LARGE CUTTING TOOLS IN THE DANJIANGKOU RESERVOIR REGION, CENTRAL CHINA: TYPOLOGY, TECHNOLOGY AND MORPHOLOGY

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A thesis submitted to the Faculty of Science, University of the Witwatersrand, in fulfilment of the requirements for the degree of Doctor of Philosophy

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DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand by published papers. It has not been submitted before for any degree or examination at any other University.

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ABSTRACT

The progress achieved on research of the different handaxe-bearing regions of China is making the study of the Acheulean an exciting and important field in the Chinese Palaeolithic. However, compared with other well-known Large Cutting Tool or LCT-bearing regions, e.g., Bose in southern China and Luonan in central China, the work in the Danjiangkou Reservoir Region (DRR) is still at the stage of data collection, and deeper research into the meaning of these materials is still under way. In international academic circles, the DRR is almost never considered in the latest discussions about the Chinese Acheulean. The work in this thesis attempts to improve this situation. The thesis is presented as four published papers and one submitted paper of Acheulean materials from the DRR, central China. Through a detailed study of these materials from typological, technological and morphological perspectives, I have now achieved significant understanding of the Acheulean techno-complex in DRR, especially in its regional variability and adaptation compared with other Acheulean regions in China. Lastly, the questions that are still awaiting resolution in the future are also discussed.

ACKNOWLEDGEMENTS

I would first like to express great thanks to my supervisor, Kathleen Kuman. Without her inexhaustible help and guidance, it is hard to image that I could have gained so much knowledge and confidence in my study of the Palaeolithic, and I am now determined to take it up as my life-long career. Sincere thanks are also due to Ron Clarke. Thank you for looking after my wife Tian like a kind father. Thank you both Ron and Kathy for caring and helping Tian and me with our daily life. I would also like to thank all my Wits friends who provided me with selfless help during my time studying in South Africa. They are: Morris Sutton, Dominic Stratford, George Leader, Matt Caruana, Matt Lotter, Nicci Sherwood and Ray Couzens from the Department of Archaeology; Kristian Carlson, Tea Jashashvili, Bernard Zipfel, Paloma de la Peña, Sarah Wurz and Lyn Wadley from the Evolutionary Studies Institute; and Lynne Schepartz from the School of Anatomical Sciences. As always, I would also like to thank all my teachers and friends in IVPP, Beijing. In particular, I would like to thank Profs Li Chaorong, Gao Xing, Wang Shejiang, Pei Shuwen, Liu Wu and Wu Xiujie, for their continuous help. Finally, I would like to give my thanks to my wife and our parents for their understanding and support of my academic pursuit.

CONTENTS

CHAPTER ONE: INTRODUCTION

1.1 Introduction

This thesis is comprised of published and submitted papers of Acheulean materials in the Danjiangkou Reservoir Region (DRR), central China. As a lesser-known region of the handaxe-bearing sites in China, there was no systematic and detailed study of the area before the writing of this thesis, and moreover study results have seldom reached English-language readers. Therefore, the purpose of this thesis is to decode the meaning of the Acheulean materials from the DRR, which will contribute to our understanding of the entire Acheulean techno-complex in China, especially its variability in a specific environmental context. Furthermore, through the publications in this thesis, I expect that the DRR materials will become more widely known by western scholars, which will benefit the discussion of early hominids' dispersal and communication from a global perspective.

1.2 Background

Research on the Acheulean or Acheulean-like techno-complex in China has been a significant but also controversial issue since the first discovery of such tools in the Dingcun localities during the 1950s (Jia 1955, 1956; Pei *et al.* 1958). Before then, an apparent absence of handaxe technology in China was the observed wisdom, indicative of isolation, stagnation and cultural inferiority (Movius 1944, 1948). Through sustained efforts in recent decades, a number of handaxe-bearing regions have now been documented, in addition to the earlier and more recent excavated finds in Dingcun. Among them, Bose in the south and Luonan in central China are most well-known to western researchers. In addition, the DRR (Danjiangkou Reservoir Region) in central China has recently been studied in detail, and the results would be presented through this thesis.

1.2.1. Dingcun

The Dingcun localities are situated in Shanxi province, northern China (Fig. 1). This region is ~11 km long from north to south and ~2 km wide from west to east. Currently, more than 30 Palaeolithic localities have been found since the earliest discovery in 1953. These localities

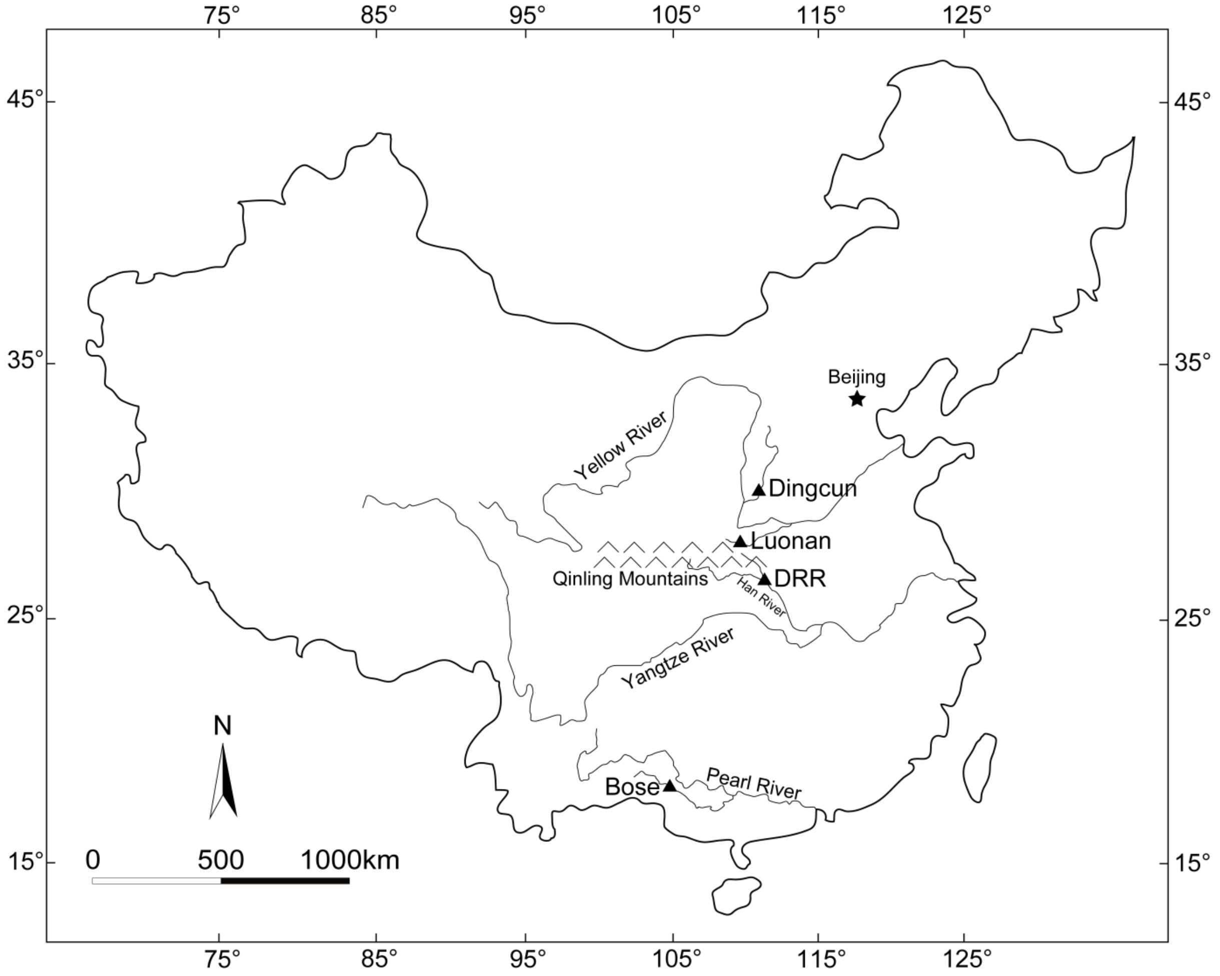

Fig. 1. The four major handaxe-bearing regions in China.

are distributed in the sand and gravel layers of three different terraces (terrace four, terrace three and terrace two) of the Fen River, a tributary of the Yellow River. The various chronological studies show that the age of the Dingcun localities extends from late Middle Pleistocene times (terrace four) to a late stage of the Late Pleistocene (terrace two) (Chen *et al.* 1984; Zhou *et al.* 1989; Zheng 1989; Wang *et al.* 1994; Li 2001; Wu & Liu 2002; Yang *et al.* 2014; Wang 2014). A consistent lithic industry occurs repetitively in the stratigraphy of these three terraces (Wang 2014).

It is around the findings in Dingcun that scholars developed the first round of arguments for Acheulean technology in China. Even today, the debate about the significance of Dingcun is ongoing. Jia Lanpo (1956) is the first scholar who acknowledged handaxes in Dingcun. Other researchers have also confirmed that some of the "chopping tools" in Dingcun are Acheulean or Achuelean-like handaxes (Henri Breuil's opinion in Pei 1965; Freeman 1977; Yi & Clark, 1983; Huang 1987; Liu 1988; see also Yang *et al.* 2014 for the latest discussion). In contrast, other scholars, such as Movius (1956), Pei Wenzhong (1958), Aigner (1978), Qiu Zhonglang (1985), Lin Shenglong (1994), Keates (2000), Corvinus (2004), and more recently Wang Yiren (2014), have maintained that the so-called handaxes in Dingcun can be regarded as pointed choppers, points (including heavy trihedral points and big points), or proto-handaxes. These two different opinions actually reflect the diverse understanding of the attributes of the Dingcun industry and confusion over how exactly to define an Acheulean industry.

Here we provide examples mainly from two recent studies to show the progress of this discussion. One study was conducted by Yang *et al.* (2014). They restudied 1177 artifacts that were retrieved in the field season of 1953 and 1954. The techno-typological analysis of these artifacts shows that the typical Acheulean tool types, i.e. handaxes, cleavers and picks, occur in the assemblage, and moreover, an incipient Middle Palaeolithic technology can be argued for on the basis of the various light-duty tools and the prepared cores in the assemblage. Overall, Yang *et al.* (2014) conclude that the Dingcun industry belongs to the Late Acheulean techno-complex, as previously suggested by Breuil and Freeman (Henri Breuil's opinion is in Pei 1965; Freeman 1977). We agree with Yang *et al.*'s opinion that the Dingcun assemblage can be ascribed to the Acheulean. However, detailed study of the *in situ* assemblages is needed to examine the specific technology that is present at Dingcun, for example a late Acheulean transition to the Middle Palaeolithic.

Another study was conducted by Y.R. Wang (2014). He systematically analysed the artifacts retrieved from 1976 to 1980, the second period of large-scale surveys and excavations conducted at Dingcun after the 1950s. The artifacts were both surface collected and excavated from three different terraces of the Fen River, including six localities on terrace four, six localities on terrace three and one locality on terrace two. Based on the large number of lithics, Wang's (2014) study further confirms some conclusions reached by Yang *et al.* (2014) and also provides new insights into the Dingcun industry.

First, the study expands the chronological and spatial range of the Dingcun culture. The original discoveries of the 13 Palaeolithic localities in the 1950s are all situated on the third terrace (older than 128ka and younger than 336ka; see Yang *et al.* 2014), while the new findings show that a consistent lithic industry is also present in the older fourth terrace

(>336ka, as suggested by Yang *et al.* 2014), with continuity in the younger second terrace (late Late Pleistocene; Wang 2014). Secondly, the study demonstrates that there are different selective strategies for raw materials. Large cobbles of hard and fine-grained hornfels were collected from the secondary branches of the Fen River, and some were probably also collected directly from the outcrops of the nearby hornfels hill (see Yang *et al.* in press). These were used to produce various tools, including handaxes, picks, and cleavers, in addition to small-sized tools. However, soft limestones and sandstones collected from the riverbed of the Fen River were mainly used to make spheroids, which is another characteristic tool type in the Dingcun assemblage. Thirdly, the Kombewa method is used; this is considered a skilful flaking technique to produce flakes with bi-convex profiles and sharp edges. Some Kombewa flakes were further shaped into cleavers, which is also suggested by Yang *et al*. (2014). Fourthly, from a typological perspective, knives were identified as a new tool type in the Dingcun assemblage (Wang 2014). This type is regarded as a representative type in the Large Cutting Tools of the African Acheulean (Kleindienst 1962; Clark 1974, 2001; Isaac 1977). In China, it has only been previously reported in the Luonan Basin (Wang 2007). With regard to the small-sized tools, denticulates, notches and different types of scrapers were identified. This is consistent with Yang *et al.*'s (2014) observations. Another point of consensus between Yang *et al.* (2014) and Wang (2014) is that the Dingcun assemblage is not dominated by chopper-chopping tools; on the contrary, chopper-chopping tools were not actually a type developed in the Dingcun industry.

So far, all observations by Wang (2014), in our opinion, are appropriate and pertinent. However, regarding the use of terminology to define the most representative tools in the Dingcun assemblage, Wang (2014) suggests using two types, trihedral points and big points. As a consequence, Wang argues for the similarity of trihedral points and big points to typical western Acheulean tools (i.e. picks and handaxes respectively. In this thesis, the term "western Acheulean" is used based on a geographic concept, which includes Acheulean sites in Africa, Europe, West Asia and South Asia) that can be regarded as a product of technological convergence. We have discussed the misuse of the term point in the Chinese Palaeolithic elsewhere (Kuman *et al.* 2014). Based on our observation of a large sample of so-called trihedral points and big points stored in the Shanxi Provincial Institute of Archaeology and the Dingcun Culture Museum, we suggest that these tools are picks and handaxes in the western sense, and there is no necessity to deny their technological attributes as Acheulean.

In general, the recent studies at Dingcun have expanded our understanding of the Dingcun techno-complex. The ongoing studies and excavations (e.g., at the Shigou site) will further demonstrate the value and significance of the Dingcun materials.

1.2.2. Bose

Twenty years after the first discovery of Dingcun in 1953, archaeologists launched a field survey in a river basin in the western Guangxi Zhuang Autonomous Region, southern China (Li & You 1975). It is this area, the Bose Basin, that scholars soon identified as another important handaxe-bearing region (Fig. 1; Zeng 1983; Huang 1987). Currently, more than 110 Palaeolithic sites have been found in an area of ~800 km^2, and all of the Large Cutting Tools (LCTs, i.e. handaxes, picks, cleavers) have been collected from the fourth terrace of Youjiang River (Hou *et al.* 2000; Huang 2003; Huang *et al.* 2012; Wang & Bae in press). In addition, several sites on terrace four have been systematically excavated in recent years and have unearthed LCTs *in situ* (Lin 2002; Pei *et al.* 2007; Xie & Lin 2008; Hou *et al.* 2011; Wang *et al.* 2008, 2014; Gao *et al.* 2014). The age of these sites has been dated to ~0.83 Ma using the $^{40}Ar/^{39}Ar$ dating method on tektites which were discovered together with the artifacts (Hou *et al.* 2000; Koeberl *et al.* 2000; Wang *et al.* 2008, 2014; Wang & Bae in press).

The Bose LCTs became widely known by western researchers after the publication of the Hou *et al.* (2000) paper, which also immediately aroused a new round of discussion about the Acheulean phenomenon in China. Some scholars argue that the findings in Bose Basin demonstrate that by ~0.8 Ma years ago in China people were flaking tools that are as sophisticated as anything made in Africa (Hou *et al.* 2000; Huang *et al.* 2005; Shen 2008; Huang *et al.* 2009; Zhang *et al.* 2010; Bar-Yosef & Wang 2012). Other scholars, on the other hand, think that it is unwise to press too close a cultural connection of the Bose LCTs with the western Acheulean examples. Their reasons include: the Bose LCTs are dominated by unifacial flaking (65% of LCTs) and only a quarter of the bifacially flaked tools are made on large flakes; there is no evidence of true cleavers (contra Huang 2003); the morphological attributes (especially the thickness) of the Bose handaxes are different from handaxes in the western Acheulean; and the sample from the various sites taken together is too small (Schick 1994; Corvinus 2004; Norton *et al.* 2006; Norton & Bae 2008; Dennell 2009; Lycett & Norton 2010; Lycett & Bae 2010; Gao 2012; Wang *et al.* 2012, 2014). In addition to the intense arguments on lithic technology and morphology, the age of the Bose LCTs has also been highly debated (see Langbroek in press and Wang & Bae in press for the latest discussion).

Based on our observation of the Bose materials stored in Y.M. Hou's office in IVPP (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences) and the related comparative study conducted by us (Kuman *et al.* 2014; Li *et al.* 2014a, b), we would argue that the Bose LCTs possess technological characteristics comparable with typical Acheulean. Although the morphology of Bose handaxes, mainly the thickness, is out of the variable range of typical Acheulean handaxes, we suggest this is the result of regional adaptation. The context of the Bose location should be carefully considered, e.g., the type and quality of the raw materials and the specifics of subsistence ecology. The thick body of the Bose handaxes is likely related to the use of large and/or poor quality river cobbles as raw material, and to the emphasis on heavy-duty woodworking activities that took place in the local subtropical environment (Yuan *et al.* 2008; Kuman *et al.* 2014; Li *et al.* 2014a). Regarding the age of the Bose LCTs, we accept that their earliest appearance in Bose can be traced back to ~0.8Ma, as several excavations have confirmed the coexistence of handaxes and tektites in the same stratigraphic layer, and importantly, these tektites have not been re-worked (Wang *et al.* 2008, 2014; Wang & Bae in press; and personal communication with G.M. Xie).

Studies in the Bose Basin have played a prominent role in understanding the issues of Acheulean technology in China. However, as noted above, it is still difficult for researchers to reach a consensus. At this moment, the findings around the Qinling Mountains, central China, are providing new clues for resolving these related arguments.

1.2.3. Luonan

The Qinling Mountains, which are located in central China, form the boundary between northern and southern China and separate the temperate and subtropical zones (Atlas of China 2007). Due to its special geographic location, it has long been regarded as a corridor of cultural transmission between north and south, and it is probably more appropriate to discuss this central region as a geographic transition zone. A series of down-faulted basins in the mountains, along with the plains east of the mountainous region, in our opinion, could be potential routes for movement and cultural transmission. LCTs found around the Qinling Mountains, such as from the sites of Lantian and Sanmenxia in northern Qinling, were very early reports (Huang 1964; Dai 1966; see Wang *et al.* 2014a for a recent report), and Liangshan (i.e. the Hanzhong Basin) in southern Qinling (Huang & Qi 1987; see Wang *et al.* 2014b for a recent report). However, these were only scattered finds. The real breakthrough discoveries in this area are the Luonan Basin that was first found in 1995 (Wang *et al.* 1997) and the DRR that was first discovered in 1994 (Huang *et al.* 1996; Li 1998).

Luonan Basin is situated in Shannxi province, central China (Fig. 1). It covers an area of ~70 km long from west to east, and 20-30 km wide from north to south. More than 300 open-air Palaeolithic sites have been found since the first field survey in 1995. These sites are distributed along the different terraces (from terrace six to terrace two) of the South Luo River, a tributary of the Yellow River. Hundreds of LCTs, including handaxes, picks, cleavers and knives, have been collected from the terraces (Wang *et al.* 2005; Wang 2005, 2006, 2007; Shannxi Provincial Insititute of Archaeology *et al.* 2007). Recent excavations on terrace two have unearthed LCTs *in situ*, which confirm the primary stratigraphy of the abundant LCTs that were mainly surface-collected from the second terrace of the Luonan Basin (Wang *et al.* 2011; Wang *et al.* 2013; Xing 2014). Multiple analyses of the chronology indicate that the first occupation of the Luonan Basin was from ca. 0.8 Ma ago, but most of the LCTs date from ca. 0.25 Ma, and they continue to be present during the early part of the Late Pleistocene (Wang & Huang 2001; Wang 2005; Lu *et al.* 2007, 2011, 2012; Sun *et al.* 2014; Xing 2014; and personal communication with S.J. Wang,).

