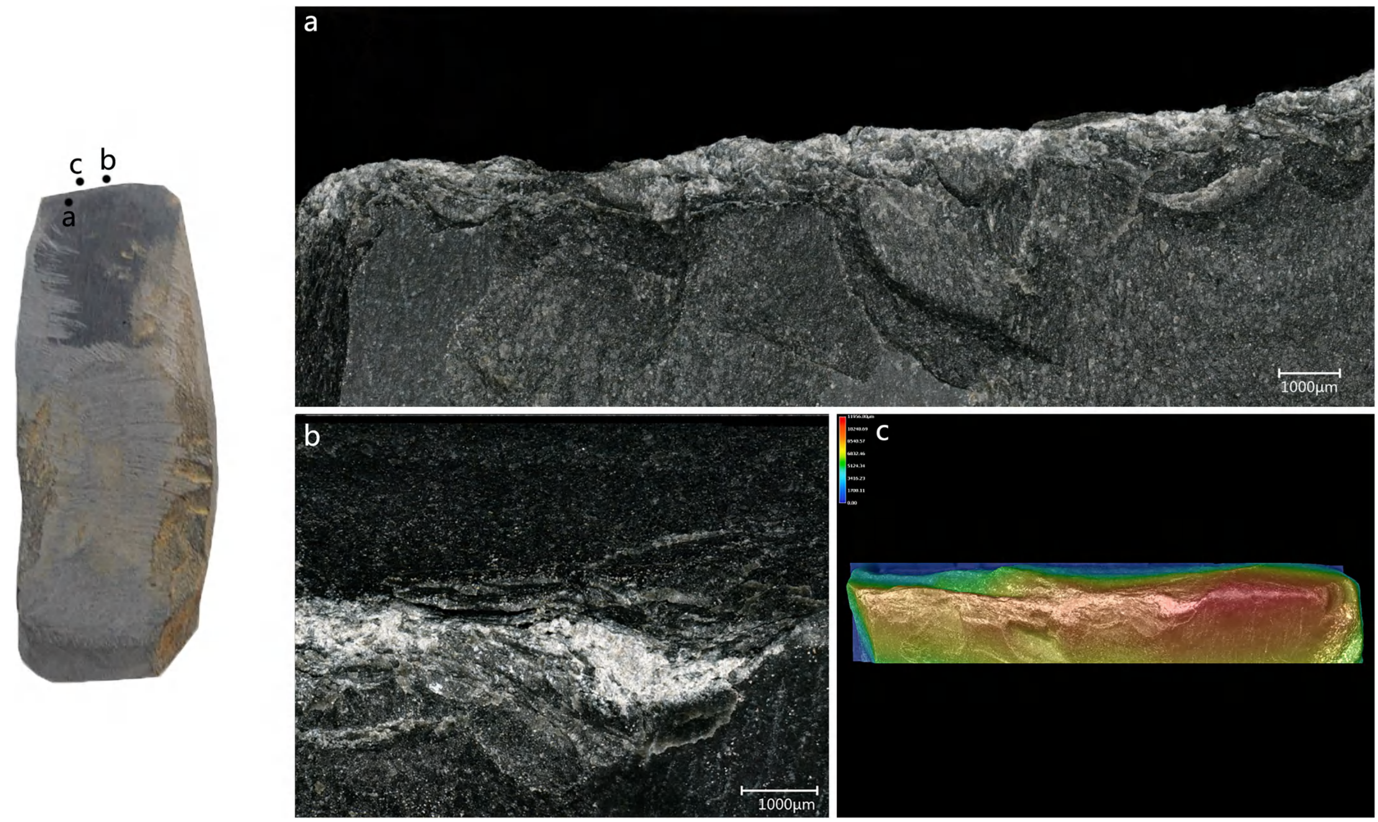

Fig. 5. Use-wear evidence on the experimental specimen working on wood materials for 20,000 hits: (a) Stepped and hinged scars in an overlapped, continuous distribution along the crushed edge, 40×; (b) Scars with the "rolled-over" appearance on the ridge, heavy rounding, 50×; (c) 3D model of the used edge.

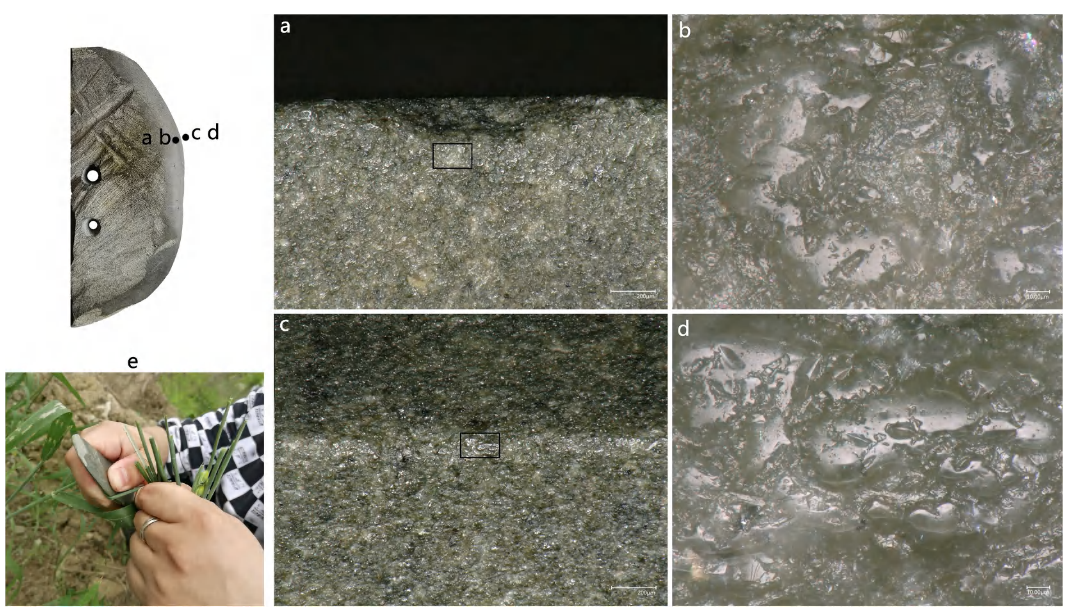

Fig. 6. Use-wear evidence on the experimental specimen harvesting Gramineae plants for 4000 actions: (a) The developing domed polish is continuously distributed along the edge, 200×, scale bar: 200 μm; (b) Surface texture of the developing domed polish in the black box of picture "a" on bright field illumination, 2000×, scale bar: 10 μm (c) The developing domed polish on the ridge, 200×, scale bar: 200 μm; (d) Surface texture of the developing domed polish in the black box of picture "c" on bright field illumination, 2000×, scale bar: 10 μm. (e) The working posture for harvesting the ears of crops, which is called "pinching" in Chinese. The polish observed on the archaeological specimens was much more developed (see Fig. 8), indicating that the tool had been intensively used.

and Pargeter, 2008; Yaroshevich et al., 2010; Groman-Yaroslavski et al., 2020).

The observation variables we considered for this research are scarring, polish, edge rounding, and striation (Table 1).

3. Results

We identified certain use-wear traces on most of the artifacts in this observation (Table 2), which provided important evidence of human

Table 1
The variables of use-wear observations used in this study.

Variables	Features	Sub-type	Description
Scarring	Size	V - very large	Visible to the naked eye
		L - large	Visible less than 10×
		M - medium	Visible above than 10×
		S - small	Visible above than 20×
		T - tiny	Visible above than 40×
	Distribution	C	Continuous
		R	Clustered
		S	Scattered
		O	Rolled-over
		U	Uneven
		P	Overlapped
	Termination	F	Feathered
		H	Hinged
		S	Stepped
		B	Broken
Polish	Distribution pattern	OP	Sporadic distribution
		DP	Diffuse distribution
		LP	Linear distribution
		SP	Schistose distribution
	Extent	IP - incipient	Initial polish
		WP - weak	Slight polish
		MP - matte	Rough polish
		BP - bright	Bright polish
Rounding		AR - absent	No rounding extent
		LR - light	Slight rounding extent
		MR - medium	Medium rounding extent
		HR - heavy	Severe rounding extent
Striation		AS - absent	No striation
		LS - parallel	Parallel to the edge
		RS - perpendicular	Perpendicular to the edge
		DS - diagonal	Diagonal to the edge

Table 2
Statistics of use-wear found on observed samples.

Tool type	Total	Observed specimen	Used specimen	Minimum usage rate* (%)
Adze	62	52	48	77.4
Knife	60	35	35	58.3
Sickle	8	4	4	50.0
Chisel	14	12	12	85.7
Spade	32	11	11	34.4
Arrowhead	9	4	4	44.4
Grinding stone	29	2	2	6.9
Others	44	0	0	0.0
Total	258	120	116	45.0

* It was not possible to determine whether specimens that were not selected for observation had ever been used, so the number of used specimens that sustained certain use-wear traces can only represent the minimum number of used specimens within the entire tool assemblage. For example, the total number of adzes is 62, and the number of used adzes determined in this study is 48, which means that there are at least 48 adzes that have been used out of 62 adzes in total.

daily life in the Dingjiacun site. In this paper, eight typical specimens (Table 3) were selected for specific descriptions.

3.1. Adzes

In this study, a total of 52 complete adzes were observed, including five stepped and three grooved adzes. Among them, 48 adzes had definite use traces, two had uncertain use traces, and two did not appear to have been used.

We noticed that most tool edges had been severely damaged and could no longer be used, implying that the tools had been used intensively over a long period. A total of 40 specimens (77%) retained woodworking features (e.g., specimen TN06W05②:1, see Fig. 7) with the working edges displaying dots of bright polish, striations nearly perpendicular to the edge and typical “rolled-over” scars (Chen et al., 2008). “Rolled-over” scars refer to the scars observed on the dorsal or ventral surfaces, but which originated from the opposite surfaces. Two specimens (TN05E01H19:1 and TN05W01④:1) presented smooth edges with almost no breakage and with rough polish, which suggests a possible correlation with hide-working. White, fractured crystals were discovered on the crushed lateral edge of specimen TN06E01②:8, which was probably due to working on dry bones (Odell, 1996). Specimen TN06E03⑥:7 was heavily impacted by post-depositional transformations and its edge was severely damaged. Additionally, it was difficult to identify its specific function, we can only suggest that it might have been used to process hard materials. Specimen TN06W02③:11 does not show any evidence of use, but manufacturing activities were identified through the artificial grinding traces and the evenly distributed polish on the tool.

It’s worth noting that seven specimens had scars on the edge that were covered with relatively new grinding traces, which could be due to re-shaping activities after edge breakage. Some adzes had been brought back into use after the maintenance and generated new use traces, while others such as specimen TN06W04G2②:12 showed no new use traces after maintenance (Fig. 8). Some artifacts (e.g., specimen TN0FW03G2②:6) were most likely to be used as a stone chisel for splitting wood, that generates scars symmetrically distributed on both surfaces. This is different from the “traditional” way of using adzes. In addition, we also noticed that several specimens mainly showed breakage on the two corners, while the central parts of the edges were relatively smooth. This pattern may be associated with the hafting method.

3.2. Knives and sickles

A total of 35 knives and four sickles were observed and identified with definite use traces. Thirty two knives had been used intensively over a long period as the working edges were obtuse and almost useless. Two specimens showed few diagnostic use-wear features, meaning that it was difficult to determine how they were used. The thick edge of specimen TN06E03⑥:6 remained unsharpened, which could serve as a reference for the identification of the tool’s function. The other 32 specimens had sustained obvious domed bright polish (Fig. 9), which is specifically related to processing soft vegetal materials. Developed

Table 3
Statistics of observed specimens discussed in detail in this study.