LCTs found in the Luonan Basin have been regarded as the technology most similar to the typical Acheulean in Africa and western Europe. One main reason is because this is currently the only area in China with numerous typical cleavers (Wang 2006; Petraglia & Shipton 2008; Gao 2012), in addition to the findings in Dingcun (Yang *et al*. 2014; Wang 2014). Moreover, the extensive use of large flake blanks and bifacial shaping technology in making LCTs are evidence of a true Acheulean techno-complex in Luonan (Wang *et al.* 2005; Wang 2005; Gao 2012). However, despite these similarities to Acheulean technology, different opinions still exist. Some scholars believe that both the technology and morphology of the Luonan LCTs fit comfortably within the Acheulean range of variation, and this may mean that hominids with knowledge of Acheulean tool making strategies dispersed into East Asia from a western source (Wang 2005; Petraglia & Shipton 2008; Shipton & Petraglia 2010; Bar-Yosef &

Wang 2012; Gao 2012; Xing 2014). In contrast, other scholars point to the fact that handaxes in Luonan Basin are generally thicker than classic western Acheulean forms, and the bifacial components of the lithic collections are proportionally very small (Norton & Bae 2008; Lycett & Bae 2010). They therefore argue that the material should not be used to support scenarios involving the intrusion of western Acheulean traditions into this region during the Middle-Late Pleistocene (Lycett & Bae 2010).

Our inter-regional comparative study of the thickness variability of handaxes has shown that the Luonan handaxes overlap with examples from a couple of western Acheulean sites, e.g., Doornlaagte in South Africa and Mudnur VIII in India (Petraglia & Shipton 2008; Kuman *et al.* 2014; Li *et al.* 2014a, b). We have also proposed that the number of handaxes in a site is not a good criterion by which to judge the attributes of an industry; rather this should be seen as a by-product of behavioural (or social) processes (Li *et al.* 2014b, c). Therefore, overall, we agree with S.J. Wang's opinion that LCTs found in the Luonan Basin do demonstrate the existence of the real Acheulean techno-complex in this area (Wang 2005).

The current understanding of the Acheulean tradition in China comes mainly from these three regions, Dingcun, Bose and Luonan. However, from our own studies, we can also provide valuable information from another lesser-known Acheulean region in China, namely the Danjiangkou Reservoir Region (DRR).

1.2.4. DRR

The DRR is located at the southeastern edge of the Qinling Mountains, and is fed by the Han River, the longest tributary of the Yangtze River (Fig. 1). The archaeological work in this region actually started as early as the 1970s with the discovery of human fossils and stone artifacts in some cave sites (Wu & Dong 1980; Wu & Wu 1982; Qiu *et al.* 1982). The most important findings in this area are two human crania (one collected from the surface and the other unearthed *in situ*), discovered in the open-air Xuetangliangzi site (or Yunxian Man site), Yunxian county in 1989 and 1990 respectively (Li *et al.* 1991; Li & Etler 1992; Li & Feng 2001; Vialet *et al.* 2005, 2010). The site is located on the fourth terrace of the Han River and has been dated by palaeomagnetism and fauna to an approximate age of 0.8 Ma (Yan 1993; Huang & Li 1995; Chen *et al.* 1996, 1997; Li & Feng 2001; de Lumley & Li 2008). In addition to the two crania, abundant animal fossils and stone artifacts were unearthed from this site, with one handaxe found *in situ* and 13 LCTs collected from the surface near to the site (de Lumley & Li 2008; Feng 2008).

The intensive discovery of LCTs in DRR occurred in 1994. In co-operation with the construction of the national South-to-North Water Transfer Project, a field team from IVPP (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences) conducted a systematic survey around the margin of the Danjiangkou Reservoir. Fifty-six open-air Palaeolithic sites (from terrace four to terrace two) were discovered associated with LCTs such as handaxes, picks and cleavers (Huang *et al.* 1996; Li 1998; Li *et al.* 2009). In addition, local museums also carried out investigations and collected numerous stone artifacts (including LCTs) from this region (Zhu 1999, 2001; Shiyan Museum & Danjiangkou Museum 1999; Shiyan Museum 2011). In 2004, the field team from IVPP conducted a second large-scale Palaeolithic survey in DRR. Through this investigation, the number of the Palaeolithic sites in DRR increased to more than 110, and many more LCTs were surface-collected (Li *et al.* 2012). From 2006, systematic excavations in this region began, and currently more than 30 Palaeolithic sites have been excavated, such as Pengjiahe (Pei *et al.* 2008a), Beitaishanmiao (Zhou *et al.* 2009), Songwan (Niu *et al.* 2012), Beitaishanmiao II (Fang *et al.* 2012), Guochachang II (Li *et al.* 2013), Shuiniuwa (Chen *et al.* 2014), and Maling 2A (Pei *et al.* 2015). Comprehensive chronological analyses indicate that LCT sites in this region have persisted for a long period, from the late Early Pleistocene to the early part of Late Pleistocene (Zhu 1955; Shen 1956; Yan 1993; Huang & Li 1995; Chen *et al.* 1996; Huang *et al.* 1996; de Lumley & Li 2008; Liu & Feng 2014; Li *et al.* 2014b; Pei *et al.* 2015).

Because of these intensive surveys and excavations, the DRR has now become one of the most important areas in Chinese Palaeolithic research. However, compared with other well-known LCT-bearing regions, the work in the DRR is still at the stage of data collection, and deeper research into the meaning of these materials is still under way. In international academic circles, the DRR is almost never considered in the latest discussions about the Chinese Acheulean. However, our recent work is trying to improve this situation.

Through a detailed study from typological, technological and morphological perspectives, we have now achieved some significant understanding of the Acheulean techno-complex in DRR, especially its regional variability and adaptation compared with other Acheulean regions in

China (Kuman *et al.* 2014; Li *et al.* 2014a, b, c, d; Li *et al.* revision submitted). The major results of our DRR research are presented in the following chapters of this thesis.

1.3 List of published and submitted papers

This doctoral thesis will be presented by publication, and a total of five papers is included:

Number # 1

Authors: Hao Li, Chao-rong Li, Kathleen Kuman

Year: 2014

Title: Rethinking the "Acheulean" in East Asia: Evidence from recent investigations in the Danjiangkou Reservoir Region, central China

Journal: Quaternary International 347: 163-175

Author contributions: H. Li and K. Kuman designed the method; H. Li analysed the data and wrote the paper; C.-r. Li collected data and provided helpful suggestions; K. Kuman provided helpful suggestions and careful proofreading in all stages of this manuscript.

Number # 2

Authors: Kathleen Kuman, Chaorong Li, Hao Li

Year: 2014

Title: Large Cutting Tools in the Danjiangkou Reservoir Region, central China

Journal: Journal of Human Evolution 76: 129-153

Author contributions: K. Kuman and H. Li designed the method and analysed the data; K. Kuman wrote the paper; C.-r. Li collected data and provided helpful suggestions.

Number # 3

Authors: Hao Li, Chaorong Li, Kathleen Kuman, Jie Cheng, Hai-tao Yao, Zhao Li

Year: 2014

Title: The Middle Pleistocene handaxe site of Shuangshu in the Danjiangkou Reservoir Region, central China

Journal: Journal of Archaeological Science 52: 391-409

Author contributions: H. Li analysed the lithic data and wrote the paper; C.-r. Li and Z. Li excavated the site; K. Kuman provided helpful suggestions and careful proofreading in all stages of this manuscript; J. Chen conducted the terrace investigation and provided the original terrace map; J. Chen conducted the ESR sampling and analysis; H.-t. Yao conducted the paleomagnetic sampling and analysis and provided the original magnetic figure.

Number # 4

Authors: Hao Li, Kathleen Kuman, Chao-rong Li

Year: 2014

Title: Re-examination of the morphological variability of East Asian handaxes from a comparative perspective

Journal: World Archaeology 46: 705-733

Author contributions: H. Li designed the method, analysed the data and wrote the paper; K. Kuman provided helpful suggestions and careful proofreading in all stages of this manuscript; C.-r. Li collected data and provided helpful suggestions.

Number # 5

Authors: Hao Li, Kathleen Kuman, Chaorong Li

Year: Submitted and under review, 2015

Title: Quantifying the reduction intensity of handaxes with 3D technology: A pilot study of handaxes in the Danjiangkou Reservoir Region, central China

Journal: PLoS ONE

Author contributions: H. Li scanned handaxes, analysed the data and wrote the paper; K. Kuman provided helpful suggestions and careful proofreading in all stages of this manuscript; C.-r. Li collected data and provided helpful suggestions.

1.4 Organization of the papers and the research questions in each paper

The order of the papers presented in this thesis is consistent with the arrangement in the section above, and each paper corresponds with a separate chapter (i.e. chapters two, three, four, five and six). These papers or chapters are linked. In papers 1 and 2 (i.e. chapters two and three), my co-authors and I mainly presented a detailed techno-typological study of surface-collected LCTs in the DRR. Because of the lack of information on small to medium sized artefacts in these two papers, in paper 3 (i.e. chapter four) I presented a detailed study of an *in situ* lithic assemblage excavated in the DRR. Papers 4 and 5 (i.e. chapter five and six) present studies on two specific topics related to handaxes in the DRR. The first is the morphological variability of handaxes, as analysed in paper 4, while the other is the reduction intensity of the DRR handaxes, as analysed in paper 5.

Each paper aims to resolve certain questions for the DRR materials, which constitute the research questions of this thesis. They are summarized as:

Papers 1 and 2 (chapters two and three):
1. How do we define the different types of LCTs (e.g., handaxe, pick) found in DRR?
2. What are the typological and technological characteristics of the DRR LCTs and are these characteristics consistent with the Acheulean tradition or not?

Paper 3 (chapter four):
3. What are the complete technological strategies contained in the *in situ* assemblage of Shuangshu?
4. What is the real proportion of LCTs in an *in situ* context in DRR and how do we interpret this phenomenon?

Paper 4 (chapter five):
5. What are the morphological characteristics of East Asian (including DRR) handaxes?
6. How do we interpret the morphological variability of East Asian (including DRR) handaxes?

Paper 5 (chapter six):
7. How do we quantify the reduction intensity of the DRR handaxes with the aid of 3D scanning technology?
8. What levels of reduction do the DRR handaxes show and what are the reasons for this?

Following this introductory chapter, the next five chapters (from chapter two to chapter six) will focus on addressing these questions. Finally, in chapter seven, the conclusions of this thesis are presented.

CHAPTER TWO: PUBLISHED PAPER #1

Thesis pages: 14-26
Published in 2014
Quaternary International 347: 163-175 (page numbers below reflect publication page numbers)

Rethinking the "Acheulean" in East Asia: Evidence from recent investigations in the Danjiangkou Reservoir Region, central China

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Rethinking the “Acheulean” in East Asia: Evidence from recent investigations in the Danjiangkou Reservoir Region, central China

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A R T I C L E   I N F O

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A B S T R A C T

Current research on Large Cutting Tools (LCTs) in East Asia, mainly China and South Korea, has provided some new interpretations for the “Acheulean” in this region. In one of the most influential interpretations, Norton and colleagues have argued that the Movius Line *sensu stricto* can be replaced by the Movius Line *sensu lato* based on several key observations, concluding that the presence of LCTs in East Asia is probably the result of short-term technological convergence. Here, the LCT materials from the Danjiangkou Reservoir Region provide us with a rare chance to test Norton et al.’s observations and conclusion, and meanwhile, to decode the probable human behaviours in the Early Palaeolithic of East Asia. The techno-economic behaviours present in the LCTs of Danjiangkou Reservoir Region would in fact support the existence of the true Acheulean techno-complex in East Asia, which explicitly shows the diversity and complexity of the Early Palaeolithic in this vast region. Moreover, the variability of the Acheulean techno-complex in East Asia is evident in the variable percentages, morphology and technology of LCTs, which could be explained as the effect of interconnected factors, such as raw material quality, landscape use strategies and population size. However, because of the relatively limited materials available, we suggest that it is still premature to decide on the emergence of LCTs in East Asia. The in-depth studies in this and the further investigations in other potential areas will shed light on our understanding of the LCT sites in East Asia.

1. Introduction

Large Cutting Tools (LCTs) are a diagnostic component of the Acheulean Industrial Complex. They represent a relatively prominent development of early humans’ lithic technology and corresponding behavioural and cognitive capability (Isaac, 1969; Gowlett, 1986; Clark, 1994; Roche and Texier, 1996; Wynn, 2002; Sharon, 2007; Pelegrin, 2009; Goren-Inbar, 2011; Stout, 2011). Moreover, the research of LCTs in different areas of the world has become an important means to probe the migration and diffusion of our ancestors and their potential cultural communication (Clark, 1994; Carbonell et al., 1999; Goren-Inbar et al., 2000; Hou et al., 2000; Bar-Yosef and Belfer-Cohen, 2001; Wang, 2005; Scott and Gibert, 2009; Lycett and Norton, 2010; Pappu et al., 2011). Compared with the abundant research achievements and active academic publications in other parts of the world, however, China’s research in this field has long been overlooked. On the one hand, we have to say that this is because of the long-term influence of the “Movius Line” model, which interpreted eastern Asia as a cultural backwater in technological development (Movius, 1948, 1969). But on the other hand, it has much to do with the limited extent of research on LCTs in China (Gao, 2012).

Thus far, LCTs have been discovered in certain regions of China, such as Bose Basin in the south and Luonan Basin in central China (Hou et al., 2000; Wang, 2005). However, regardless of typological classification or technological and morphological characteristics, divergent opinions exist amongst scholars because of the limited information available. It is even more difficult to reach consensus when discussing their origins (Yi and Clark, 1983; Dai, 1985; Huang, 1987, 1993; An, 1990; Lin, 1994; Schick, 1994; Gao and Olsen, 1997; Keates, 2002; Corvinus, 2004; Derevianko, 2008; Dennell, 2009; Huang et al., 2009; Gao, 2012). One prominent expression of this situation is the controversy over the validity of the “Movius Line”,

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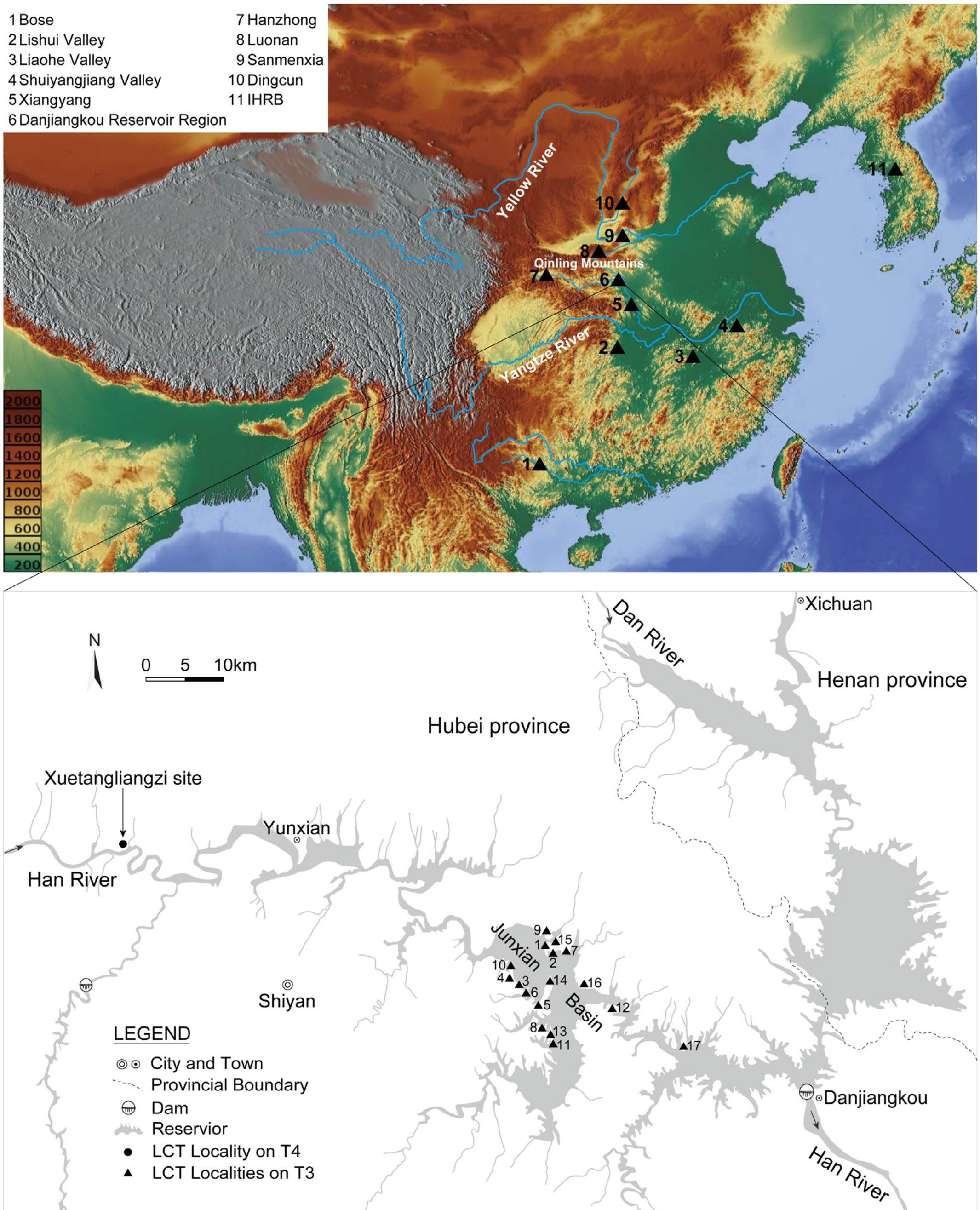

Fig. 1. The top map shows the locations of major LCT sites in East Asia. The bottom map shows the DRR in central China and the distribution of sites along the third terrace of Han River in Junxian Basin. LCT sites are numbered in the following: 1. Guochachang (LCTs 16); 2. Majiazui (LCTs 12); 3. Shuangshu (LCTs 8); 4. Balamiao (LCTs 5); 5. Guanmenyan (LCTs 4); 6. Dudian (LCTs 4); 7. Caijiadu (LCTs 3); 8. Datubaozi (LCTs 3); 9. Fengjiawa (LCTs 3); 10. Hongshikan (LCTs 3); 11. Niuchangmatou (LCTs 3); 12. Pengjiahe (LCTs 2); 13. Waibiangou (LCTs 2); 14. Beitaishanmiao (LCT 1); 15. Changjiayuan (LCT 1); 16. Longkou (LCT 1); 17. Zhuangzigou (LCT 1). The fourth terrace Xuetangliangzi site is also presented in the bottom map.

where very different views exist. Many researchers consider LCTs an indigenous development and do not recognize the presence of any true Acheulean technology in eastern Asia (Lin, 1994; Schick, 1994; Corvinus, 2004; Norton et al., 2006; Derevianko, 2008; Norton and Bae, 2008; Lycett and Bae, 2010; Lycett and Norton, 2010). Others hold that western Acheulean populations moved into eastern Asia (Huang, 1987; Hou et al., 2000; Wang, 2005; Huang et al., 2009). In addition, a more complex explanation has also been proposed that the Luonan basin represented the movement of Acheulean peoples into eastern Asia, while other LCT sites in eastern Asia were indigenous developments (Petraglia and Shipton, 2008; Shipton and Petraglia, 2010; Gao, 2012). To answer the questions raised in these debates, more data are certainly needed for detailed research on the typology, technology and morphology of LCTs in East Asia.

The Danjiangkou Reservoir Region (DRR) has provided material for research on LCTs. As part of a comprehensive research project, Kuman et al. (submitted for publication) have previously analysed data from an initial survey in 1994. This paper focuses on the LCTs recovered in new Palaeolithic field investigations, which began in 2004. The aim of this paper is to reveal the typological, technological and morphological characteristics of the LCTs and to discuss their cultural affinities and the implications for the understanding of the “Acheulean” in East Asia.

2. Danjiangkou Reservoir Region (DRR)

DRR is located at the southern edge of the Qinling Mountains which is considered to be the boundary between North and South China, and it is fed by the Han River, the largest tributary of the Yangtze River (Fig. 1). During Pleistocene times, this area had a relatively stable subtropical environment with abundant plant and animal resources suitable for hominid subsistence (Xue et al., 1996; Li and Feng, 2001; Yuan et al., 2008). The discovery of human fossils and stone artifacts since the 1970s has now made it a pivotal area for the study of human migration and cultural communication between South and North China (Wu and Dong, 1980; Qiu et al., 1982; Wu and Wu, 1982).

The most important findings in this area are two human crania discovered at the Xuetangliangzi site, Yunxian county (one collected from the surface in 1989 and the other unearthed *in situ* in 1990) (Li et al., 1991; Li and Etler, 1992; Li and Feng, 2001). Xuetangliangzi is an open-air site located in the fourth terrace of the Han River and has been dated by paleomagnetism and fauna to ca. 0.8 Ma (Yan, 1993; Huang and Li, 1995; Chen et al., 1996, 1997) (Fig. 1). In addition to the two crania, abundant animal fossils and stone artifacts were also unearthed from this site, with one handaxe found *in situ* and nine collected from the nearby surface of the fourth terrace (Li and Feng, 2001; De Lumley and Li, 2008; Feng, 2008).