Specimen ID	Tool type	Max length(mm)	Max width(mm)	Max thickness(mm)	Edge angle(°)	Weight (g)	Status
TN06W05②:1	Adze	49.29	46.56	15.50	65	67.7	Broken
TN06W04G2②:12	Adze	56.37	52.27	11.08	75	42.9	Broken
TN05E04①:1	Knife	107.6	54.4	8.65	60	45.2	Broken
TN06W04F21:1	Sickle	85.70	49.60	10.97	64	56.3	Broken
ZDG2②:10	Chisel	102.18	42.49	41.71	71	321.2	Broken
TN06W03G2②:6	Spade	54.16	107.57	15.60	66	58.5	Broken
TN05E03④:2	Arrowhead	70.14	17.38	7.12	/	18.45	Broken
TN06E01⑥:2	Pestle	132.4	59.53	56.23	/	373.5	Broken

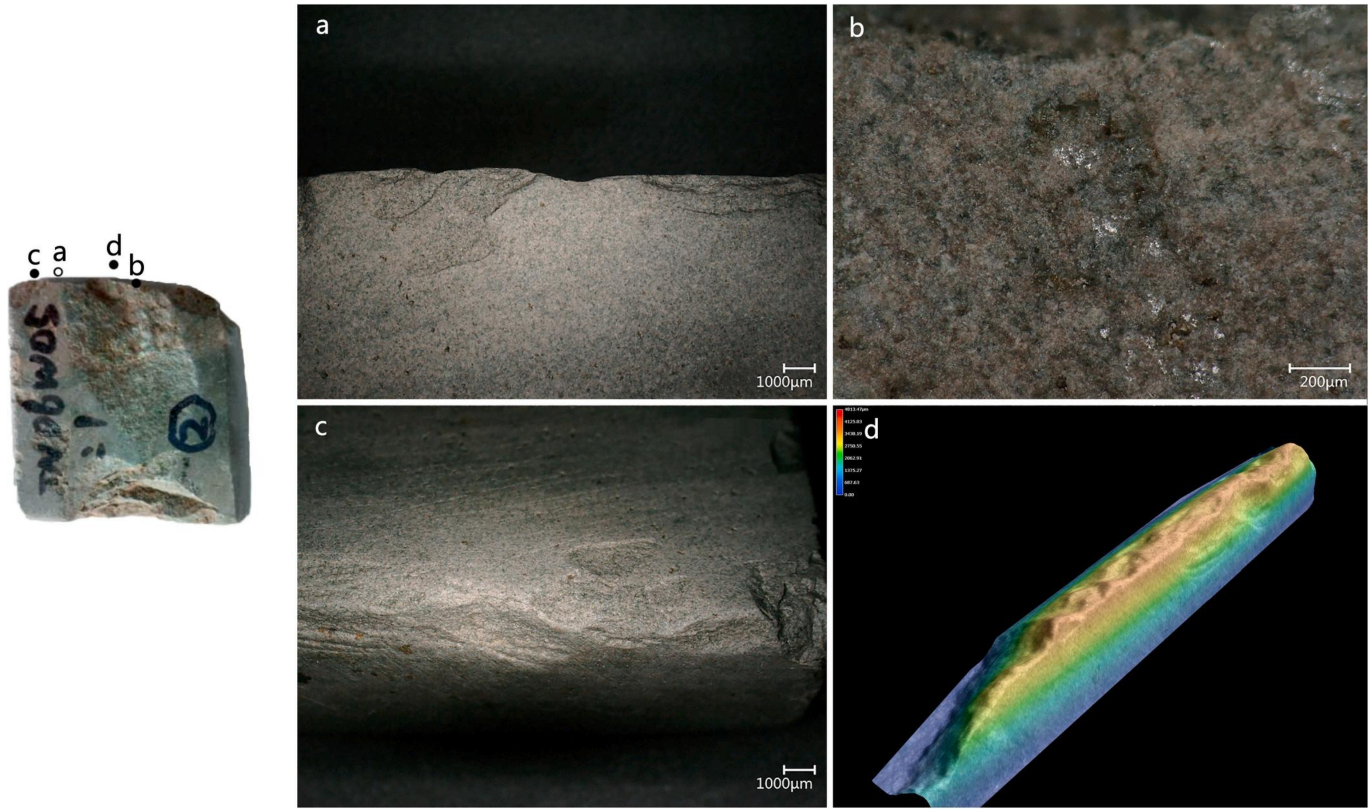

Fig. 7. Use-wear found on adze TN06W05②:1. (a) Stepped and hinged scars in an overlapped distribution on the other side, 20×; (b) Dots of diffuse polish extending away from the impact fracture, 200×; (c) Scars with the "rolled-over" appearance on the ridge, heavy rounding, 20×; (d) 3D model of the used edge.