At the time of the construction of the national South-to-North Water Transfer Project, the field team of IVPP (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences) conducted several investigations along the banks of the Han and Dan Rivers in the Danjiangkou Reservoir Region from 1994. Approximately 100 Palaeolithic open-air sites (from terrace four to terrace two) were discovered, with some sites associated with LCTs such as handaxes, picks and cleavers, which possess Acheulean technological characteristics (Li et al., 2009; Li et al., 2012). At the same time, local museums also carried out investigations and collected numerous stone artifacts from this region (Shiyan and Danjiangkou, 1999; Zhu, 1999, 2001; Shiyan, 2011). Comprehensive chronological analyses indicate that LCTs in this region have persisted for a long period, from the late Early Pleistocene to the Late Pleistocene (Zhu, 1955; Shen, 1956; Yan, 1993; Huang and Li, 1995; Chen et al., 1996; Huang et al., 1996). In 2006, intensive excavations in this region began, and more than 20 Palaeolithic sites have been excavated, such as Pengjiahe (Pei et al., 2008), Beitaishanmiao (Zhou et al., 2009), Songwan (Niu et al., 2012), Beitaishanmiao II (Fang et al., 2012) and Guochachang II (Li et al., 2013). The efforts taken by archaeologists in this region have made Danjiangkou Reservoir Region one of the few large regional concentrations for LCTs discovered in China. The systematic and detailed research on LCTs in Danjiangkou Reservoir Region will contribute to resolving the debate on the characteristics and the origins of LCTs in China.

3. Materials and methods

3.1. Archaeological material

The artefacts discussed in this paper are from the field surveys along the banks of the Han River in the DRR since 2004. LCTs analysed here were collected from 17 sites, all of them located on the third terrace of the Junxian Basin, which is one of the main basins of the DRR along the Han River (Fig. 1). The LCT assemblage comprises 36 handaxes, 21 picks, nine cleavers and six unifacial cobble picks. Of these, 14 were found *in situ*. The assemblages compare well with the LCTs from excavated sites in Terrace Three, such as Beitaishanmiao II (Fang et al., 2012), Guochachang II (Li et al., 2013), Shuangshu (Li et al., submitted for publication). The age of the third terrace, estimated from the sedimentary observation is Middle Pleistocene (Zhu, 1955; Shen, 1956; Zhao and Yang, 1995; Yang et al., 1996; Huang et al., 1999; Zhao et al., 2004; Yin and Guo, 2006; Pei et al., 2008; Yuan et al., 2008; Zhou et al., 2009; Niu et al., 2012; Li et al., 2013). This is due to the presence of strongly weathered red clay, which forms in humid period. Studies have shown the loess-paleosol sequence S5–S4 (equal to MIS 15-11, 621–374 ka) was predominantly an intense humid stage in the Pleistocene and a best fit for the formation of the red clay found in this region (Zhao and Yang, 1995; Yang et al., 1996; Huang et al., 1999; Zhao et al., 2004; Yin and Guo, 2006; Yuan et al., 2008). ESR and palaeomagnetic dating of the third terrace Shuangshu site has demonstrated that the absolute age falls in the early to middle stage of the Middle Pleistocene, which is consistent with the former observation (Li et al., submitted for publication). Nevertheless, dating work in DRR is still very limited, and the application of additional dating methods to confirm or modify the current age is a top priority for future research.

3.2. Techno-typological method

Methodologies for the study of the Acheulean Industrial Complex have been diverse. Generally, however, they can be categorised as the typological approach (Bordes, 1961; Kleindienst, 1961, 1962; Leakey, 1971, 1994; Clark, 1974, 2001a; Isaac, 1977, 1997; Bar-Yosef and Goren-Inbar, 1993; Leng and Shannon, 2000) and the *Chaîne Opératoire* approach (Pelegrin, 1990, 1993; Sellet, 1993; Texier and Roche, 1995; Roche and Texier, 1996; de la Torre and Mora, 2005, 2009; de la Torre, 2009). Both methodologies have gone through long-term development and provide a unique perspective for understanding lithic industries. The comprehensive use of the strongest points of each approach underlies the methodology of this paper.

In this paper, an African typological classification will be used as the basis to achieve our goal, considering two factors. First, the popular European-based Lower Palaeolithic typological system used by Chinese archaeologists has proved inadequate to discuss the Acheulean Industrial Complex in other parts of the Old World (Sharon, 2007). Secondly, and in contrast, African typological classification, which includes an intact developmental sequence for the entire Acheulean Industrial Complex, provides more comprehensive information. African typology has been developed over many years through the study of a series of Acheulean sites spanning about 1.5 Ma, from such sites as Olduvai Gorge (Leakey, 1971, 1994; de la Torre and Mora, 2005), Koobi Fora (Isaac, 1997), Kalambo Falls (Clark, 1974, 2001a), Olorgesailie (Kleindienst, 1961; Isaac, 1977), and Cave of Hearths (Mason, 1988; McNabb and Sinclair, 2009).

As technical knowledge is embodied in knapping strategies, it is therefore most suitable for evaluating cognitive capabilities among early tool-makers (de la Torre and Mora, 2009; Stout, 2011). The systematic and thorough technological analysis in this paper will provide us with direct material evidence to explain the knapping and cognitive capabilities of early hominids.

The detailed analysis of raw materials available in this region will be presented first. The source, abundance, quality, shape and size of raw materials are analysed. And for better understanding of the technological constraints imposed by raw materials, these attributes are correlated with other parameters, such as blank type and shaping extent. The blank types of LCTs, along with the blow direction and striking platform type, are then discussed. Finally, we analyse shaping in the operational sequence through counts of primary and secondary scars (primary scars are produced in the

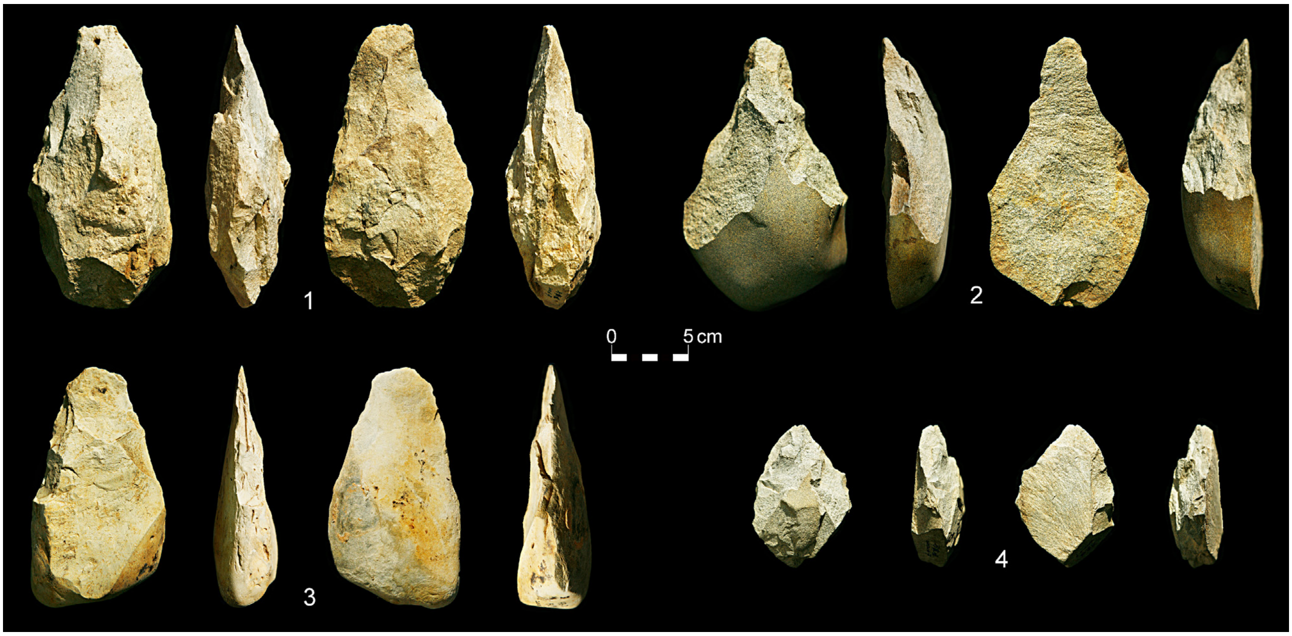

Fig. 2. DRR handaxes: 1. handaxe made on an igneous flake with short chisel-end distal; 2. handaxe made on a bipolar flake in trachyte with thin distal; 3. handaxe made on an igneous cobble; 4. handaxe made on a corner-struck flake in trachyte.

initial shaping of a blank and are large removals that shape the overall body of a tool, while secondary scars consist of small removals or retouch that regularize or refine the edges of a tool). These distinctions are important to document the degree of shaping done for the whole body of the tool, as well as its edges. The distribution pattern of scars is also analysed to consider the shaping pattern on each portion of the piece.

4. Results

4.1. Classification

One contribution of African typological classification is the identification of variability in the Acheulean Industrial Complex both through its long developmental sequence and across different regions. Ecology also influences our definitions of LCTs in the DDR, where there are significant differences in environment and raw material. Thus, a slight modification to the African typological classification is necessary for this paper. For instance, the unifacial cobble pick has been regarded as a unique LCT type in the assemblages in DDR, whereas there are no western assemblages showing the consistent occurrence of this type. The definition of each type of LCT in DRR is given below:

4.1.1. Handaxe

A convergently shaped heavy-duty tool made on a large flake, nodule or cobble. Shaping mainly focuses on the distal end and the lateral edges, which can be shaped bifacially, partly bifacially or unifacially (Fig. 2: 1-4; Fig. 3: 1–4).

4.1.2. Pick

A convergently shaped heavy-duty tool made on a large flake, nodule or cobble, which can be bifacial, partly bifacial or unifacial. Picks differ from handaxes mainly in the purpose of shaping; the notably strong and narrowed distal end looks specialized for some functions. Therefore, a pick usually has a trihedral cross-section in morphology (Fig. 4: 4–5).

4.1.3. Cleaver

A large heavy-duty tool with a sharp transverse or oblique edge as the functional part. The typical cleaver is made on a large flake with a clean functional edge and shaping most often occurs on the laterals. However, a cobble can also be used to make an atypical cleaver with the functional edge formed by a tranchet blow or shaping (Fig. 4: 1–3).

4.1.4. Unifacial cobble pick

A unique heavy-duty tool type in the Danjiangkou Reservoir Region. It is made on a cobble, usually with unifacial shaping, with cortex dominating on one face. The distal end of a unifacial cobble pick is usually more rounded, which may indicate a special technological adaptation to the function (Fig. 4: 6–7).

4.2. Raw materials

Raw materials for making LCTs are cobbles from the nearby river bank. In total, five local raw materials were employed (Table 1). Quartz phyllite was used for 70.8% of the LCTs and 95.2% of picks. Trachyte was used for 20.8%, with a relatively higher proportion for cleavers and handaxes. Igneous rock, quartzite and quartz were much less used. These different proportions indicate a clear preference for certain raw materials that corresponds with the quality of each rock type.

Table 1
Raw material proportions of DRR LCTs.

	Quartz phyllite	Trachyte	Igneous rock	Quartzite	Quartz
Handaxes	25	8	3	0	0
Picks	20	1	0	0	0
Cleavers	3	4	1	0	1
Unifacial Cobble Picks	3	2	0	1	0
Total	51 (70.8%)	15 (20.8%)	4 (5.6%)	1 (1.4%)	1 (1.4%)

Quartz phyllite dominates the LCTs despite having a platy structure which makes it more difficult to control the fracture (see

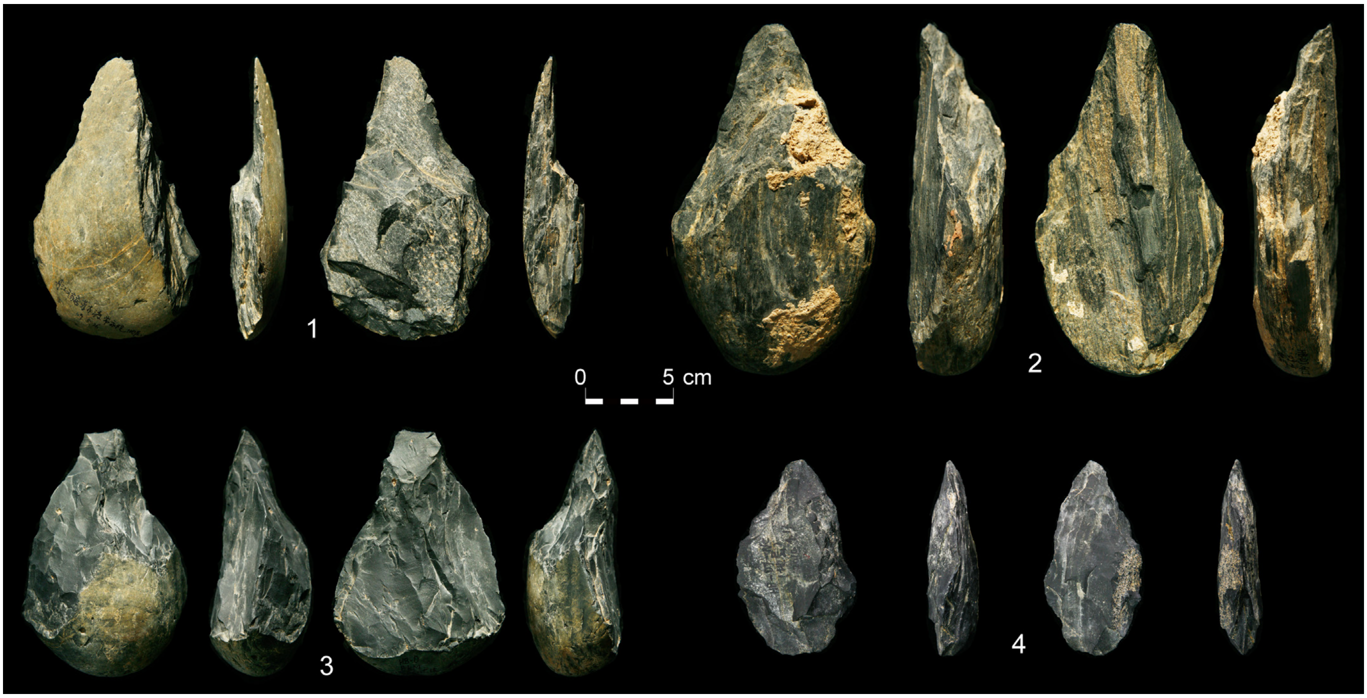

Fig. 3. DRR handaxes: 1. handaxe made on a quartz phyllite flake with thin distal; 2. handaxe made on a bipolar flake in quartz phyllite; 3. handaxe made on a quartz phyllite cobble with short chisel-end distal; 4. handaxe made on a quartz phyllite flake.

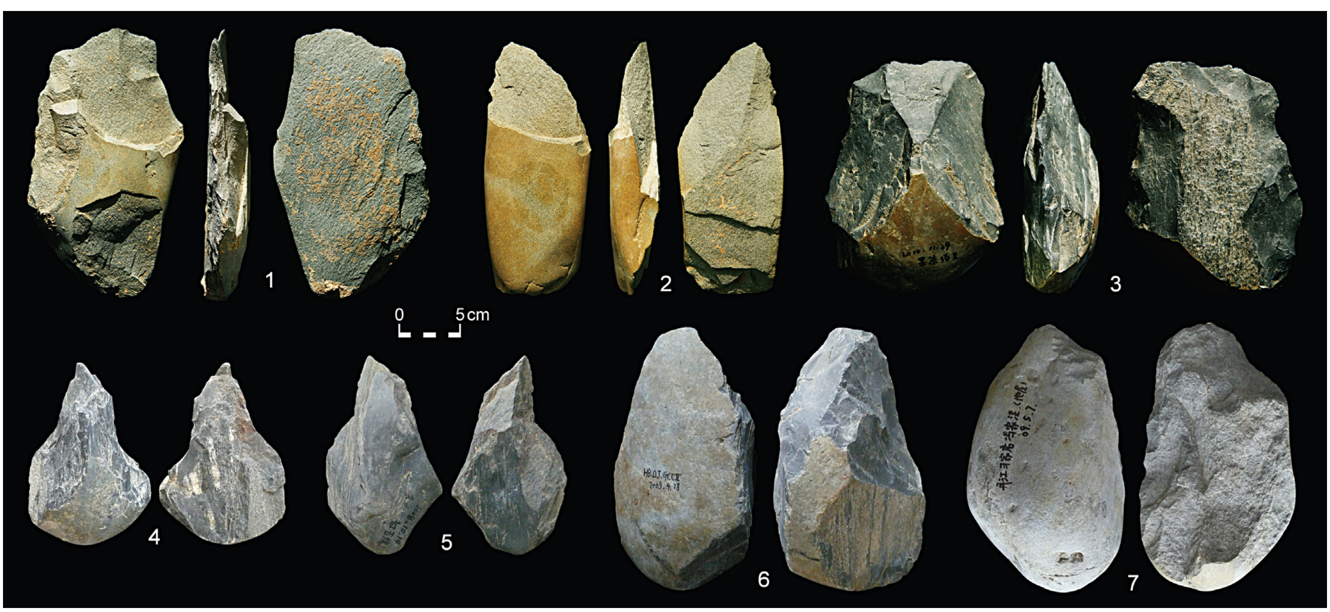

Fig. 4. DRR cleavers, picks and unifacial cobble picks: 1. cleaver made on an end-struck flake in trachyte; 2. cleaver made on a trachyte flake; 3. cleaver made on a natural split quartz phyllite cobble; 4. pick made on a split quartz phyllite cobble; 5. pick made on a quartz phyllite cobble; 6. unifacial cobble pick made on a quartz phyllite cobble; 7. unifacial cobble pick made on a trachyte cobble.

Fig. 3: 1–2). Even so, as a main raw material in the local river bank, it was still used effectively to make LCTs, which supports other scholars' research that raw materials in East Asia did not constrain the making of LCTs (Schick, 1994; Lycett and Bae, 2010). However, its flaking properties did have a certain influence on the technology and final morphology of LCTs, which will be analysed in the below sections below. In some fine-grained quartz phyllite pieces, elaborate shaping is seen (Fig. 3: 4). Compared with quartz phyllite, trachyte and igneous rock fracture less during flaking and are relatively softer. The weathering seen on eight of 19 trachyte and igneous rock specimens highlights the softer quality of these materials, which also lends itself to more regular and easy flaking of specimens (Fig. 2: 3). The cobbles in this region are generally well-rolled oval shapes. The size of cobbles varies, with lengths concentrated in the 2–15 cm range, which has a big influence on the flaking methods.

4.3. Blanks

Different kinds of blanks were exploited by these hominids to make LCTs (Table 2). Cobbles were used more than any other blank, for 47.2% of all LCTs and 61.9% of picks, which includes all of the unifacial cobble picks. Flakes and bipolar flakes comprise 40.3% of the blanks, which indicates that hominids possessed the ability to produce large flakes and could apply different techniques according to the local raw materials. Flakes and bipolar flakes were more commonly used in the production of handaxes and cleavers.

Table 2
Blank types of DRR LCTs.

	Cobble	Naturally split cobble	Split cobble	Flake	Bipolar flake	Indeterminate
Handaxes	12	0	2	12	9	1
Picks	13	0	4	2	2	0
Cleavers	3	1	1	4	0	0
Unifacial Cobble Picks	6	0	0	0	0	0
Total	34 (47.2%)	1 (1.4%)	7 (9.7%)	18 (25%)	11 (15.3%)	1 (1.4%)

The cobbles used to make the LCTs were well selected, in that they tend to be elongated oval or flat shapes, which can provide a suitable platform and angle for direct invasive flaking of the laterals (Fig. 2: 3; Fig. 3: 3). The size of original cobbles was more or less uniform, a size comfortable for holding in the hand. The dorsal faces of the LCTs made on flake blanks often retain a high proportion of cortex, sometimes with completely cortical dorsal faces. For those LCT blanks where striking platform could be identified, 86.7% have a cortical platform and 13.3% a plain platform. This indicates that many flakes are primary flakes or cobble opening flakes. This technique required an intentional selection of the shape and size of the original cobbles. For striking platform position in relation to long axis, four LCTs are end struck, three are corner struck and only one is side struck, which indicates that the makers intentionally detached the flakes on the long axis of the cobbles. The bipolar technique was commonly used for handaxes, which is evidenced in the type of flake scars on the dorsal and/or ventral face of the proximal end, and splitting always followed the platy structure of poor quality quartz phyllite, which is a special adaptation to the local raw materials (Fig. 3: 2).

4.4. Shaping

To explore the intensity of shaping, the numbers of primary and secondary scars are counted (excluding heavily weathered specimens). There is a clear pattern that the average number of secondary scars is higher than the average number of primary scars, which indicates that more shaping was conducted to refine the edges than to shape the body of the piece (Fig. 5). The average number of scars on handaxes (20.6) is higher than that on picks (16.8), cleavers (16.6) and unifacial cobble picks (15.8). The total average number of scars is relatively low compared with western Acheulean LCTs (Sharon, 2007), which manifests a least-effort strategy in shaping.

Table 3 shows the shaping patterns: 17 LCTs are unifacial, 20 are bifacial, and 35 partly bifacial, which is the highest proportion (48.6%). Most of the picks are partly bifacial (61.9%). Handaxes comprise the highest proportion of bifacial shaping (36.1%). This indicates that the hominids paid more attention to the shaping of handaxes.

Table 3
Shaping data of DRR LCTs.

	Bifacial	Partly bifacial	Unifacial
Handaxes	13	18	5
Picks	3	13	5
Cleavers	4	4	1
Unifacial Cobble Picks	0	0	6
Total	20 (27.8%)	35 (48.6%)	17 (23.6%)

Fig. 6 shows the shaping on the distal, middle and proximal portion of LCTs. For all pieces, the distal end has the highest concentration of primary and secondary shaping, with an average of 79.9%, reflecting a focus on the functional part of the tool. The

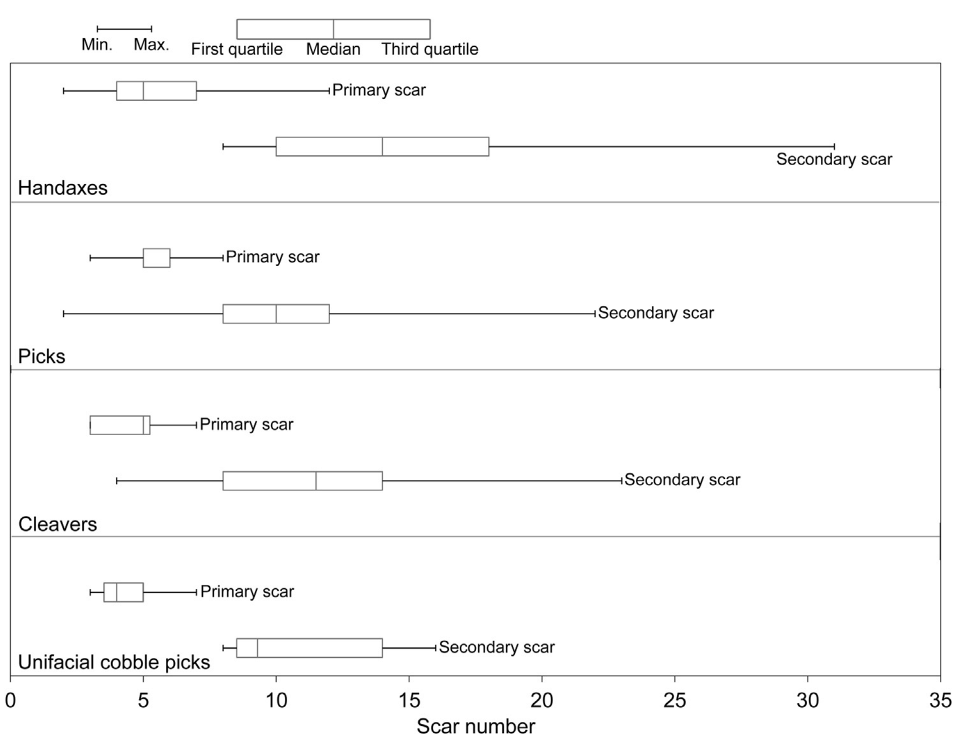

Fig. 5. Box plot of primary and secondary scar numbers on the DRR LCTs.

average proportion of shaping for the middle portion is 54.5%, and for the proximal end is 27.2%. When we look at handaxes and picks in more detail, we see they have a very close average percentage of shaping in the distal, 86.8% and 85.7% respectively. However, handaxes have higher shaping than picks on the proximal end, 38.9%:14.3%. This shows that there is a higher degree of shaping of the overall body in handaxes than picks.

Overall, handaxes have a shaping (primary and secondary) proportion of 64.4%, picks 53.9%, cleavers 66.7%, and unifacial cobble picks 30.6%, which is lower than other LCTs because of the almost unifacial shaping pattern. With regard to secondary shaping, which shows the attention paid to refining the edges, handaxes have the highest proportion (44.7%).

4.5. Measurements and indices

Measurements and indices are commonly used as morphological indicators for the attributes of East Asian LCTs. Here, we provide complete information of the DRR LCTs in terms of weight, length, width, thickness, and elongation and refinement ratios (see Appendix). For weight, unifacial cobble picks have a higher value than the other types, with an average of 1411 g, while handaxes have the lowest average weight of 731.94 g (Table 4). The greater weight value for Bose LCTs (1534 g average) led to the tentative hypothesis that they cannot be ascribed to the Acheulean industry (Shipton and Petraglia, 2010). However, we can argue that this is likely to be related to the function of the tools. The heavier unifacial cobble picks would be suitable for heavy-duty wood working in the wooded environment. The environment in Bose is considered to have been tropical, with abundant resources of wood (Yin and Guo, 2006; Yuan et al., 2008), so hominids might well have preferred to use much heavier tools. The unifacial cobble picks in DRR point to the same situation.

Table 4
Measurements and indices of DRR LCTs.

		Handaxes ($N = 36$)[a]	Picks ($N = 21$)	Cleavers ($N = 9$)	Unifacial cobble picks ($N = 6$)
Weight (g)	Min	144.00	208.00	174.00	912.00
	Median	687.00	886.00	926.00	1440.00
	Max	1554.00	1488.00	1886.00	1868.00
	Mean	731.94	886.86	1092.22	1411.00
	SD	352.45	358.14	395.70	357.80
Length (mm)	Min	89.8	117.00	154.16	143.00
	Median	156.57	162.47	165.55	192.00
	Max	216.62	229.87	235.70	220.00
	Mean	158.77	166.48	183.49	187.05
	SD	28.92	30.41	31.75	26.00
Width (mm)	Min	56.14	61.00	74.64	99.00
	Median	185.42	97.51	95.61	112.00
	Max	130.21	129.00	152.28	115.00
	Mean	93.59	99.46	105.27	109.18
	SD	16.33	15.66	27.56	6.54
Thickness (mm)	Min	25.52	34.00	32.89	46.45
	Median	47.88	53.09	48.57	58.50
	Max	71.16	81.45	66.90	70.00
	Mean	48.77	52.19	50.47	59.41
	SD	11.38	10.61	12.08	8.71
L/W (Elongation)	Min	1.34	1.29	1.37	1.25
	Median	1.67	1.67	1.81	1.71
	Max	2.07	2.30	2.41	2.02
	Mean	1.71	1.69	1.80	1.72
	SD	0.19	0.28	0.33	0.27
T/W (Refinement)	Min	0.33	0.32	0.26	0.45
	Median	0.53	0.54	0.50	0.54
	Max	0.78	0.77	0.80	0.63
	Mean	0.53	0.53	0.51	0.54
	SD	0.11	0.11	0.18	0.06

[a] Because of damage to two handaxes, the weight, length and L/W of handaxes are for 34 pieces. See appendix for raw data.

Thickness is also an important factor in the morphological analysis (Norton et al., 2006; Petraglia and Shipton, 2008; Lycett and Bae, 2010). East Asian handaxes (Luonan Basin in China and Imjin/Hantan River Basin in Korea) have a thicker profile than western examples, which Lycett and Bae (2010) regard as a "plesiomorphic trait" that supports the technological convergence of East Asian industries with the Acheulean. The mean thickness of DRR handaxes in our sample is 48.77 mm (Table 4). When we calculate the thickness of the handaxes made on flake blanks only, an even lower mean thickness (44.21 mm) is shown (Table 5), which is lower than that for other regions of East Asia and much closer to Western examples (Table 6). The low thickness of DRR handaxes is closely related to the selection of blanks. This is confirmed with the Student's *t*-test. Comparing handaxes made on flake blanks with those made from cobbles results in a small *p*-value ($p < 0.05$), and therefore there is statistically significant difference (Table 5).

Table 5
Comparisons of the mean length, width, thickness, L/W (Elongation) and T/W (Refinement) between handaxes made on flakes and cobbles.

	Flakes ($N = 21$)[a]	Cobbles ($N = 12$)	*t*-statistic	*p*-value*
Length (mm)	154.56	167.38	−1.17	0.25
Width (mm)	93.07	96.20	−0.51	0.616
Thickness (mm)	44.21	55.42	−2.95	<0.05
L/W (Elongation)	1.68	1.74	−0.83	0.413
T/W (Refinement)	0.48	0.58	−2.82	<0.05

*P (two-tail)<0.05 was considered statistically significant difference.
[a] Because of damage to two handaxes made on flakes, the weight, length and L/W of flake handaxes are for 19 pieces. See appendix for raw data.

Table 6
A comparison of the thickness (in mm), T/W (Refinement) and L/W (Elongation) of Western Acheulean and East Asian assemblages. Blank means no data available.

	Thickness			T/W (refinement)			L/W (elongation)		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
Western Acheulean	503	43.53	14.31	503	0.52	0.13	650	1.66	
DRR	36	48.77	11.38	36	0.53	0.11	34	1.71	0.19
Bose	64	73.14	12.26	64	0.62	0.13	64	1.40	0.20
Luonan	236	58.41	13.46	236	0.61	0.14			
IHRB	58	60.19	12.92	58	0.65	0.14	58	1.64	0.27

Note: Western Acheulean (Africa, Europe, Middle East and India) data from Petraglia and Shipton (2008) and Shipton and Petraglia (2010).
Bose data from Huang (2003); Luonan data from Wang (2007); Imjin/Hantan River Basins (IHRB) data from Norton et al. (2006).

Two indices, elongation and refinement are thought to be useful variables for characterising and discriminating LCT assemblages (Wynn and Tierson, 1990; White, 1998; Shipton and Petraglia, 2010). The Refinement Index (or Thickness/Width) in particular is thought to be an important indicator for the blank selectivity or the reduction intensity of LCTs (White, 1998; Noll and Petraglia, 2003; McPherron, 2006; Petraglia and Shipton, 2008). The average value of refinement for DRR handaxes is 0.53, which falls within the range of Western Acheulean in Africa, Middle East and India (Petraglia and Shipton, 2008; Shipton and Petraglia, 2010), but different from Luonan in China and Imjin/Hantan River Basin (IHRB) in South Korea (Table 6). From analysis of the shaping technology, we can see that this is not related to intensive reduction, but to the original size of the raw materials and the types of blanks. With regard to the elongation of handaxes, the results from DRR are also similar to those from the western Acheulean (Table 6).

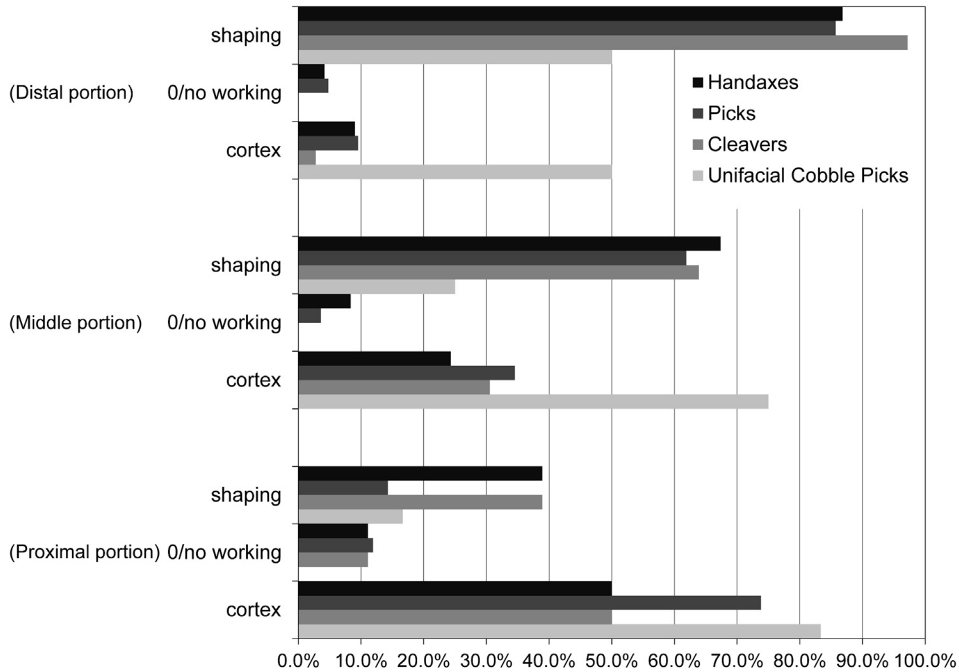

Fig. 6. The proportion of shaping on each portion of LCTs. The tool is proportionally divided into distal, middle and proximal portion based on the length. “shaping” includes the primary and secondary shaping. “0/no working” stands for the unworked ventral face of flake LCTs.

5. Discussions and conclusion

The current research of LCTs in East Asia, mainly China and South Korea has provided some new interpretations for the “Acheulean” in this region. In one of the most influential interpretations, Norton and colleagues have argued that the Movius Line *sensu stricto* can be replaced by the Movius Line *sensu lato* based on several key observations, concluding that the presence of LCTs in eastern Asia is the result of short-term technological convergence (Norton et al., 2006; Norton and Bae, 2008; Lycett and Bae, 2010; Lycett and Norton, 2010). Here, the LCT materials from the DRR provide us with a rare chance to test Norton et al.’s observations and conclusion, and meanwhile, to decode the probable human behaviours in the Early Palaeolithic of eastern Asia.

A low frequency of handaxe sites in eastern Asia is one of the observations used to support the Movius Line *sensu lato* (Norton et al., 2006; Norton and Bae, 2008). This is generally true, but until now, only four regions are well known and frequently cited as containing LCT for the extensive area of eastern Asia, namely, Dingcun, Bose and Luonan in China, and Imjin/Hantan River Basins (IHRB) in South Korea. However, as with the DRR reported in this paper, it is not impossible that more LCT sites might be found in East Asia, as the extremely small number of active researchers in China has led to limited research. For example, there are some areas which have been reported to have LCTs (Fig. 1), such as Sanmenxia, Hanzhong and Xiangyang in central China (Huang, 1964, 1987; Li, 1983; Huang and Qi, 1987; Leng and Shannon, 2000), and Lishui, Liaohe and Shuiyangjiang River valleys in southern China (An, 1990; Li and Xu, 1991; Yuan, 1996; Fang, 1997; Chu, 1998). Nevertheless, very limited research has been conducted since these reports. Although the interpretation of these sites is therefore still vague, two possible routes for the dispersal of LCT hominids, in the authors’ opinion, could be extracted from the sporadic incidence of LCTs in these areas. One is through the plains east of the mountainous regions, while the other is along the Yangtze River and its tributaries (Fig. 1). It is believed that in-depth research in these most promising areas will shed light on the distribution frequency and pattern of LCT sites in eastern Asia in the future.

The second observation by Norton et al. is the low percentage of handaxes at sites in eastern Asia compared with many coeval Acheulean sites in Africa, Europe and western Asia (Norton et al., 2006; Norton and Bae, 2008). This observation is also supported by our research in DRR, where surface finds show that the average number of LCTs per site is 4.2, and the highest number is 16 at the Guochachang site. Moreover, the small number of *in situ* LCTs from excavations is consistent with these findings from surface collections (Pei et al., 2008; Zhou et al., 2009; Li, 2012; Li et al., 2013; Li et al., submitted for publication) (Table 7). Until now, the most prolific discovery of handaxes has occurred at the Zhanghuokou site in Luonan basin, with seven handaxes unearthed from 75 m^2 (Wang et al., 2011). Hence, the low percentage of LCTs can be seen as an objective fact in DRR, as well as in Bose and Luonan.

Table 7
The artifacts and LCTs number and their density in the excavation sites in DRR.

Site	Excavation area	Artifacts		LCTs		Reference
		N	Density (/m^2)	*N*	Density (/m^2)	
Guochachang II	500 m^2	150	0.3	4	0.027	Li et al., 2013
Pengjiahe	600 m^2	264	0.44	8	0.013	Pei et al., 2008
Beitaishanmiao	800 m^2	277	0.346	7	0.009	Zhou et al., 2009
Shuangshu	1435 m^2	706	0.492	13	0.009	Li et al., submitted for publication

However, this observation cannot be used to support Norton et al.’s opinion that a low percentage of LCTs means that a “true” Acheulean tradition does not exist in East Asia (Norton and Bae, 2008). In this paper we assert that the percentage of LCTs in sites does not have a categorical meaning but can only be understood as a by-product of behavioural processes (Tryon and Potts, 2011; Diez-Martín and Eren, 2012). Setting an arbitrary proportion to characterize a site as Acheulean is actually a type-fossil approach used under the cultural history paradigm and masks the diversity and richness of hominid behaviours at local scales (Diez-Martín and Eren, 2012). Moreover, research on LCTs in past decades has revealed that variability within the Acheulean Industrial Complex is a common phenomenon across space and time. This variability can be seen not only in tool type frequencies (Pope, 2002; Sharon et al., 2011), but also in technological strategies (Clark, 2001b; McPherron, 2003; Schick and Clark, 2003; Archer and Braun, 2010) and in morphology (Gowlett and Crompton, 1994; Gamble and Marshall, 2001; Lycett, 2008). When considering LCTs in East Asia, the low percentage found to date should not prevent the use of the term Acheulean to describe the assemblages.

Norton et al. also consider that the low proportion of LCTs most likely has a demographic explanation (Lycett and Bae, 2010; Lycett and Norton, 2010), and with this we agree. The relatively small population sizes in East Asia probably led to less intensive hominid activity and the ephemeral occupation of the sites, which resulted in few artefacts being left on the sites. In addition, another explanation is also put forward here: landscape use. As East African Acheulean sites have revealed, channel contexts always contain large number of LCTs, while lakeshore paleoenvironments or even the sands just beyond the channels are always in the dearth of LCTs (Isaac, 1981; Rogers et al., 1994; Potts et al., 1999; de la Torre, 2009). Currently, the LCT sites found in DRR are all located in clay terrace contexts, i.e., the environment of a floodplain (Pei et al., 2008; Li et al., 2009, 2012; Zhou et al., 2009; Li, 2012; Li et al., 2013; Li et al., submitted for publication). This is likely why numbers of LCTs are low. In addition, due to the relatively stable sub-tropical climate and the uniform river terrace habitat existing in the Pleistocene Junxian Basin, the Palaeolithic sites on the third terrace of the Han River appear to have a continuous "background scatters of artifacts", which is consistent with a relatively homogeneous land surface and resources during the hominids' occupations of DRR. It is considered that the low percentage of LCTs in East Asia may have resulted from multiple factors, each of which may have an important implication for interpretation of human behaviour.

The third observation by Norton et al. is the presence of morphological differences between East Asian handaxes and classic Acheulean examples, especially those of the Middle Pleistocene age (Norton et al., 2006; Norton and Bae, 2008; Lycett and Bae, 2010). This has been demonstrated by the comparative study of several key measurements and indices for LCTs, particularly thickness and the Refinement Index. The results for the IHRB and Bose LCT assemblages by different researchers are consistent in that they both show higher values for thickness and less refinement than the western Acheulean forms (Norton et al., 2006; Petraglia and Shipton, 2008; Lycett and Bae, 2010; Shipton and Petraglia, 2010). Nevertheless, it is not adequate to interpret the differences between the eastern Asia LCT assemblages and the western Acheulean assemblages as indigenous development when some fundamental factors, such as raw material, technology and functional activities, have not been considered sufficiently. The average values of thickness and refinement of DRR handaxes are much closer to western Acheulean examples, which may be mainly caused by the original size and shape of raw materials and the selection of blanks. In addition, as a special technical solution to the sub-tropical ecological context in DRR, the unifacial cobble pick generally has a thicker and heavier body, which could be related to woodworking functions.