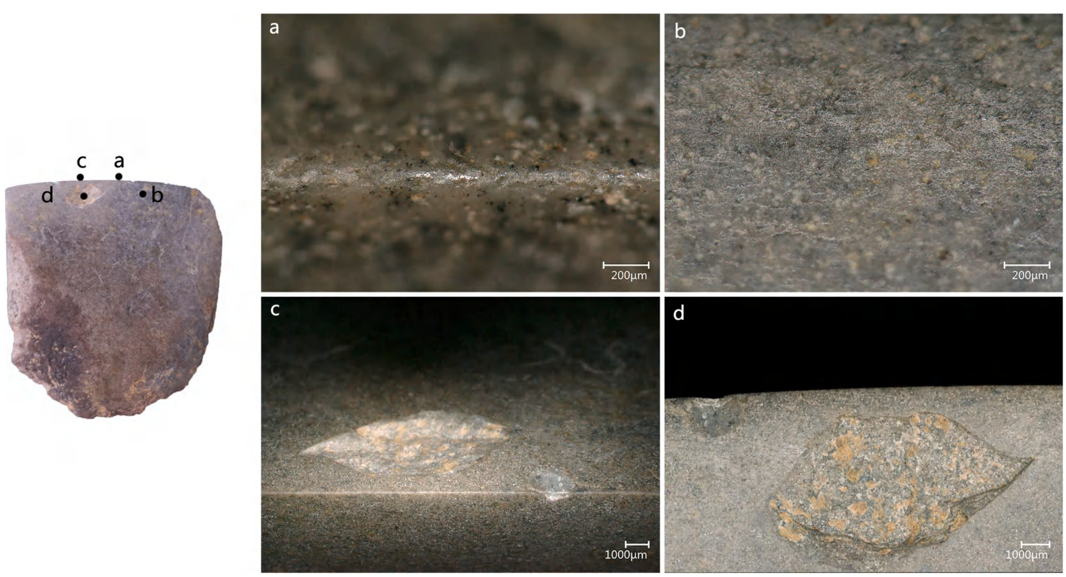

Fig. 8. Use-wear found on adze TN06W04G2②:12. (a) Bright polish on the ridge, 200×; (b) Matted grinding polish on the tool's surface, 200×; (c) The refreshed edge without reused impact fracture, 20×; (d) Grinding traces over the huge used scar, 25×.

polish appears mostly on one surface in a banding distribution, approximately 2–3 mm away from the edge, indicating that the tools were probably used for "pinching" the crops (Xie, 2008; Harada, 2013; Fig. 5. e). Moreover, specimen TN06E02M4:1 displayed scars with similar direction on both sides of the edge, suggesting that both sides of the tool were possibly used in turns.

Two sickles (TN06W04F21:1, 2015ZDC:7) showed dots of bright domed polish-which were produced by processing soft vegetal materials, similar to those observed on the knives-but less developed, indicating that it was likely used for harvesting soft grass (Fig. 10). Considering the local flora data from the archaeobotanical analysis, the grasses were likely to be from the Gramineae family. The other two sickles underwent heavy post-depositional processes, which made it hard to identify the specific activity for which they were primarily used. However, it can be inferred that they were used for harvesting soft vegetal materials, based on the consistency in typology between them and the other two sickles

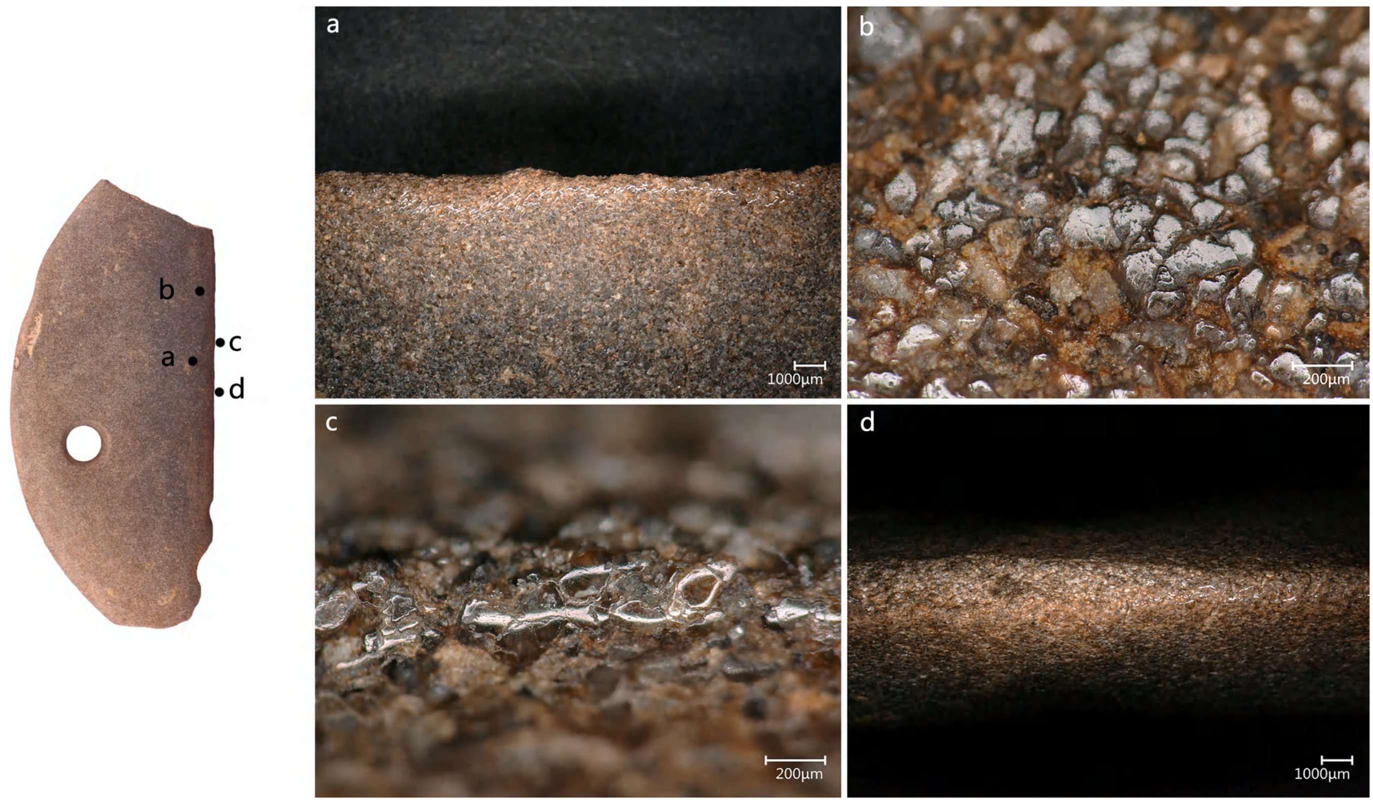

Fig. 9. Use-wear found on knife TN05E04①:1. (a) The scarring and polish are continuously distributed along the edge, 20×; (b) Well-developed bright domed polish on the surface, 200×; (c) Well-developed bright domed polish on the ridge, 200×; (d) The rounding and polish patterns observed on the ridge, 20×.

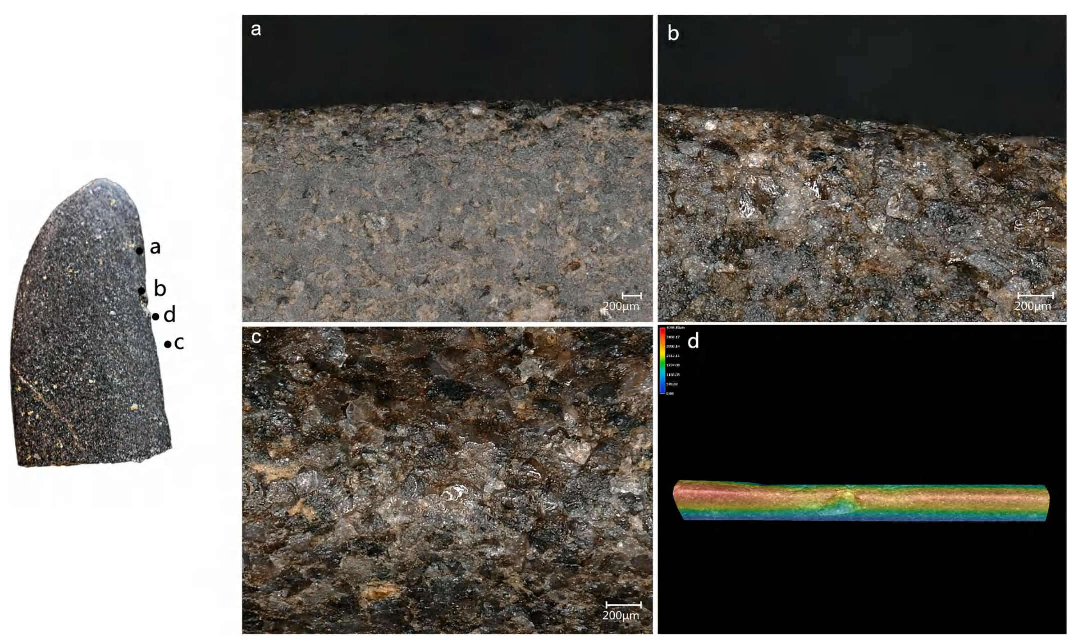

Fig. 10. Use-wear found on sickle TN06W04F21:1. (a) The edge profile, 80×; (b) Dots of bright domed polish near the edge, 150×; (c) Dots of bright domed polish on the ridge, 150×; (d) 3D model of the used edge.

determined with definite use-wear traces.

3.3. Chisels

Definite use traces were observed on 12 chisels, with all of them having been heavily affected by the post-depositional process, suffering from abrasion and corrosion. For these artifacts, scarring was the dominant feature of use-wear, while polish and striations were almost absent. Ten specimens presented similar patterns of edge damage and rounding, which may be associated with the processing of medium-hard materials. Typical "rolled-over" scars were observed on most of the specimens. For example, specimen TN06W04G2①:5 was observed with bright polish, indicating wood-working, which suggests that these tools were probably used for processing woody materials.

Another two specimens were potentially used for processing hard materials since their edges were badly damaged with crushing breakage. Specimen ZDG2②:10 had obvious overlapped scars across the whole edge and the angle on one side was severely damaged (Fig. 11). The ridge of the edge had significantly deviated from the central axis. These features were similar to those tools used to chop dry bones (Chen et al., 2017), meaning that it was likely to have been used for working on dry bones. Specimen TN06W04G2②:3 showed punching striations perpendicular to the edge, which was itself partially crushed, indicating that it was probably used for processing stone materials.

3.4. Spades

Most of the spades recovered at the Dingjiacun site were blanks or fragments. In this study, a total of 11 artifacts were selected for use-wear analysis.

The specimen TN06W03G2②:6 showed use-wear patterns of overlapped breakages on both sides of the edge, typical "rolled-over" scars, and well-linked bright polish, which is similar to wood-working (Fig. 12). Moreover, there were diagonal striations on the surface. Striations parallel to the side edge were also observed. Based on these features, we suggest that this spade was used for chopping wood, similar to cleavers.

The other ten specimens showed similar edge damage patterns, dominated by overlapped scars and heavy rounding. These patterns were probably caused by severe friction generated from intensive working. Bright polish developed in a few spots and striations were observed on the surface of specimen TN06W02④:3, suggesting that these tools were probably used to process medium-hard inorganic materials, and possibly for earth-working (Wang, 2008; Chen et al., 2013).

3.5. Arrowheads

Four arrowheads were sampled for use-wear analysis, and all of them presented definite use traces. Their badly damaged tips showed *Diagnostic Impact Fractures* (Dochall, 1997), including bending fractures and burinations (e.g., specimen TN05E03④:2, see Fig. 13). These features could be recognized as diagnostic features for projectile use (Yaroshevich et al., 2010; Groman-Yaroslavski et al., 2020), which suggests a close correlation between the tool type and its function.

3.6. Grinding stones

Two cylindrical grinding stones showed clear, dense, and deep grinding traces on the surface, which are significantly different from the striations caused by the use or traces produced by the manufacturing process. Specimen TN06E01⑥:2 showed dense parallel grinding traces. The red residue was observed on the circular surface and edge of one end, indicating that it was probably used to grind mineral pigments (Fig. 14). Similar grinding traces were also found on the circular surface of one end of specimen TN08W05②:12, but no residue was observed.

4. Discussion

Given the analysis results of use-wear, we propose that the ground stone tools found at the Dingjiacun site can be divided into three main functional groups: wood-working tools, agricultural tools, and tools used in other activities. Through these, we can get a picture of the people's daily life at the Dingjiacun site.