In addition to a morphological comparison between East and West, we believe that a technological comparison is another meaningful approach for the related archaeological interpretation. The techno-economic behaviours presenting in the LCTs of DRR are:

- Selection of the local available raw materials for LCT making. Although raw materials do not constrain the production of LCTs, their final forms are influenced by the poor quality of many raw materials, which is evident in scars with stepped terminations.
- The use of different blanks in the making of LCTs, such as cobbles, split cobbles, naturally split cobbles and flakes. The choice of blanks mainly depends on the original shape and size of raw materials. As one of the most relevant technical advances related to the Acheulean techno-complex, the ability of detaching large flakes from large cores required skilful control by the hominids in DRR.
- A least-effort shaping strategy was adopted and most shaping was concentrated on the distal and middle part of the LCTs. The number of secondary shaping scars is larger than that of primary shaping scars, which indicates that the makers paid more attention to refining the edges.
- The co-existence of classic and non-classic LCTs as judged by their technology and morphology demonstrates that the hominids had a flexible adaptation to the mental and technological construct of the LCTs.

The present research into LCTs in DRR would in fact support the existence of the true Acheulean techno-complex in East Asia, which explicitly shows the diversity and complexity of the Early Palaeolithic in this vast region. Moreover, the variability of the Acheulean techno-complex is evident in the variable percentages, morphology and technology of LCTs, which could be explained as the effect of interconnected factors, for instance, the raw material quality, the reduction intensity, the landscape use strategies and the population size. However, because of the relatively limited materials available, we suggest that it is still premature to decide on the original mechanism of East Asian LCTs.

Thanks to the continuous updating of approaches and ideas in Acheulean research, we can now make more exciting plans for the study of the LCT sites in East Asia, such as the functional study of LCTs and the technological and morphological analyses of handaxes with the aid of 3D scanning. These in-depth studies in one region and the further investigations in other potential areas will contribute to our understanding of the evolution of earlier East Asian populations.

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Appendix. Measurements and indices for LCTs. Missing data corresponds with damage. Weight (g), length, width and thickness (mm).

Artefact number	Site	Weight	Length	Width	Thickness	L/W (elongation)	T/W (refinement)
Handaxes ($N = 36$)							
1	Majiazui	912.00	185.42	96.46	59.94	1.92	0.62
2	Changjiayuan	428.00	160.55	96.10	34.85	1.67	0.36
3	Balamiao	704.00	140.13	97.07	55.10	1.44	0.57
4	Balamiao	688.00	156.63	86.60	47.48	1.81	0.55
5	Balamiao	818.00	172.16	104.05	46.58	1.65	0.45
6	Hongshikan	1182.00	206.92	120.91	45.41	1.71	0.38
8 *in situ*	Niuchangmatou	464.00	159.95	103.66	34.33	1.54	0.33
9	Fengjiawa	1168.00	216.62	122.07	48.21	1.77	0.39
10	Shuangshu	494.00	135.99	81.27	47.54	1.67	0.58
11	Niuchangmatou	144.00	111.44	56.14	25.52	1.99	0.45
12	Guanmenyan	340.00	134.24	72.56	45.27	1.85	0.62
13	Majiazui	168.00	89.80	60.90	30.02	1.47	0.49
14	Niuchangmatou	510.00	150.00	79.83	45.81	1.88	0.57
15	Guochachang	1182.00	200.31	114.15	56.25	1.75	0.49
16	Caijiadu	786.00	151.73	92.36	60.88	1.64	0.66
17	Balamiao	1184.00	188.79	91.24	71.16	2.07	0.78
18 *in situ*	Majiazui	566.00	174.27	84.42	43.15	2.06	0.51
19	Shuangshu	318.00	126.33	78.10	32.41	1.62	0.41
20	Hongshikan	742.00	171.03	88.69	52.70	1.93	0.59
21	Guochachang	572.00	152.11	92.25	39.93	1.65	0.43
22	Guochachang	324.00	125.94	82.27	31.61	1.53	0.38
23	Shuangshu	604.00	131.42	82.94	50.23	1.58	0.61
24	Caijiadu	826.00	130.43	97.25	64.96	1.34	0.67
25	Guochachang			92.62	52.34		0.57
26	Shuangshu	572.00	134.61	77.22	57.07	1.74	0.74
27	Guanmenyan	1046.00	152.58	97.95	54.98	1.56	0.56
28	Shuangshu			100.33	49.88		0.50
62	Guochachang	1554.00	203.00	109.00	68.00	1.86	0.62
63	Balamiao	1362.00	195.00	103.00	66.00	1.89	0.64
64	Waibiangou	836.00	173.00	113.00	39.00	1.53	0.35
65	Guochachang	686.00	170.00	85.00	51.00	2.00	0.60
66	Dudian	1278.00	185.97	130.21	62.70	1.43	0.48
67	Dudian	592.00	156.50	105.62	41.78	1.48	0.40
68	Dudian	958.00	171.72	109.25	59.64	1.57	0.55
69	Pengjiahe	428.00	140.96	75.10	37.92	1.88	0.50
70	Zhuangzigou	450.00	142.77	89.58	45.95	1.59	0.51
Picks ($N = 21$)							
29 *in situ*	Guochachang	1240.00	198.23	94.36	59.54	2.10	0.63
30 *in situ*	Shuangshu	522.00	129.72	90.47	52.55	1.43	0.58
31 *in situ*	Datubaozi	418.00	136.37	78.56	47.99	1.74	0.61
32 *in situ*	Datubaozi	694.00	146.91	102.61	56.54	1.43	0.55
33 *in situ*	Guochachang	886.00	153.72	114.49	51.93	1.34	0.45
34	Majiazui	956.00	161.87	102.32	45.11	1.58	0.44
35	Majiazui	564.00	173.19	88.45	46.65	1.96	0.53
36 *in situ*	Guochachang	514.00	123.69	96.17	42.48	1.29	0.44
37 *in situ*	Guochachang	726.00	130.98	96.05	61.78	1.36	0.64
38 *in situ*	Guochachang	566.00	151.31	90.81	40.01	1.67	0.44
39	Majiazui	680.00	162.47	109.14	34.89	1.49	0.32
40	Shuangshu	1284.00	193.26	127.95	58.33	1.51	0.46
41	Hongshikan	738.00	164.48	97.51	53.09	1.69	0.54
42 *in situ*	Fengjiawa	1098.00	177.84	88.21	63.48	2.02	0.72
43	Majiazui	1136.00	192.50	93.33	55.61	2.06	0.60
44	Guanmenyan	1124.00	205.00	120.00	56.00	1.71	0.47
71	Datubaozi	1378.00	205.00	129.00	55.00	1.59	0.43
72	Beitaishanmiao	1088.00	183.00	102.00	45.00	1.79	0.44
73	Waibiangou	208.00	117.00	61.00	34.00	1.92	0.56
74	Pengjiahe	1316.00	229.87	99.85	54.51	2.30	0.55
75	Dudian	1488.00	159.75	106.33	81.45	1.50	0.77
Cleavers ($N = 9$)							
7	Longkou	902.00	159.14	103.22	51.75	1.54	0.50
46	Majiazui	1042.00	219.29	121.38	32.89	1.81	0.27
47	Majiazui	926.00	209.92	87.13	40.58	2.41	0.47
48	Majiazui	1602.00	235.70	152.28	39.34	1.55	0.26
49	Guochachang	1886.00	194.52	142.36	66.90	1.37	0.47
50	Caijiadu	1092.00	165.55	91.67	66.67	1.81	0.73
51	Majiazui	912.00	158.98	74.64	60.00	2.13	0.80
55	Shuangshu	674.00	154.17	79.16	47.50	1.95	0.60
56	Majiazui	794.00	154.16	95.61	48.57	1.61	0.51
Unifacial Cobble Picks ($N = 6$)							
45 *in situ*	Guochachang	912.00	175.32	103.07	46.45	1.70	0.45
58	Guochachang	1652.00	192.00	112.00	70.00	1.71	0.63

(*continued*)

Artefact number	Site	Weight	Length	Width	Thickness	L/W (elongation)	T/W (refinement)
59	Guanmenyan	1154.00	143.00	114.00	68.00	1.25	0.60
60 *in situ*	Fengjiawa	1608.00	192.00	115.00	60.00	1.67	0.52
61 *in situ*	Guochachang	1272.00	200.00	99.00	55.00	2.02	0.56
76	Guochachang	1868.00	220.00	112.00	57.00	1.96	0.51

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Large cutting tools in the Danjiangkou Reservoir Region, central China

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ABSTRACT

Handaxe-bearing sites in China are currently known to occur in a number of alluvial basins, the best known being Dingcun, Bose and Luonan. Bose in the south and Luonan in central China on the northern margin of the Qinling Mountains are most familiar to English-speaking researchers. Here we document the Danjiangkou Reservoir Region (DRR) as another major area for large cutting tools (LCTs), located in central China on the southeastern edge of the Qinling Mountains. Large cutting tools are preserved in three terraces of the Han and Dan Rivers in Hubei and Henan Provinces, with dates from ca. 0.8 Ma (millions of years ago) (Terrace 4) to the first half of the Middle Pleistocene (Terrace 3), and possibly to the Late Pleistocene (Terrace 2). This paper reports on LCTs discovered in Terraces 3 and 2, with a majority from the older terrace (and one specimen from Terrace 4). Regional environments during the Middle Pleistocene were relatively warm, humid and stable. Despite the poor quality of raw materials (predominantly quartz phyllite and trachyte for the LCTs), good examples of both handaxes and cleavers are present, plus two types of picks. The LCT technology is compared and contrasted with other Asian industries and with the Acheulean. Overall the DRR LCTs show both technological and morphological similarities with Acheulean LCTs, with some differences that are mainly attributed to raw material properties, subsistence ecology, and ‘cultural drift.’ The DRR LCTs expand the range of morphological variability of the East Asian material and highlight the need for greater reliance on technological analysis and raw material evaluation for best comparison of Chinese assemblages with the Acheulean tradition.

Introduction

Handaxes and other large cutting tools (LCTs) are now a well-known phenomenon in the Early Palaeolithic archaeology of China in certain regions. In both surface surveys and controlled excavations in recent years, a number of ‘Mode 2’ industries has been documented in southern China in the Bose Basin (Hou et al., 2000; Wang et al., 2008; Zhang et al., 2010; Huang et al., 2012; Wang et al., 2012, 2014) and in central China in the Luonan Basin (Figs. 1 and 2; Wang, 2005, 2006, 2007a,b; Lu et al., 2006, 2011a,b; Sun et al., 2012; Zhang et al., 2012). A few earlier discoveries of LCT sites in China are also well known but are currently less well published or researched than those cited above. These include Lantian in northern central China (with Late Pleistocene dates so far; Wang et al., 2014), and Dingcun (between 0.336 and 0.128 Ma [millions of years ago]) and Sanmenxia in the southern reaches of northern China (Fig. 2; Leng, 2001; Huang et al., 2005; Yang et al., 2014). There are also well excavated LCT sites of controversial age in Korea (Norton et al., 2006; Norton and Bae, 2009), as well as reports of undated handaxes and cleavers in the Philippines (Dizon and Pawlik, 2010). In Indonesia, LCTs are said to be present by ca. 0.8 Ma (Simanjuntak et al., 2010).

The origins and significance of the Chinese handaxe industries are highly debated topics. Many researchers consider them an indigenous development and do not recognize the presence of any true Acheulean technology in eastern Asia (e.g., Lin, 1994; Schick, 1994; Corvinus, 2004; Lycett, 2007; Derevianko, 2008; Gao, 2012). Others consider that they represent at least some movement of populations into Asia (Hou et al., 2000) or even support the notion of a ‘porous boundary’ between West and East. For example, Huang (1987) and Huang et al. (2009) believe that all Western technological elements are present through time to some degree in China, and have challenged the historically entrenched concept of the Movius Line a virtual line separating eastern Asia with simple core and flake (Mode 1) industries from western Eurasia and Africa,

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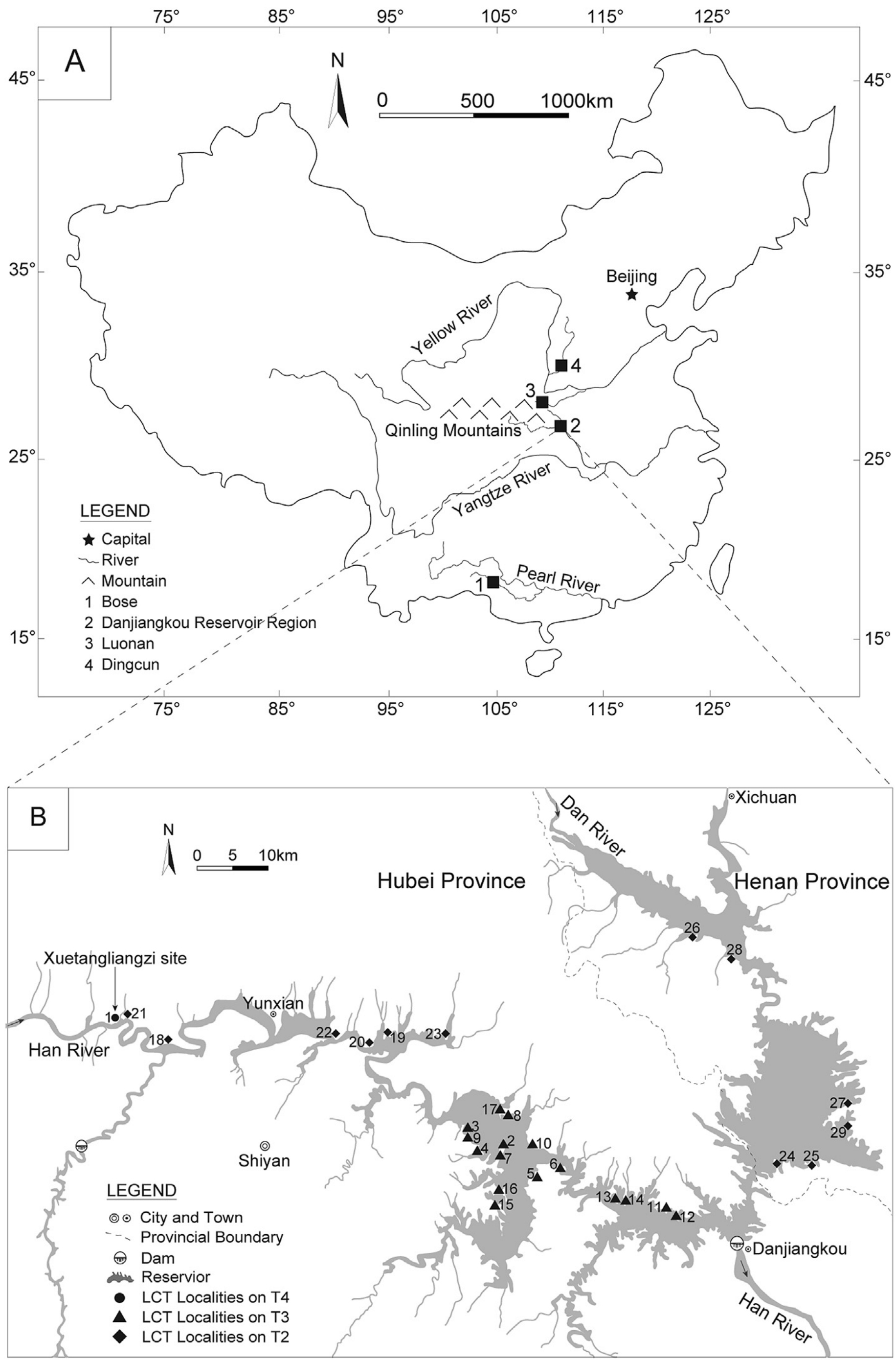

Figure 1. Location of the Danjiangkou Reservoir Region in central China and the sites documented in 1994. See Appendix A for site names.

which have widespread handaxe industries (Movius, 1944, 1948). On the other hand, Norton et al. (2006) and Norton and Bae (2009) have argued that China's LCT discoveries still do not seriously challenge the notion that Acheulean technology (sensu strictu) is absent in the East, thus supporting the concept of an indigenous development in Asia from Mode 1 technology. Petraglia and Shipton (2008) and Petraglia (2010) take a more complex position. They argue that the LCTs from Bose in South China and from Korea are not Acheulean-like, whereas those from the Luonan Basin in central China are, concluding that both indigenous development and movement of Acheulean peoples into eastern Asia occurred. Lycett and Norton (2010) believe that East Asian LCTs are the product of convergence and agree with the concept of the Movius Line sensu lato in eastern Asia, as argued by Norton et al. (2006). They particularly invoke a demographic model of low population size to explain how such sporadic and isolated occurrences could be short-lived, in contrast with innovation that is more likely to thrive in large populations (see also Lycett and Bae, 2010). Convergent development is often argued on the basis of the greater thickness of Asian LCTs, which usually also translates to differences in shape.

Leng and Shannon (2000) and Leng (2001) focus on technology and advocate the in-depth examination of the flaking properties of

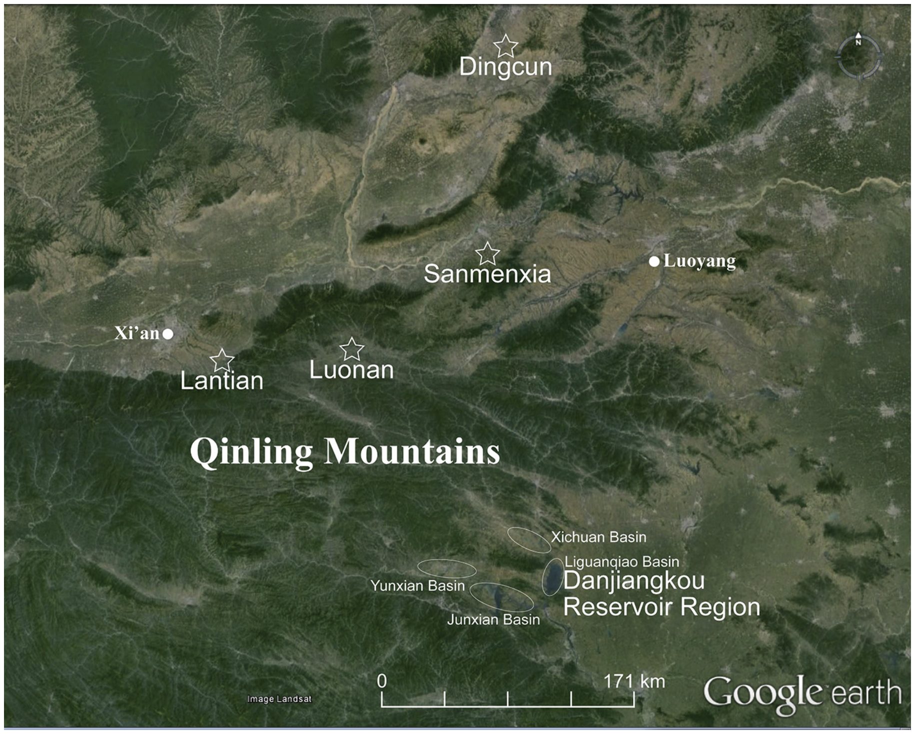

Figure 2. Location of several of the central and northern sites mentioned in the text (stars) and the four river basins (ellipses) of the Danjiangkou Reservoir Region.

the relevant raw materials to achieve an informed appreciation of the constraints imposed on the typological end-products. They argue that the Movius Line is an outdated concept based on a classificatory scheme that is no longer valid. They also emphasize the need to consider the 'bamboo hypothesis' (e.g., Pope, 1988; Toth and Schick, 1993; Pope and Keates, 1994), which considers that the widespread use of bamboo artefacts in southeastern Asia only required simple core and flake tools for their creation, reducing the need for LCTs. Experiments conducted by Bar-Yosef et al. (2012) have shown how easily bamboo can be made into cutting tools and how well it performs. They also observe that unifacial choppers, which are extremely common in the Palaeolithic of Southeast Asia through to the Early Holocene, are sharp and efficient tools for the working of bamboo, together with ordinary flakes. However, we should note that despite the bamboo hypothesis being widely cited, some researchers question the assumption that bamboo was a widespread and stable resource in China throughout the Pleistocene (Brumm, 2010; Lycett and Bae, 2010).