4.1. Wood-working tools

Adzes are mainly wood-working tools at the Dingjiacun site and were mainly used for chopping wood. However, some of the adzes were also used to split wood like chisels, while a few of the light adzes were possibly used in hide-processing. Considering the quantity and frequency of use, adzes clearly played an essential role in people's daily lives at the Dingjiacun site as a kind of production tool widely used during the West Zhou Dynasty.

The main function of chisels was processing wood, but some of them were also used to split bone or stone materials. The spade TN06W03G2②:6 was used for chopping wood, suggesting that not all the spades were used for earth-working.

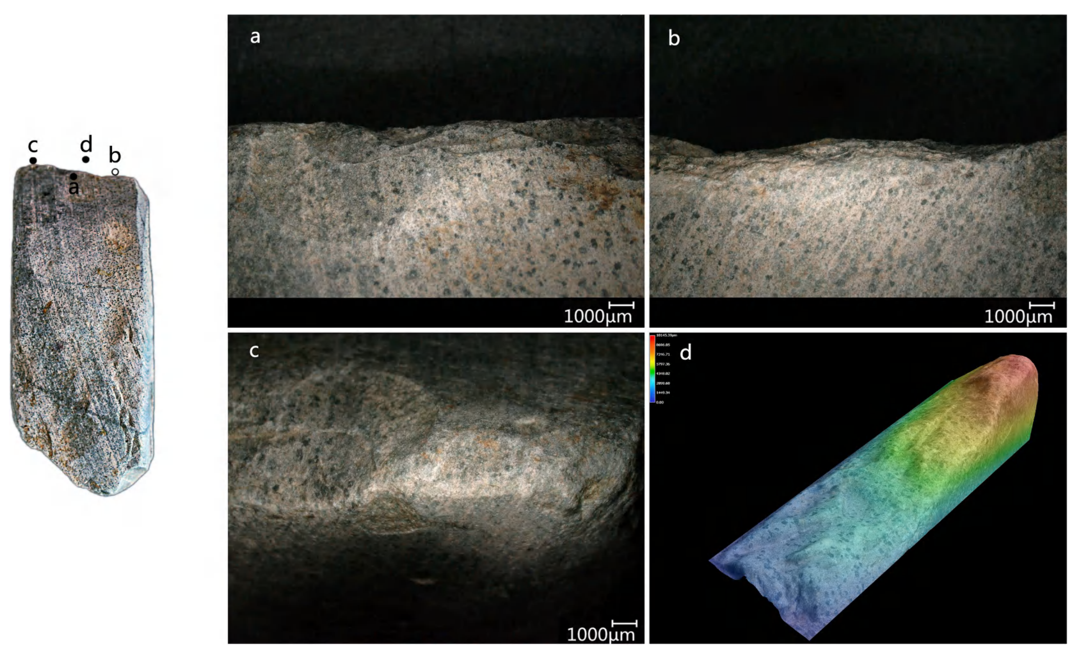

Fig. 11. Use-wear found on chisel ZDG2②:10. (a) Stepped scars in an overlapped distribution along the edge, 20×; (b) Stepped and broken scars distributed on the other side, 20×; (c) Scars with the "rolled-over" appearance on the ridge, heavy rounding, 20×;(d) 3D model of the used edge.

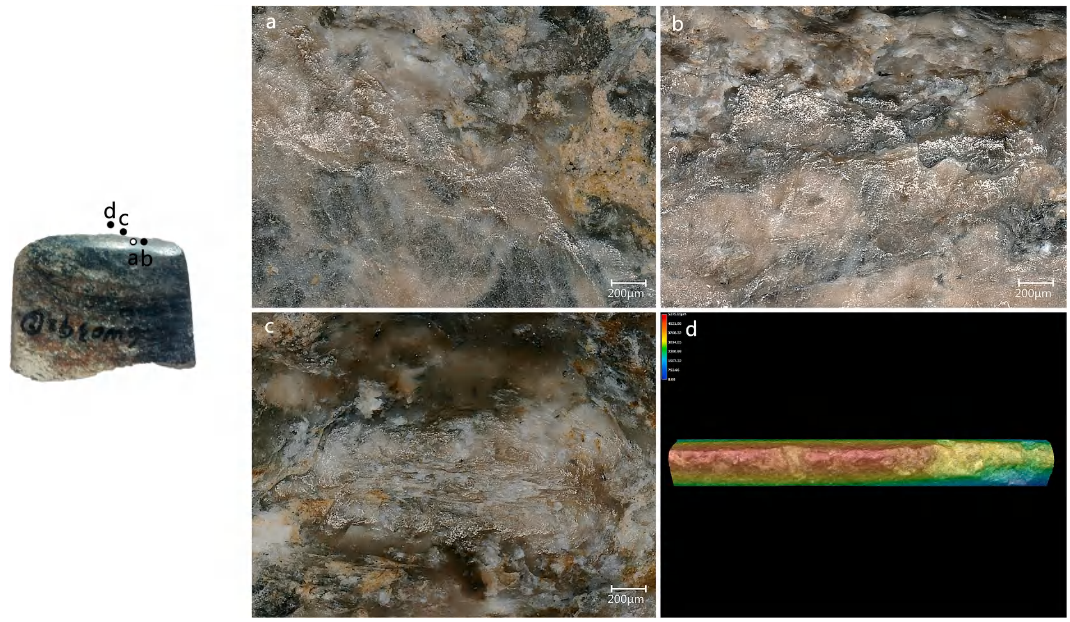

Fig. 12. Use-wear found on spade TN06W03G2②:6. (a, b) Well-linked bright smooth polish distributed along the edge on both sides, interpreted as the traces of wood-working (Liu et al., 2019), 150×; (c) A cluster of striations parallel to the working edge on the ridge, surrounded with woody polish, 150×; (d) 3D model of the used edge.