With regard to these debates, we agree with Leng and Shannon (2000) and Leng (2001) that raw material constraints need to be fully considered in any interpretation of Chinese LCT industries that employs morphometric data. As Bar-Yosef et al. (2012) have argued, an expert knapper may be able to produce Western forms such as prepared cores on poorer quality rocks, but the raw material constraints will still have an influence on the overall character of an industry. An equally important point to consider is that routes of passage allowing east–west movements would have been limited geographically and controlled by episodes of climatic opportunity, creating periods of both isolation and potential contact (Dennell, 2009; Moncel, 2010). Given these geographic restrictions and the great distances involved, emigrant groups would have been small compared with their source populations (Bae, 2010; Lycett and Norton, 2010). For those bands of hunter-gatherers that survived eastward expansion, cultural and technological signatures must certainly have been diluted by isolation or tempered by distance, environmental differences, and the demographics of small population sizes. This would undoubtedly have impacted the way in which cultural and technological adaptations were expressed in new territories, and we should not expect to see industries identical to those in the West or even in India. Thus the low demography model of Lycett and Bae (2010) and Lycett and Norton (2010) is in our view an important influence on the character of the Chinese LCT industries, regardless of whether these types are the result of convergent development or population movements from the West.

As a result of the complexities involved, interpretations of the origins of LCT industries in Asia differ according to the conceptual framework of researchers and their weighting of specific assemblage features (e.g., the limited geographic distribution of sites, low LCT numbers, size, thickness, weight, and unifacial versus bifacial shaping). For example, greater weight and thickness are commonly thought to be the most important attributes that set East Asian LCTs apart from the Acheulean. However, debates are complicated by the limited data at hand, particularly as the number of active researchers in China is extremely small relative to the vast size of the country and the amount of research that has been accomplished to date (Braun et al., 2010; Gao, 2013). As more data are published and more detailed analyses that consider raw material properties appear, more information is available to fuel debates and challenge previous conclusions.

The purpose of this paper is to present a sample of 120 LCTs from a lesser-known handaxe-bearing region in central China.[1] The study area consists of the Han and Dan River terraces in Hubei and Henan Provinces, respectively, and includes four river basins (the Yunxian and Junxian Basins in Hubei and the Liguanqiao and

[1] The 120 LCTs in this study are only a portion of the finds in the DRR, which were made available to the first author. We consider the DRR to be a new 'handaxe region' in central China because other finds are being published that will demonstrate that the handaxe phenomenon is consistent in this large geographic area.

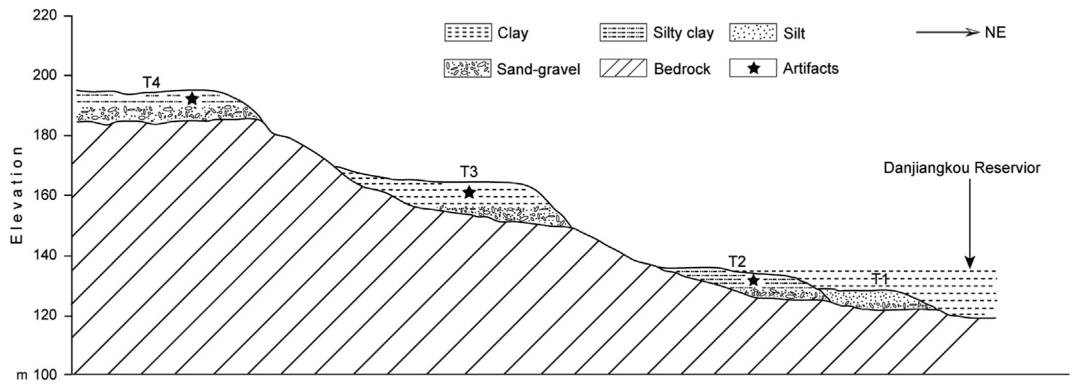

Figure 3. A representative cross-section of the study area, recorded in the Han River valley in the Junxian Basin. Adapted from Pei et al., 2008, with permission.

Xichuan Basins in Henan; Fig. 2). These two rivers converge near Danjiangkou city and have been dammed to construct the Danjiangkou Reservoir, with over 100 open-air sites now discovered during archaeological work over the last two decades (Li et al., 2009, 2012). For ease of reference we refer to the study area as DRR (Danjiangkou Reservoir Region). In this paper we focus on the technology of the LCTs from an African Acheulean perspective, and especially on the major influence that the local raw materials have on determining the character of the industry. We provide measurements and indices and propose a typology of LCTs intended to help highlight both the similarities and differences with Acheulean industries. Later we comment on the overall pattern of LCT industries in China in relation to raw materials and environments and the question of the populations who made them, and we provide comparative data for both Asian and Western Acheulean assemblages.

Geographic location and chronology

The DRR sites are located at the southeastern margin of the Qinling Mountains, which form the boundary between northern and central to southern China (Figs. 1 and 2). Current descriptions of the regional geomorphology are still very limited. Thus far, detailed information on the Pleistocene deposits and dating has only been published for terraces in the Hanzhong Basin some 400 km to the west, where human occupation has been dated from 0.6 to 0.1 Ma and ca. 0.086 Ma (Sun et al., 2012). In our study area, there are four terraces (T1 to T4) at different heights, which are related to the Han River, the longest tributary of the Yangtze River (Zhu, 1955; Pei et al., 2008). Terrace 1 is of Holocene age and lacks LCTs. It is the lowest terrace and is now flooded. Terrace 4 is the highest and oldest terrace. It preserves late Early Pleistocene fossils and is dated by fauna and palaeomagnetism to ca. 0.8 Ma (Li and Feng, 2001).[2] Until now, T3 has been argued on climatic interpretation of its 'red soil' sediments to date to the mid-Pleistocene humid period in China: MIS 11–15, between 0.621 and 0.364 Ma (Li et al., 2013). However, new dating results are available, which confirm that the T3 sites fall within the first half of the Middle Pleistocene (Li et al., 2014c). Terrace 2 is thought by many researchers to be younger because of its lower elevation. Recently Liu and Feng (2014) have announced TT-OSL (thermally transferred optically stimulated luminescence) results of 50–100,000 years for the T2 site of Dishuiyan on the Han River, which has unearthed more than 20 handaxes. Fig. 3 provides a schematic cross-section of the Han River valley. Terrace 2 lies 10–15 m above the riverbed, T3 (a red clay terrace) lies at 30–40 m, and T4 at 60–70 m. Distances between the terraces vary from <100 m to >200 m, depending on the location. Generally the distances between T2 and T3 are <100 m, and those between T3 and T4 are usually >200 m (information courtesy of Pei Shuwen and Figure adapted from Pei et al., 2008).

For northern and central China, the loess-palaeosol sequence of 37 glacial-interglacial cycles and 110 interstadials is well established and used extensively as a record of equal quality to the Marine Isotope Stages (MIS; Liu, 1985; Huang and Zhang, 2010; see Zhou and Derbyshire, 2008 for an historic account of this research). Analysis of the magnetic susceptibility of deposits, which is high in palaeosols and low in loess layers, is used to define the strata within a sequence when absolute dates are lacking (e.g., Sun et al., 2012). Today the DRR habitat is subtropical, with evergreen broadleaf forest and ca. 900 mm of precipitation per year (Guo et al., 2013). Terrace 4 (ca. 0.8 Ma) has been reconstructed in the loess-palaeosol sequence as representing a period of climatic transition from glacial to interglacial conditions from MIS 20 to MIS 19 (Guo et al., 2013). Terrace 3 (Middle Pleistocene) belongs to a phase of red soil development that was relatively humid (Pei et al., 2008). The forthcoming publication on the dating of T3 (Li et al., 2014c) should provide a welcome confirmation of this interpretation.

Materials and methods

The 120 LCTs analysed in this paper were collected during survey work by C. Li in 1994 (Li et al., 2009), with 67% of the sample deriving from T3 and the remainder from T2. During the 1994 fieldwork, 56 Palaeolithic sites were recorded in the DRR, 29 of which contained the LCTs reported in this paper. Although the sites are located in the four basins shown in Fig. 2, 16 sites were in T3 of the Junxian Basin, where most of the work was focused due to its proximity to the dam construction. Over two-thirds of the LCTs in this study derive from the 16 sites in the Junxian Basin. In subsequent investigations from 2004, the Junxian Basin has continued to be the core area of investigation. A further 72 LCTs from 17 localities (nine of which were previously sampled) have been retrieved from T3 in the Junxian Basin (Li et al., 2014b). Overall, 192 LCTs have now

[2] Li and Feng (2001) provide an age of 0.83–0.87 Ma for the Xuetangliangzi site at Yunxian in T4 based on palaeomagnetism and rates of sedimentation. de Lumley and Li (2008), however, give some alternate interpretations based on the combined data from fauna, palaeomagnetism and ESR. They interpret the site as falling within the Upper Matuyama reversed palaeomagnetic period of 0.780–0.984 Ma, but with brief normal phases, which could be either the Santa Rosa excursion at 0.936 Ma or the Kamikatsura excursion at 0.899 Ma. They favour the age of 0.936 Ma in their overall conclusion, but they also refer to the more general age of 0.780–0.984 Ma. Because of this lack of precision in the age of the site, most researchers prefer an age of ca. 0.8 Ma, which we have used here.

been retrieved in the DRR, with 152 of these from 24 localities found in T3 of the Junxian Basin since initial investigations in 1994.

Such low frequencies of LCTs within a large geographic study area are typical for all of the alluvial basins in China that have been described as handaxe-bearing regions. The limited geographic distribution and small numbers of LCTs have often been argued to differentiate Chinese sites with the Acheulean. However, low proportions of LCTs are equally characteristic of earlier Acheulean sites in Africa in excavated, non-winnowed contexts, a feature that may relate not only to time but also to low population sizes or site context. By ca. 1 Ma, some African assemblages contain relatively large numbers of LCTs (e.g., Olorgesailie; Isaac, 1977), which presumably is also related to a greater reliance on heavy duty tools for subsistence during the course of the Acheulean. The Chinese LCT site characteristics may well be reflecting demographic factors (Lycett and Norton, 2010).

Although most tools are surface finds, the terraces are located at distances from one another and mixing is unlikely. Moreover, 10 LCTs were also collected in situ at Beitaishanmiao, which has yielded the largest number of tools from a single site in this survey (24 of the 51 handaxes in T3), and one LCT was also found in situ at Hongshikan in T3. In addition to those pieces found in situ, the DRR tools are comparable with material published from four excavated sites in the Han River terraces (Pei et al., 2008; Zhou et al., 2009; Fang et al., 2012; Li et al., 2013). Sites have been named after the nearest village or a local geographic feature (see Appendix A). Both the T3 sites of Beitaishanmiao and Hongshikan are located in the Junxian Basin of the Han River. Only one LCT in this study derives from T4 of the Han River, as this terrace was not a focus of the survey. It was visited because it is the location of two hominid crania from Xuetangliangzi (the Yunxian hominid site), which will be discussed later, as well as lithics published in French (de Lumley and Li, 2008).

Questions of terminology

Terminology has often been a barrier to effective communication about Chinese LCTs. For example, some Chinese researchers prefer to call all convergently shaped tools picks rather than handaxes (e.g., Lin, 1994; Pei et al, 2008; Zhou et al., 2009), especially for those large convergent pieces that are unifacial or mostly unifacial. However, many Western archaeologists would call such pieces handaxes. Another example is the assumption that thick pointed pieces that lack thinning and soft-hammer retouch do not qualify as handaxes, particularly if they are found in later Middle to Late Pleistocene assemblages when such techniques occur in the Western Acheulean (Gao, 2013). Such a definition, however, would exclude many African Acheulean handaxes that are older than 1 Ma, when shaping and flaking techniques tended to be more basic. Some Chinese researchers also prefer to use the term 'proto-biface' for less fully flaked examples (e.g., Niu et al., 2014), but there is no consistent use of this term today by most Acheulean specialists. We argue that the comparison of Chinese LCTs must be made with the whole of the Acheulean through time and not restricted to the classic concept of later Acheulean handaxes, as described, for example, by Schick (1994).

The typological approach used in our study is based primarily on the classification instigated by Kleindienst (1962) and Clark and Kleindienst (2001) for the Earlier Stone Age (ESA), which is widely used by Africanist archaeologists, and was developed particularly for comparative study of late ESA sites in East Africa. They define handaxes, cleavers and knives as shaped 'large cutting tools' with emphasis on the cutting edge/s. They further define picks as heavy-duty tools with a minimum of overall trimming and with emphasis on the point rather than the edges.

In our study, we use the generic term of LCT, which is commonly done in Africa (e.g., McNabb et al., 2004; de la Torre and Mora, 2005), for cleavers, handaxes, knives and picks. We specifically include picks because pick-like handaxes and crude handaxes are noted in some African early Acheulean assemblages (e.g., Asfaw et al., 1992; Kuman, 1994; Lepre et al., 2011), and handaxes versus picks are not always defined in publications where they are noted. Including 'pick-like handaxes' in our classification thus allows us to search for similarities with the earlier Acheulean.

The pick-like shapes of some handaxes may be related to the function/s for which they were used in the earlier Acheulean (1.7–1.0 Ma). Although we are not aware of experiments conducted with this type, it is plausible that this shape could lend itself to digging and extracting roots and tubers, hence the emphasis on a convergent distal cutting edge. de la Torre et al. (2008) and de la Torre (2009) have also described early Acheulean handaxes in Tanzania from Peninj and from EF HR, Olduvai as resembling massive scrapers with notched edges and robust tips, which suggests that wood working may have been an important function for some early LCTs. Such pieces also occur in the early South African sites of Sterkfontein and Rietputs 15, although they are not dominant. A third function for handaxes suggested by experiments is the butchery of medium and large sized game (Toth and Schick, 1993; Jones, 1994). Toth and Schick (2009) report that both crude and refined handaxes were efficient in butchery, while Jones (1980) found handaxes more efficient and less tiring to use in butchery than sharp flakes.

Thus, handaxes are likely to have had variable functions implied by the shapes of their working ends, e.g., digging for underground food sources, woodworking, and butchery being the most obvious. Later Acheulean LCTS in both Africa and Europe have often been the subject of classification by shape (e.g., Kleindienst, 1962; Debénath and Dibble, 1994; Roe, 1994), a task that is easier for these specimens than for the more variable earlier Acheulean examples. We do not discuss knives in the LCT category in this study because our sample did not include their collection. However, knives are reported in the Luonan sites by Wang (2007a), and later we also discuss the knife-like cutting edges of some of the handaxes.

'Biface' has long been used in the West as a generic term for handaxes and cleavers that avoids functional implications (e.g., Leakey, 1971; Debénath and Dibble, 1994). However, 'LCT' is in effect a more appropriate term because not all examples are bifacially worked. In particular, some East African Acheulean assemblages are dominated by unifacial pieces (de la Torre and Mora, 2005; de la Torre, 2011). An illustrative case is the Acheulean at Konso in Ethiopia. At five sites that date from 1.25 to 1.75 Ma, the percentage of unifacial handaxes ranges from 30 to 75% (Beyene et al., 2013). Partly bifacial pieces also do not tend to be noted in most publications, which is an issue we address later in this article.

The tool types we use for this study are described below. Definitions for handaxes, cleavers and picks are similar to the types described by Kleindienst (1962) and Clark and Kleindienst (2001). However, we have added pick-like handaxes, to include the variability seen in earlier LCTs in Africa, and unifacial cobble picks, which appear to be unique to Asia.

Handaxe: a tool shaped by primary flaking to a convergent distal end. Primary flaking is defined as large removals that shape the blank, whether it be a cobble or a large flake. Secondary shaping that regularizes an edge with small removals may also be present. Shaping is not restricted to the distal end and there is usually a significant degree of overall shaping of the body of the tool. A blank used in the DRR may be a cobble, a flake, or a bipolar-worked cobble. Handaxes in African industries are frequently, but not always, made on flakes, and this trait depends very much on the size and shape of the raw material.

Cleaver: a large shaped tool with a broad cutting edge (the bit) that is rarely retouched and is more or less perpendicular to the long axis of the piece. Shaping occurs most often on one or both laterals and can be used to reduce the bulbar area. Blanks for the DRR cleavers include flakes, split-cobbles and flat oval cobbles. Western cleavers are most often made on flakes, but exceptions made on cobbles occur. Cleavers are particularly prominent in some African assemblages where the raw material lends itself to large flake production. Side-struck flakes are the most typical blank, but end and corner-struck are also common.

Pick: a heavy-duty tool shaped to a sturdy pointed end. Less attention is paid to the overall shaping of the body when compared with handaxes, or if more shaping is present, the piece is thick and sometimes trihedral. Both cobbles and large flakes are used as blanks.

Pick-like handaxe: a convergently shaped tool that is intermediate in morphology between typical handaxes and picks, sometimes having a more trihedral shape to the body. Unifacial or bifacial shaping is not an important criterion and diagnosis is based on the morphology, which at least for the distal portion is more closely linked to function. This intermediate type is not common in the current DRR sample as there is only one specimen in T3 and three in T2. This term is not used in Chinese typology but is used informally by some researchers for earlier Acheulean pieces in Africa. If numbers in the DRR do not increase in future samples, the type could be merged with picks. (Some Chinese researchers employ the term proto-handaxe for specimens that are more roughly or simply shaped than a typical handaxe, but the term is not a widely used in the African Acheulean.)

Unifacial cobble pick: a markedly 'heavy-duty tool,' which is fully to almost fully unifacial, with cortex dominating one face. The distal end varies from convergent to more rounded, and the angle of the functional end of the tool is steeper than for handaxes. In the current sample, there is only one of this type in T2 but there are 13 in T3.

The DRR LCTs in this sample are readily classified into these five types, four of which commonly occur in Western Acheulean assemblages, but unifacial cobble picks appear to be unique to the Chinese assemblages. To our knowledge, there are no Western assemblages in which they occur as a consistent type. In China, such tools are more common in some assemblages than others, which may be related to differences in regional environments and subsistence ecology and to the quality of raw materials (both discussed later). Cleavers occur in small numbers in DRR but they form an integral part of some Chinese assemblages, such as those in the Luonan region (Wang, 2006). Several are reported here for DRR, but we retrieved many more in June 2012 that are not discussed in this paper (see Li et al., 2014a).

We suggest that these type descriptions may help to provide a common language that facilitates comparison of Eastern and Western LCTs. We have already discussed the potential over-use of 'pick' in some Chinese publications. Another difference in terminology is the use of 'point' by some Chinese scholars for potential handaxes, usually reflecting the view that points are an indigenous development from chopping tools (bifacially worked choppers, as termed by Movius, 1944, 1948). Choppers (unifacial) and chopping tools (bifacial) are ubiquitous in China and are considered to be the most characteristic heavy-duty tool of the Mode 1 industries. However, the distinction between true choppers as tools rather than cores is not often made by researchers on both sides of the Movius Line. We take the position that use-wear must be present to demonstrate that the worked edge of a chopper has been used. If wear is not macroscopically visible, it is better justified to call the piece a chopper-core (i.e., a chopper-shaped core), until microscopic study of edge damage, residues or micropolish can demonstrate it as a tool. Chopper-cores are also very common in the African ESA, as well as in some early Middle Stone Age (MSA) industries (e.g., Kuman et al., 2005). If the distinction between true choppers and chopper-cores can be applied more rigorously, we would achieve a better understanding of this important type within China's Mode 1 industries.

Returning to the question of the term 'point' in the typology used by some Chinese scholars, we can emphasize here that handaxes and points are very separate types in Acheulean terminology. Acheulean researchers do not ordinarily refer to points until the late ESA, when there are similarities in some regional industries with MSA types and technology and small handaxes may occur (e.g., Porat et al., 2010; Wilkins et al., 2010; Wilkins and Chazan, 2012; Shipton et al., 2013). In the West, points are most characteristic of industries that involve hafting, but more importantly they are technologically distinct from what Chinese researchers call retouched points in their Mode 1 core and flake industries (e.g., in the Zhoukoudian assemblages). In African Acheulean assemblages prior to 1 Ma, small bifaces and crude tools that resemble thick points also occur occasionally, even in the early Acheulean (e.g., at the BK 'Developed Oldowan' site at Olduvai; see Leakey, 1971; Kuman, 2014). The term 'pygmy pick' has even been used by one analyst for such types in the final ESA/early MSA in southern Africa (Cooke, 1966, 1968). This is perhaps the best description for such tools as they are rather thick and unlike the points that characterize the MSA and Middle Palaeolithic, which are shaped on prepared cores and/or by careful retouch.