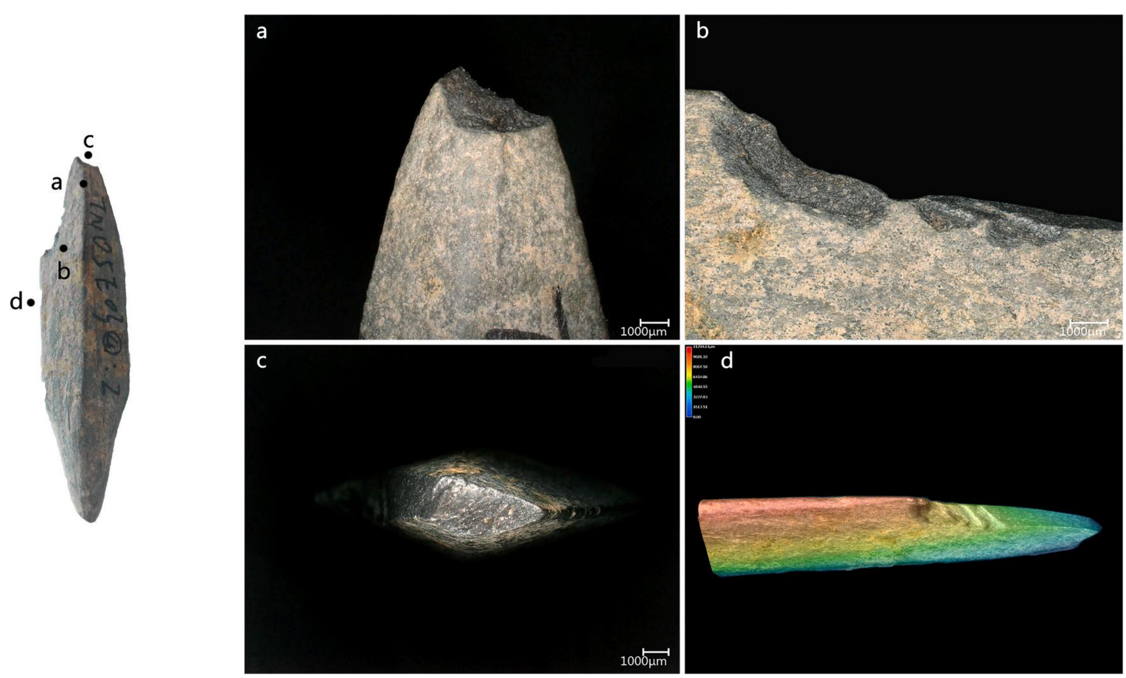

Fig. 13. Use-wear found on arrowhead TN05E03④:2. (a) A stepped termination bending fracture near the tip, 20×; (b) Impact scars with stepped and broken terminations on the lateral edge, 25×; (c) A burination DIF extending from the tip to the lateral edge; 20×; (d) 3D model of the damaged lateral edge, showing the burination DIF on the lateral edge close to the impact scars.

4.2. Agricultural tools

Spades were mainly used for earth-working such as digging and turning the soil. Both knives and sickles were primarily used for harvesting Gramineae plants. Knives may relate to the action of "pinching" crops. They were important agricultural tools that were usually used intensively over a long period. More knives than the sickles were found at the site, and the knives showed more evidence of intensive use indicating that they played a bigger role in harvesting activities at the Dingjiacun site.

4.3. Tools used in other activities

The main function of arrowheads is the projection, which was probably used for hunting animals and occasionally for self-defense. Our study determined that the use-wear patterns and residues derived from the grinding stones indicated that they were used on different kinds of worked materials, stone materials, and mineral pigments were determined in this study, and there was also a possibility that they were used for processing plant material.