A second and rather significant source of contention over Chinese material is the division of handaxes into only two shaped categories: unifacial versus bifacial. This has led to descriptions of some LCT assemblages as dominated by unifacial tools (Hou et al., 2000), but as discussed earlier, so are some African Acheulean assemblages. This bi-partite lumping leads to an emphasis on differences rather than any similarities that may exist with Western material. In the African earlier Acheulean (1.7–1.0 Ma), the same broad dual distinction is also typically made by many researchers (e.g., de la Torre et al., 2008). However, we suggest that it is more useful to distinguish three categories of unifacial, partly bifacial, and bifacial shaping, as these sub-types apply equally well to both African and Chinese material. When such a distinction is made for African LCTs, all three categories are present. In some cases, it is evident that re-sharpening is responsible for an increase in the degree of bifacial shaping (e.g., in the BK assemblage at Olduvai; Kuman, 2014; and see Jones, 1994). There is in fact much greater variability present in African Acheulean assemblages than is currently reported in the literature because of this tendency to lump specimens into only two categories.

Methods

In order to quantitatively analyse the location of flaking on the two faces of an LCT, we divide each tool into 12 equal sectors, as shown in Fig. 4. If the blank is a flake, the dorsal face is recorded first. As noted above, primary flaking is defined as large removals that shape the cobble or the flake blank after it has been detached from the core. Secondary flaking consists of small removals or retouch that regularizes or refines a tool edge. With the 12-sector method, the proportion of overall flaking is calculated together for all sectors that have primary and/or secondary scars. The proportion of secondary flaking is also tallied separately to document the degree of attention paid to refining the edges of a piece. The sector method is then used to classify LCTs into the three types of bifacial, unifacial, and partly bifacial: 1) a bifacial piece has flaking in half or

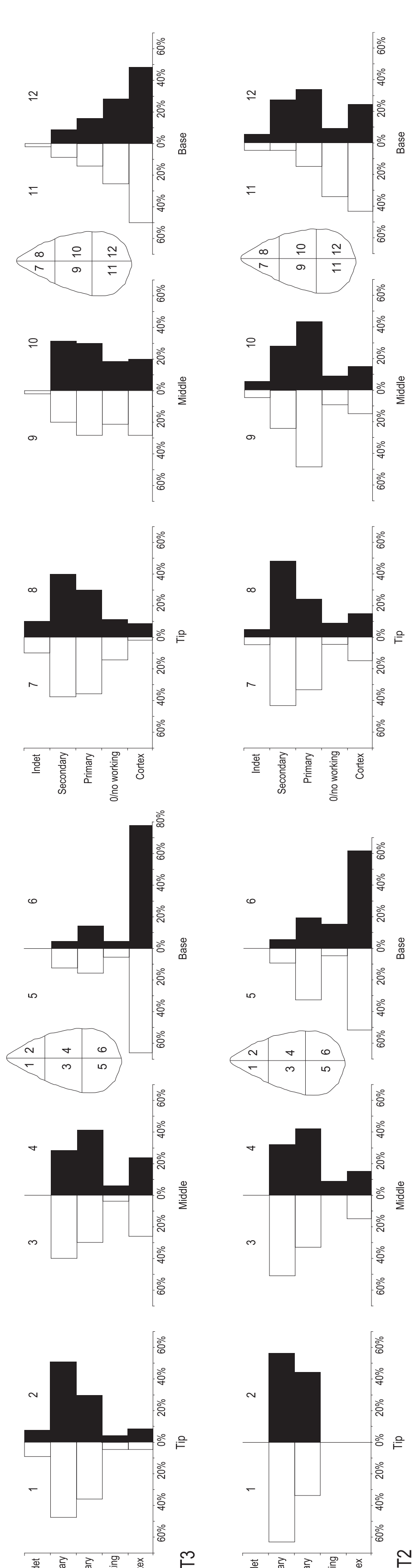

Figure 4. Method for recording the percentages of flaking by sector for LCTs over two faces, with results. The tool is divided along its long axis into distal, medial and proximal sectors of equal length. Primary flaking scars are used to shape a cobble or a flake blank. Secondary scars indicate fine flaking or retouch used to regularize or refine an edge. Indet means that scars on that surface could not be reliably interpreted and are thus indeterminate. The lack of working and cortex are also recorded in the figure.

more of the sectors for both faces; 2) a unifacial piece has flaking either on one face only or on one face plus one of the six sectors on the opposite face; 3) a partly bifacial piece must have scars in two to three sectors of the lesser worked face (i.e., between 16.6% and 50.0% of the second face). Both primary and secondary scars are used for these calculations. A visual record of the location of flaking is provided (Fig. 4), so that location of cortex and areas of working on tools can be compared. While the sector method is not as precise as 3D scanning to calculate the shaping coverage for an LCT, it is easy to assess as a graph and provides a good summary of the degree of shaping. It can then be translated into sub-types and correlated with blank types and raw materials. We believe this approach will provide a more informed basis for comparative evaluation, which can be supplemented with experiments on local raw materials, as replications always provide superior insight into technology.

Various statistical tests are used in this study to support our interpretations. The student's *t*-test is used to check for significant differences in tool attributes that may relate to time, tool types, blank types, and shaping. Principal component analysis (PCA) and regression analysis have been used to identify the most significant sources of variability in handaxe attributes for both the East Asian and Western assemblages.

Results and preliminary discussion

Raw materials and flaking methods

The DRR handaxes, cleavers and picks are classified in Table 1 and pictured in Figs. 5–9. The majority of LCTs in our sample is made on quartz phyllite (discussed below): 80.0% in T3 and 56.3% in T2 (Table 1). For handaxes alone, the figures are even higher: 86% for T3 and 62% for T2. A student's *t* test (Table 2) shows that there are no statistically significant differences in the various measurements and indices between handaxes in T2 and T3 as the *p*-value (two tail) is >0.05 in all cases. Three of the five cleavers collected from both terraces are also made on quartz phyllite, as well as 91% of picks in T3 and 60% in T2.

There is clear raw material selectivity for LCTS, as the excavated assemblages published for T3 show a much greater variety of raw materials in their overall assemblages. At Guochachang II with four LCTs, quartz comprises 79% of the lithics, with the remainder in sandstone and quartz phyllite (Li et al., 2013). At Pengjiahe, there are eight raw materials, with quartzite, igneous rock and sandstone comprising 83% of the assemblage (Pei et al., 2008). Pengjiahe has two handaxes from surface collections and none listed from the excavation. However, there are eight excavated picks published, and personal observation (H. Li) suggests there is at least one handaxe in the Western sense in the assemblage. At Beitaishanmiao, 56% of the lithics are in quartzite (Zhou et al., 2009). There are seven picks and three points from the excavation, but at least two of these appear to be a handaxe. At the Shuiniuwa site, one diorite handaxe was excavated in a small assemblage of 55 artefacts dominated by quartz and some hornfels (Chen et al., 2014).

Phyllite is a metamorphic rock that belongs to the schist family (Pellant, 1992). It is formed through the metamorphism of rocks such as slates and mudstones and is characterized by a foliated structure due to the preferred orientation of mica within the rock (Farndon, 2006; Marshak, 2013). More specifically, the DRR material is quartz phyllite, with quartz arranged in a preferred orientation with the metacrystal texture and micro sericite micas having a phyllitic (leafy) structure that is distributed in the rock unevenly (description provided by the Sichuan Province Bureau of Geology and Mineral Exploration and Development-Huayang Testing

Table 1
Raw material proportions for LCTs in the DRR by terrace. Only one tool was collected from T4 at the site of the Yunxian hominid discoveries. Rocks that could not be confirmed as trachyte have been listed as 'other igneous rocks'.

	T2 Han River	Quartz phyllite	Trachyte	Other igneous rocks	Chert	Quartzite	Indet	*N*
Handaxes		6	1	3	1	0	1	12
Pick-like handaxes		1	0	0	0	0	0	1
Picks		2	0	0	0	0	0	2
Broken LCTs		0	0	2	0	0	0	2
Cleavers		1	0	0	0	0	0	1
Unifacial cobble picks		0	0	0	0	0	0	0
Subtotal		*10*	*1*	*5*	*1*	*0*	*1*	*18*
	T2 Dan River							
Handaxes		7	0	0	2	0	0	9
Pick-like handaxes		0	0	2	0	0	0	2
Picks		4	0	2	0	2	0	8
Broken LCTs		0	0	0	0	0	0	0
Cleavers		1	0	0	0	0	0	1
Unifacial cobble picks		0	0	0	0	1	0	1
Subtotal		*12*	*0*	*4*	*2*	*3*	*0*	*21*
Total		22 (56.3%)	1 (2.6%)	9 (23.1%)	3 (7.7%)	3 (7.7%)	1 (2.6%)	39
	T3 Han River	quartz phyllite	trachyte	other igneous rocks	chert	quartzite	indet	N
Handaxes		44	1	4	0	0	2	51
Pick-like handaxes		1	0	0	0	0	0	1
Picks		10	1	0	0	0	0	11
Broken LCTs		0	0	0	0	0	0	0
Cleavers		1	1	0	0	0	1	3
Unifacial cobble picks		7	1	4	0	1	0	13
Notched pick with two points		1	0	0	0	0	0	1
Total		64 (80.0%)	4 (5.0%)	8 (10.0%)	0	1 (1.3%)	3 (3.8%)	80
	T4 Han River							
Unifacial cobble pick		1						1
Total								120

Center). As the metamorphosis of phyllite occurs at temperatures high enough to cause recrystallization of the mica (Marshak, 2013), the latter grows into plates with a preferred orientation that impart the foliated structure (Farndon, 2006). Rocks with a foliated structure make flaking properties more challenging for toolmakers compared with more highly metamorphosed or homogeneous textures. The foliated structure of many of the DRR rocks is clearly visible in Figs. 7.4,6, 8.2 and 9.1). However, these properties also made the splitting of cobbles and bipolar flaking a convenient method for creating LCT blanks (e.g., Figs. 5.6 and 7.6). All lithic material was sourced from gravels as cobbles that are well rolled and smooth. They commonly exhibit flat or oval shapes (clearly visible in the Figures), which assist with bipolar splitting and flaking. Longitudinal splitting or bipolar flaking of such cobbles is best done along the long axis, which is in line with the planes of weakness that created the elongated cobble shapes during the original weathering and fragmentation process from rock outcrops. Table 3a shows that 32% of the handaxe blanks in both terraces are made on pieces that have been split or bipolar-flaked, and 36% are made on whole cobbles. Table 3b compares handaxes made on cobbles versus flakes and shows that the only significant difference lies in the thickness.

For all LCTs made on flakes (both freehand and bipolar-struck flakes), 60% are end-struck, with the impact point or bulb in line with the long axis. Thirty percent are corner-struck, with the bulb slightly angled in relation to the long axis, which is a technique closer to end-struck flaking than to side-struck. Only two LCTs could be read as side-struck, and these were both made on igneous rocks. These flaking characteristics of the DRR LCTs are clearly influenced by the properties of the quartz phyllite and trachyte that were used.

Another marked characteristic of the DRR material is the large number of handaxes with very thin distals, suggesting that cutting functions were a prominent subsistence activity in the collection. In T2, 57.1% of 21 handaxes have markedly thin distals (mean tip angle 37.1°, versus 45.6° for the other handaxes), and all are made on quartz phyllite. In T3, 58.8% of the 51 handaxes have thin distals (mean tip angle 33.0°, versus 41.8° for the other handaxes), and all but three are made on quartz phyllite. The suitability of the phyllite to create blanks for cutting functions is reflected in the high proportion of split cobbles and bipolar flakes for handaxes in the 'thin-distal group': 59% for T2, and 29% for T3.

Shaping

Of the 72 handaxes in the collection, we were able to record shaping data for all 12 sectors on 62 specimens (Table 4). The T2 handaxe types are calculated as 63.2% bifacial, 26.3% partly bifacial, and 10.5% unifacial. Even if the partly bifacial and unifacial handaxes are grouped together, the great majority is still bifacial for T2. For the larger and older T3 sample, the majority (67.4%) of handaxes is partly bifacial, with bifacial at 18.6% and unifacial at 14.0%. For a later sample of 36 handaxes collected in 2004 (Li et al., 2014b), the pattern for T3 is similar, with a majority of pieces being partly bifacial and a small minority unifacial. This suggests there is consistency for T3 in the minor occurrence of unifacial flaking when this more rigorous method of shaping analysis is applied.

Figures for the amount of secondary flaking (Table 5) show that limited attention is paid to finer flaking of edges: 31% coverage for the combined sample, compared with 58% coverage for the overall flaking of handaxes (i.e., secondary and primary scars combined). Such an observation can be useful for future comparative studies between Chinese handaxes and the Acheulean. For example, McNabb's (2009) analysis of later Acheulean LCTs from Cave of Hearths in South Africa (ca. 0.45 Ma) concludes that 57% have extensive marginal trimming, even though the LCTs are not highly

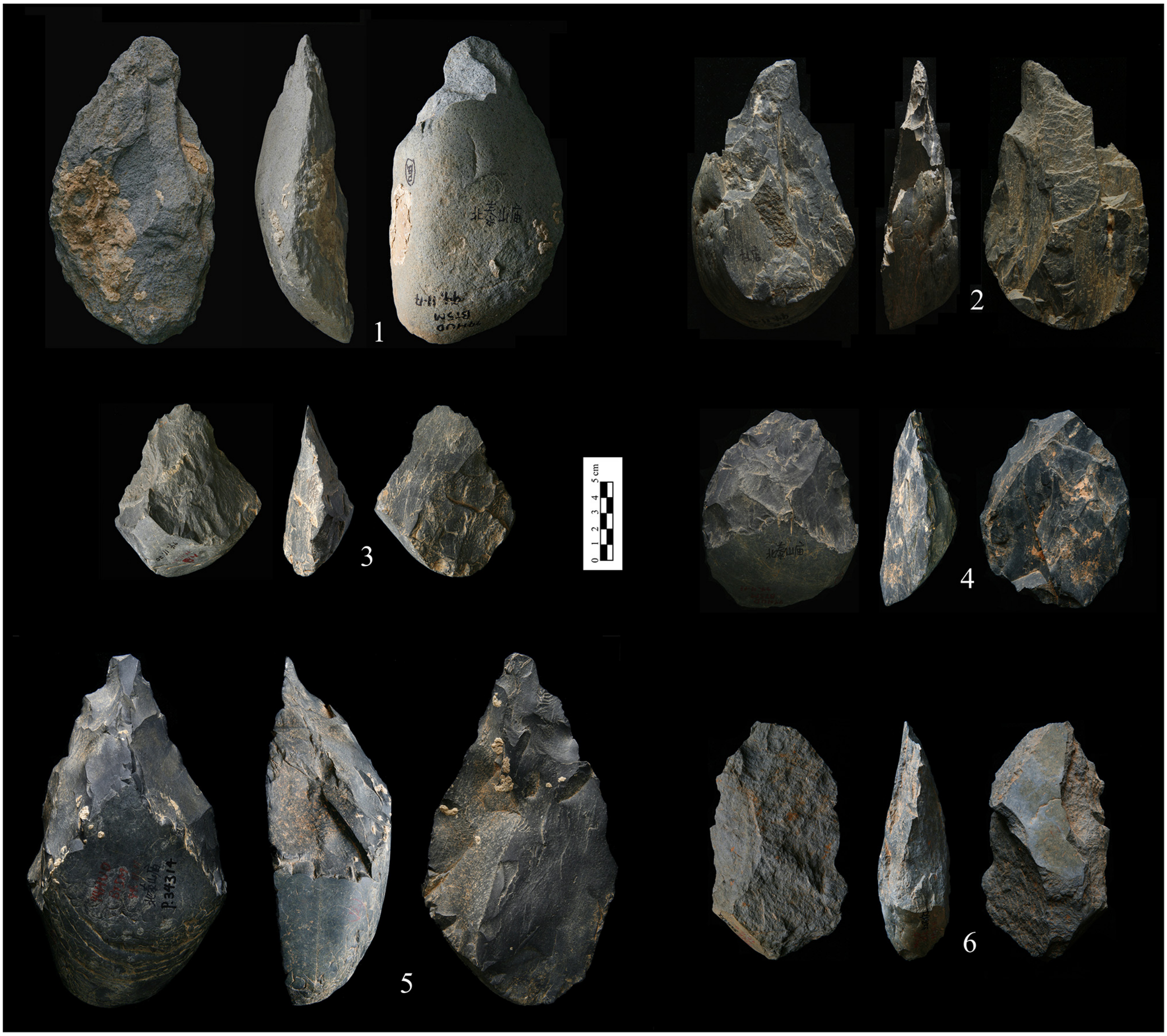

Figure 5. DRR handaxes from Terrace 3. No. 1 is on an igneous side-struck flake. Nos. 2–6 are on quartz phyllite. The distal end of No. 6 is broken.

standardized and show a 'least effort' approach to shaping. However, secondary flaking must be studied in conjunction with an understanding of the local raw materials, as it is well known that some materials hold a working edge better than others that require more maintenance to be sharp. Handaxe functions may also be related. Fig. 4 shows that the location of secondary flaking is relatively more prominent on distal portions, which is to be expected. It also shows that cortex is most frequently preserved on the base of LCTs, which is also not surprising.

Descriptive data, indices, and statistical analysis

As complete data sets are more useful for future comparisons than summary data, we provide the weights, measurements and indices for all specimens in Appendix B and a summary in Table 6. For the mean weights of LCTs, the most interesting result is for T3, where the large number of unifacial cobble picks (UCP) can be compared with the handaxes: handaxes have a mean weight of 929.07 g (median 844 g), while the mean weight for UCPs is more than double at 1948.62 g (median 2022 g). Although the handaxe sample is larger, the standard deviation for UCP weights is also much greater, suggesting that handaxes were more subject to weight constraints. The morphological and shaping differences between the two types must reflect some very significant functional differences. The mean working angle of the functional end for T3 UCPs is 50.5° (range 33°–79°; median 48°), and for the single specimen in T2 it is 52.0°. For handaxes, the mean angle is more acute (36.1° for T3 and 40.5° for T2). Ordinary picks have a mean that is intermediate between UCPs and handaxes (46.6° for T2 and 46.7° for T3). Table 7 shows that UCPs are statistically different in most measurements and indices with handaxes and ordinary picks.

It is remarkable that the mean length for T3 UCPs is not distinct from the other types (Table 6), which probably reflects the available raw material sizes. However, they do show greater thickness, width and weight, which suggest the need for a heavy duty tool, presumably with the distal end used in a chopper-like action. These picks appear to have more in common functionally with the notion of the classic Asian chopper than they have with other DRR LCTs, and where they occur in numbers they give the assemblages a distinct local character that differs with Western Acheulean industries.

Figure 6. DRR handaxes from Terrace 3. Nos. 1 and 4–6 are on quartz phyllite. No. 2 is on an end-struck flake in trachyte. No. 3 is made on an igneous cobble.

Fig. 10 provides a Principal Component Analysis (PCA) of length, width and thickness for the Chinese and Korean handaxes. It shows that the first principal component (PC 1, 56.8% of variance explained) does not separate the different assemblages very well, while the loading vectors on PC 1 indicate that handaxes with large thickness tend to have large length and width. However, the second principal component (PC 2, 27.5% of variance explained) easily distinguishes the Bose assemblage from the two DRR assemblages. The large proportion of negative values for the two DRR assemblages along PC 2 reflects decreased thickness and increased length when compared with the Bose assemblages.

Fig. 11 provides the same analysis for Acheulean handaxes from Western Europe and Africa. Regardless of distance or time, these Acheulean examples are less variable. There may be a few reasons to explain this fact: 1) demography: larger population sizes in the original Acheulean societies creating more social cohesion or less cultural drift; 2) function: a subsistence ecology based on savannah grassland resources; and 3) the simple fact that the great majority of these handaxes is made on flake blanks. The greater Chinese assemblage variability may well be linked to smaller population sizes, more varied subsistence ecologies, and larger numbers of handaxes made on cobbles. The correlation of greater thickness with greater length and width is also exemplified by the Doornlaagte Acheulean handaxes from South Africa. The PCA results correspond well with the descriptive data in Table 8. Although the Asian handaxes are characterized by larger average weights, there were not enough raw data to include this variable in Figs. 10 and 11.

Two particular indices have been used for comparison of LCTs from Asia with those in the West (Norton et al., 2006; Petraglia and Shipton, 2008; Norton and Bae, 2009; Shipton and Petraglia, 2010).