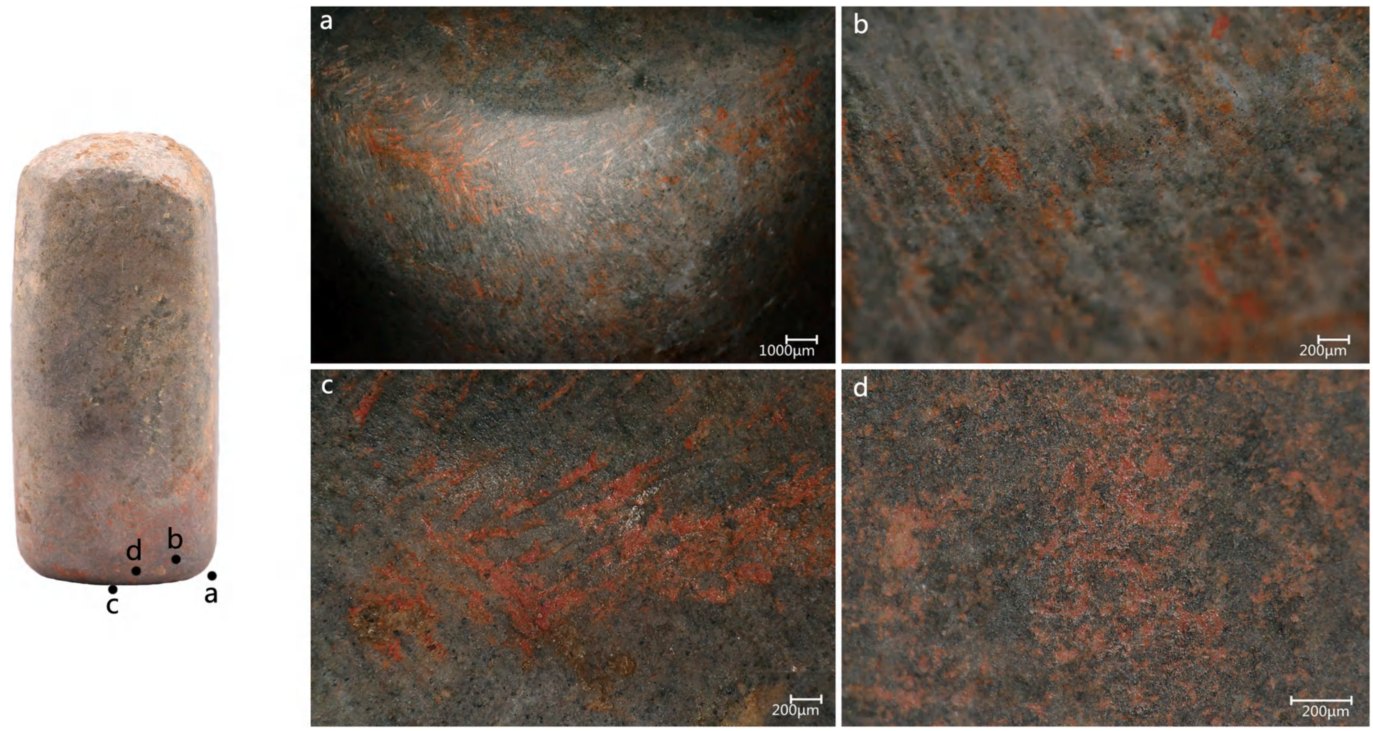

Fig. 14. Use-wear and residue found on pestle TN06E01⑥:2. (a) The overall profile of the used area, 20×; (b) Fine parallel grinding striations on the tool's surface, 100×; (c) Deep crossed grinding striations filled with red residue on the tool's surface, 100×; (d) A cluster of red residue on the tool's surface, possibly mineral pigments, 200×. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.4. Earlier research and comparative discussion

Use-ground stone tools began to appear during the Upper Pleistocene and Early Holocene in China, commonly grinding slabs and handstones (Liu and Chen, 2012: 42–63). Liu et al. (2011) have suggested that grinding stones at the Shizitan Locality 9 (13,800–8500 cal BP), a Paleolithic site in North China, were used for processing various materials, likely include plants, minerals, wood, and perhaps some hard objects. In this case, the study of the grinding stones at the Dingjiacun site indicates that the multi-functional use of use-ground stone tools lasted for a long period and continued into the Bronze Age.

Manufacture-ground/polished stone tools were emerged and increased in the Neolithic cultures in China as a new cultural element, major tool types such as axes, adzes, chisels, spades, sickles, knives, and arrowhead have been found at various early Neolithic (7000–5000 BCE) site (Liu and Chen, 2012: 123–161). These tools were still used by the occupants of the Dingjiacun site, to a certain extend, which showed stability and continuity in the ground stone tool assemblages from the Neolithic Age to the Bronze Age. However, the regional and chronological variability was reflected by certain specific tools, such as sickles. The denticulate sickles, which have denticulated cutting edges, are thought to be harvesting tools in the Peiligang culture (9000–7000 cal BP) in the Yellow River Region, but this tool type has not been found in any Neolithic Age or Bronze Age site in the Yangtze River Region (Liu and Chen, 2012: 141–144). A recent article by Fullagar et al. (2021) demonstrates that the denticulate sickles were multi-purpose tools, used for harvesting Poaceae grasses, cutting *Typha* cattails or stripping tree branches to recover fruits or nuts. However, the sickles found at the Dingjiacun site, whose cutting edges never had any denticulation, were only used to harvest Gramineae plants as specialized harvesting tools. There is still not enough evidence to show that if the morphological difference can correspond to the functional difference, but the specialization of the function of sickles may indeed occur from the Neolithic to the Bronze Age.

The only published use-wear analysis of ground stone tools of the Bronze Age was the functional study of stone tools of the Erlitou Period (1900–1500 BCE) at the Huizui site in the Yellow River Region, including four knives, three sickles, and one spearhead (Liu et al. 2018). The results indicate that these tools were used to harvest cereals, as well as to cut or process beans and tubers. While the spearhead was not found at the Dingjiacun site, the knives and sickles recovered from both sites were similar in shape and function. This may reflect, in some ways, the physical and cultural exchanges between the two different regions in terms of harvesting tools.

5. Conclusion

Ground stone tools were widely used during the Bronze Age as they were often of high quality and low cost. According to the statistical analysis of remains recovered from Bronze Age sites throughout the Lower Yangtze River region, bronze wares were most commonly found in high-ranking tombs, they were rarely found in the common villages that occupy areas of approximately 1 ha, or even in larger settlements (approximately 10 ha). We have demonstrated that the major tools of production in this area, particularly agricultural tools, were ground stone tools.

The archaeological excavation of the Dingjiacun site has yielded a large number of relics, including a large amount of pottery and a large number of stone tools used in everyday activities. There were a few bronze arrowheads, but bronze artifacts associated with agriculture were not found. This suggests that the Dingjiacun site was probably an ordinary, settled agricultural community.

Ground stone tools were the main implements used in daily production, based on the fact that the number of recovered ground stone tools was much greater than the bronze wares found at the Dingjiacun site. The site itself is located in a mountain valley, next to a small river. Raw materials could be easily accessed from the riverbed within a kilometer of the site, which greatly reduced the procurement cost and made lithic manufacture at the Dingjiacun site more convenient.

Given the recovered artifacts and existing research, we argue that people at the Dingjiacun site engaged in many daily activities, including agriculture and wood-working. Most of the harvesting tools were probably relatively small stone knives, indicating that the agricultural practices at the Dingjiacun site were probably small in scale. However, although stone sickles had already appeared in the Neolithic period, the occupants of the Dingjiacun site had not adopted them as their main harvesting tools.

In this study, we provide the first clues to reveal the livelihood pattern of people who lived in the Lower Yangtze River Region during the Bronze Age and an essential reference for further discussion of the ground stone tool assemblages in settlements of different hierarchies and characteristics in this region. According to the results of the use-wear analyses of ground stone tools and the comprehensive studies of animal and plant remains as well as carbon and nitrogen stable isotope analysis of human bones, we argue that the subsistence strategy at the Dingjiacun site was based on agriculture and was supplemented by animal breeding, fishing and hunting.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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