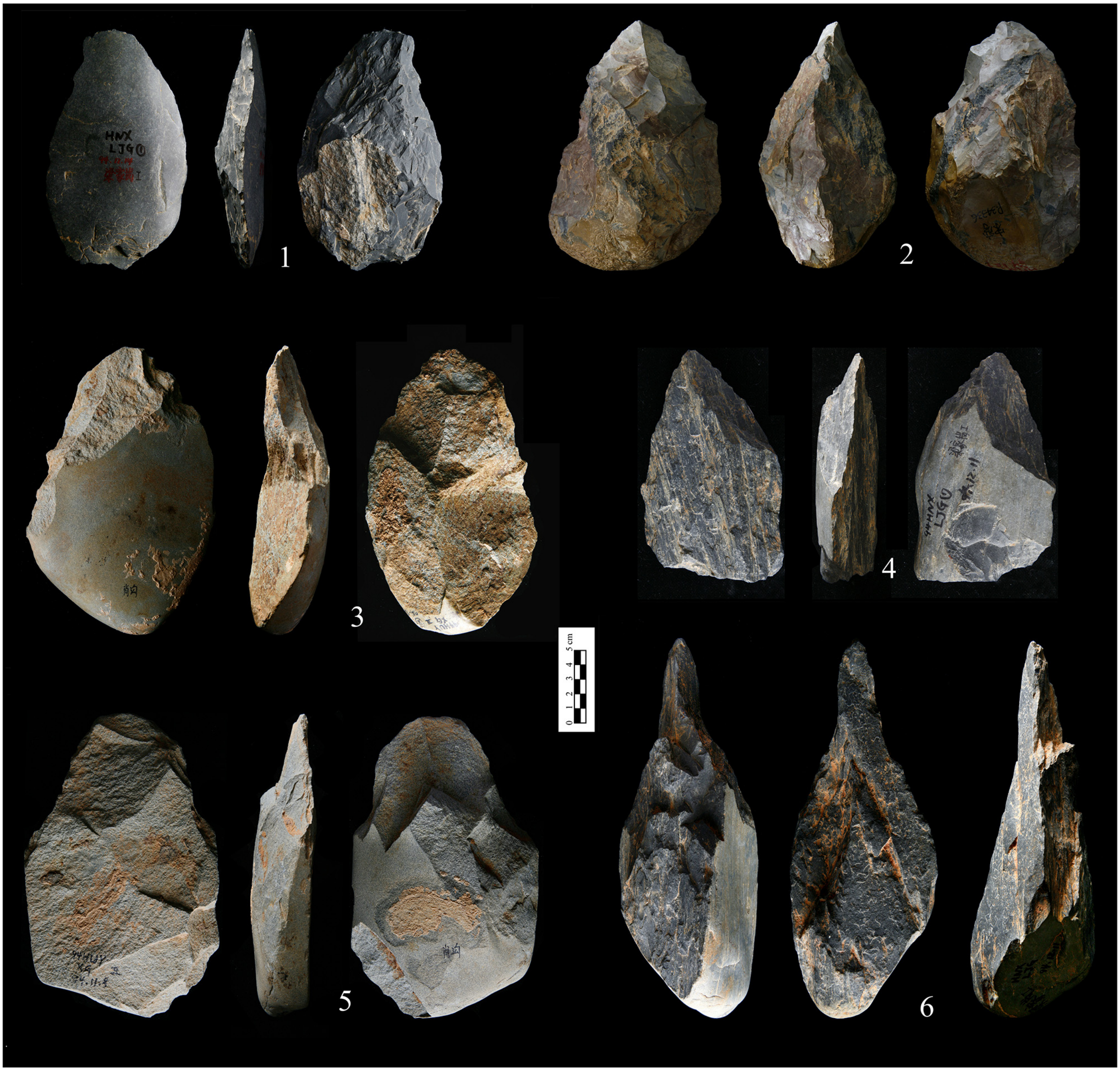

Figure 7. DRR handaxes and a pick, Terrace 2. Nos. 1 and 4 are handaxes on quartz phyllite. No. 2 is a handaxe made on a chert cobble. No. 3 is a handaxe with distal damage made on an igneous cobble. No. 5 is a handaxe made on a split cobble of trachyte. No. 6 is a pick on a split cobble of quartz phyllite.

First is the Elongation Index of Length/Width (or L/W). Although handaxe shapes have been studied extensively (Kleindienst, 1962; Roe, 1968, 1994, 2001), elongation has been challenged in terms of its comparative value. Jones (1994) documents experimentally that elongated handaxes are more at risk of breaking with end-shock during flaking, while McPherron (2000) argues that the main determinant of handaxe shape is reduction intensity, with length reducing faster than width with continued re-sharpening. The latter point is well illustrated by Fig. 8.4, a T2 handaxe that was rejuvenated and conjoins with its original distal portion; note that its L/W index shifts from 2.13 to 1.82 in the process (Appendix B). Nevertheless, this index is still widely used as a useful indicator of shape differences. The T2 handaxes show a mean L/W index of 1.66 versus 1.73 for the T3 index average (Table 6), with no statistically significant difference between these two values (Table 2). In comparison with published values for Acheulean handaxes (Table 8), DRR shows a similarity to the African means of 1.62 and 1.72 for a range of raw materials, but smaller values pertain to a European sample dominated by flint and chert. Compared with the available figures for East Asian examples also presented in Table 8, the DRR sample is somewhat more elongated, which may reflect the dominance of elongated oval cobble shapes.

The Refinement Index of Thickness/Width (or T/W; Table 8) may be more useful, as lower values suggest the use of thinner blanks and/or more invasive shaping of the body. The scatterplot in Fig. 12 shows that thickness and the Refinement Index are highly correlated for handaxes from DRR, Bose and Korea. For T2, this index is 0.50 and for T3 it is 0.46 (although the difference is not statistically significant, Table 2). However, these means are lower than the values for the other East Asian samples (Table 8), and they also compare well with the lowest values for the Acheulean samples shown in Table 8. They may well be explained by a dominance of

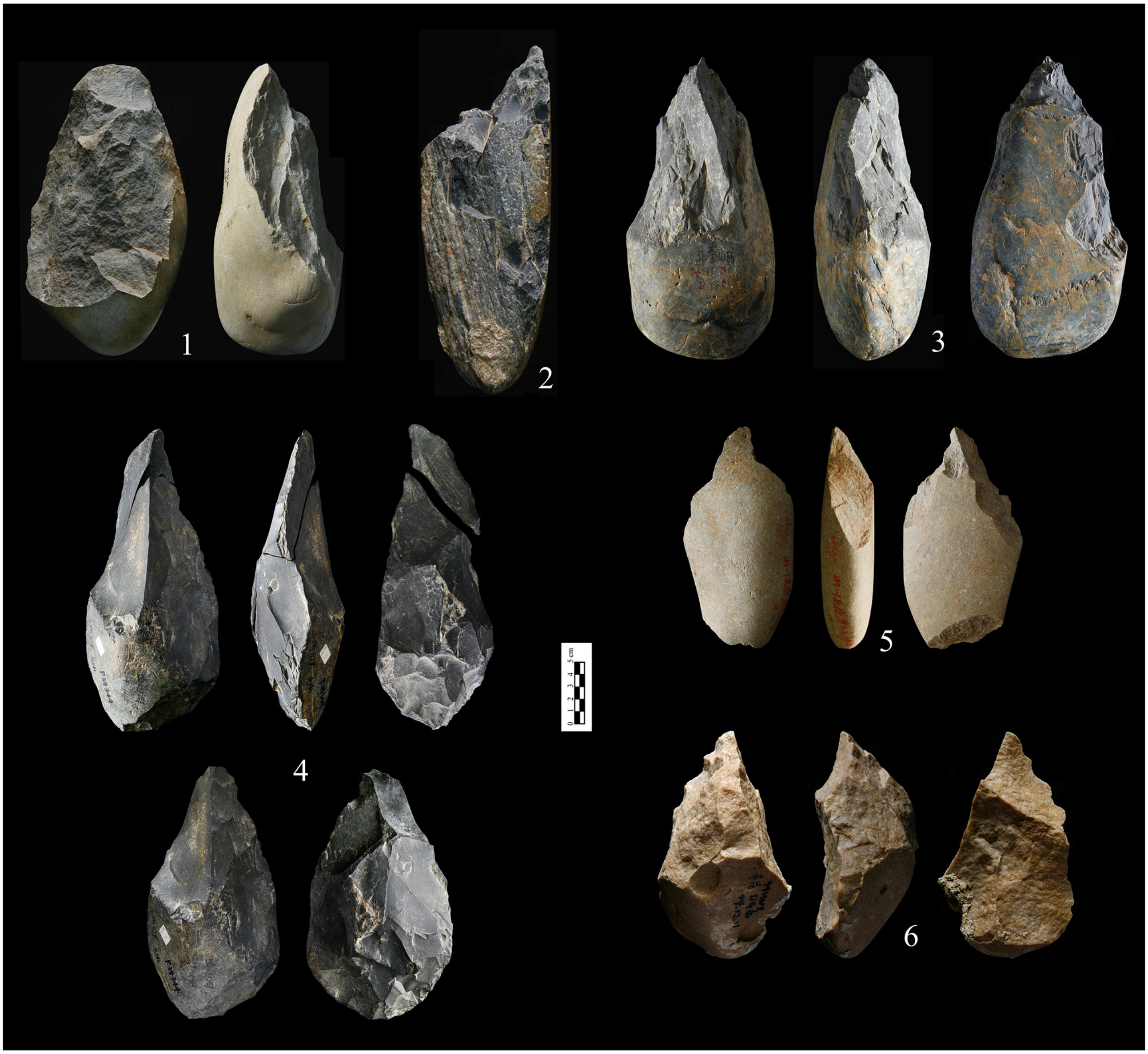

Figure 8. DRR picks and handaxe from Terraces 2 and 3. Nos. 1–2 are both unifacial cobble picks from Terrace 3, with No. 1 made on an igneous cobble and No. 2 made on a quartz phyllite cobble. No. 3 is a pick from Terrace 3 made on a quartz phyllite cobble. No. 4 is an elongated handaxe from Terrace 2 (upper images) made on a quartz phyllite flake, which was subsequently rejuvenated with a distal removal, resulting in the shorter ovate handaxe in the lower images. Nos. 5–6 are picks from Terrace 2 made on an igneous cobble and a thick quartzite flake, respectively.

blanks that were made on flat cobbles, split cobbles, and flakes (both freehand and bipolar percussed). Overall these comparisons suggest that the Refinement Index may be helpful for comparisons only if it is applied with consideration of raw material shape and properties. When Thickness is considered on its own, it is interesting that both the African earlier and younger Acheulean samples are similar (44.20 mm and 44.31 mm, respectively), which probably reflects the dominance of handaxes made on flake blanks irrespective of time. The mean thickness for Indian handaxes is only slightly higher at 45.14 mm. The DRR thickness values appear most different to the other East Asian values. Once again, this fact is probably reflecting the raw material properties more than any other factor. Even internally, a difference is apparent for the T2 handaxes, which are thicker than T3. While the difference is not statistically significant (Table 2), this attribute probably relates to the T2 handaxes being made on a greater variety of raw materials than those in T3, where 86.3% are made on quartz phyllite (see Table 1).

Raw materials and ecological considerations for the Chinese handaxe regions

South China: In the Bose Basin, 114 sites are reported for T4 of the Youjiang River, where fresh tektites date the deposits to 0.803 Ma (Hou et al., 2000; Huang et al., 2003; Wang et al., 2008; Xu et al., 2012; Wang et al., 2014). In the first publication in English, 84% of the artefacts discussed were from excavated contexts (Hou et al., 2000), and in situ finds have continued to be reported at a number of sites (Lin, 2002; Pei et al., 2007; Xie and Bodin, 2007; Wang et al., 2008; Xie and Lin, 2008). More recently, Wang et al. (2014) provided a history of work in the Bose Basin since 1973 and presented details of five in situ handaxes and 99 from surface

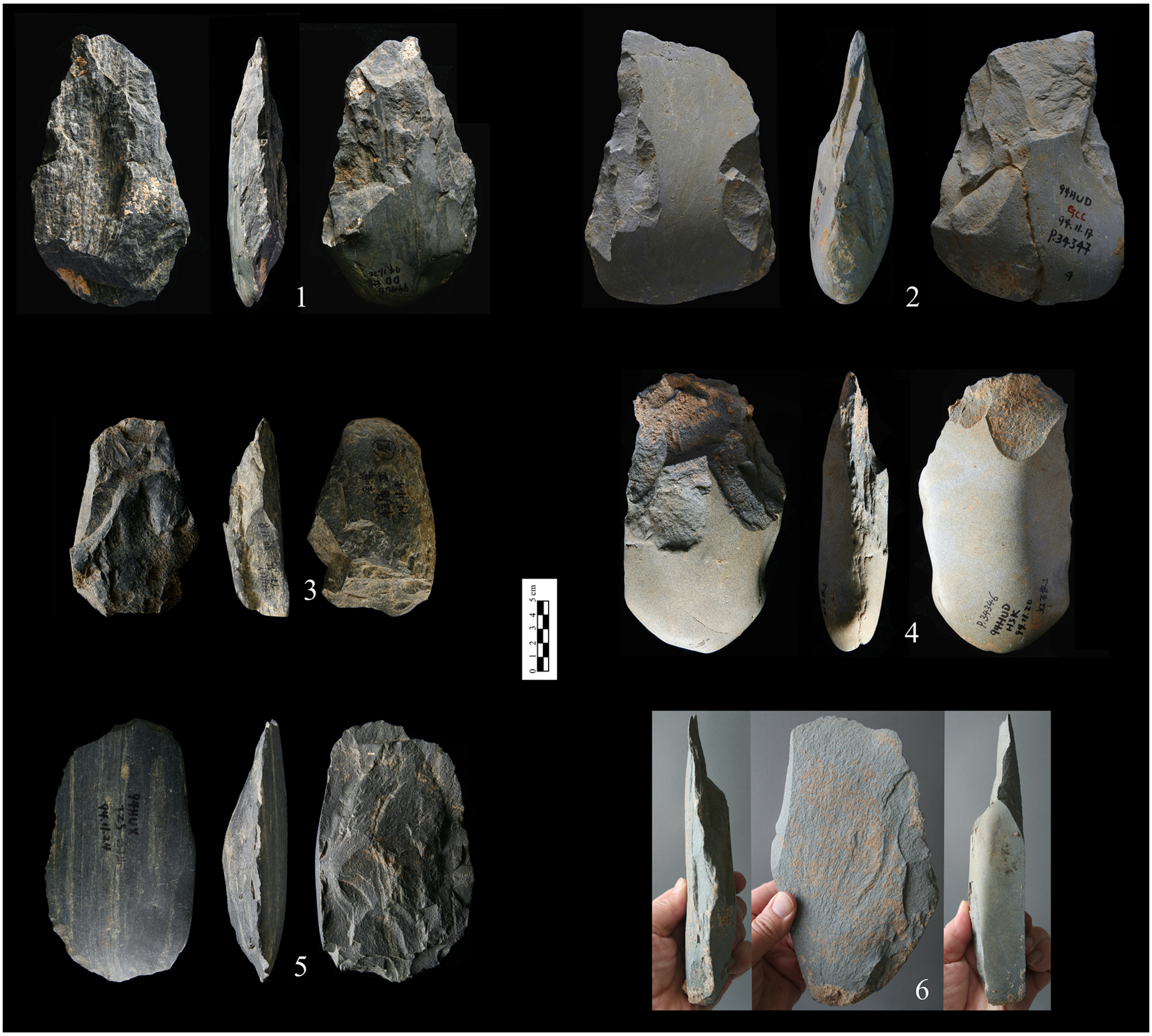

Figure 9. DRR cleavers from Terraces 2 and 3. No. 1 is a cleaver from Terrace 3 made on a corner-struck flake in quartz phyllite. No. 2 is a cleaver from Terrace 3 made on a cobble of trachyte. No. 3 is a cleaver from Terrace 2 made on an end-struck flake of quartz phyllite. No. 4 is an atypical bifacial cleaver from Terrace 3 made on a cobble of trachyte. No. 5 is a cleaver from Terrace 2 made on a side-struck flake of quartz phyllite. No. 6 is from surface collection in 2012 and illustrates how trachyte can be worked to produce an end-struck flake with typical cleaver traits of a wide cutting bit and lateral shaping.

collections. Measurements of LCTs from a number of the Bose sites, mostly as surface finds, have been published by Huang et al. (2001) in a pictorial catalogue that gives a good representation of the morphological variability present. While the Bose research is often criticized as based on a majority of finds that derive from surface collection, years of exploration show that only T4 has been found to contain handaxes in situ and the tektites that date the occurrence to ~0.803 Ma are not re-worked.

Of particular interest at Bose are the various aspects of the raw materials that have been discussed by different authors. Quartzite and sandstone are the rocks predominantly used for LCTs. Zhang et al. (2010) describe the local quartzite as a material that may appear superficially to be homogeneous but which frequently contains inclusions and joints that result in failures during flaking. The authors conclude that such flaws limit the extent to which the quartzite can be worked, resulting in handaxes and other heavy duty tools that are worked more extensively on the distal and medial portions. Of the 129 handaxes they discuss, 57% are made on flake blanks and the remainder on cobbles. Most handaxes are thick, with the average size being 15 × 12 × 7 cm, which is not very different to the other Bose values in Table 8. Secondary retouch is often present on distal and medial edges, and the illustrations suggest that rounded distals may be common. Zhang et al. (2010) did not identify cleavers at Fengshudao, which they suggest is either due to sampling error or to the heterogeneity of the raw material that limits the size of flakes. Wang et al. (2014) also note that thickness values for Bose handaxes tend to be higher when made on cobbles versus flakes, which make up a significant portion of the blanks (39 cobbles versus 65 flakes in their sample).

In a review of the overall technology of 970 artefacts from a number of the T4 sites in the basin, Xie and Bodin (2007) also characterize the raw materials (principally quartzite, sandstone, quartz and siliceous rocks) as of poor quality, with coarse grain sizes and numerous fracture planes. Picks and bifaces (i.e., LCTs) are

Table 2
Student's *t*-test comparing mean weight in grams, measurements in mm, and indices for DRR handaxes from the two terraces. Results show that there are no significant differences between the LCTs from the two terraces.

	N	T2	*N*	T3	*t*-statistic	*p*-value
Weight	21	848.19	45	929.07	−0.841	0.404
Length	19	170.00	44	172.70	−0.304	0.762
Width	21	103.38	51	99.88	0.944	0.348
Thickness	21	51.52	51	45.45	1.452	0.151
T/W	21	0.50	51	0.46	1.112	0.270
L/W	19	1.66	44	1.73	−1.136	0.260

often made on elongated or triangular blocks of raw material, and proximal ends are commonly cortical. As is often done in China, Xie and Bodin (2007) call all unifacial LCTs picks and recognize only the bifaces as handaxes. However, it is notable that they also identify 17 cleavers in the collections, with 65% made on cobbles and 35% on flakes.

Huang et al. (2003) have also published some detailed information for Bose. Handaxes on cobbles are in the majority in their sample. They also discuss the poor quality quartzite and sandstone (coarse-grained and textured) that are used for LCTs. Like Zhang et al. (2010), they consider the knapping and trimming technology to be Acheulean-like, with shallow scars concentrated on the tip. Handaxes are characterized by stepped scars (Huang et al., 2003), which is common for poor raw materials. Modification is simple and cross-sections are relatively thick (Huang et al., 2003). Picks are described as unifacial tools, made mostly on cobbles, with plano-convex or triangular cross sections and are said to be a distinguishing feature of the industry. In general, the cleavers are crudely made, and large, heavy scrapers are another common feature of the industry. Huang et al.'s (2003) conclusion is that the Bose industry is Acheulean, but due to the local environment, it also shows a strong affinity with the Lower Palaeolithic of South and Southeast Asia, where hilly forested landscapes dominate, open grassland is limited, and heavy-duty tools are the dominant cultural signature. Although both Huang et al. (2003) and Zhang et al. (2010) consider the Bose technology to fall within the Acheulean tradition, the greater thickness and weight of many of the LCTs has led others to emphasize its differences, which to them suggest convergent development (e.g., Shipton and Petraglia, 2010; Wang et al., 2012).

A feature often noted for the Bose sites is the tongue-shaped distal portions of many of the LCTs (Huang et al., 2003). In Zhang and Wang's (2010) study, they occur on 38% of the handaxes. Yuan et al. (2008) have used computer simulation experiments to model the stress loads that could be sustained by the more rounded shape of these specimens, concluding that the tools are suitable for splitting and chopping activities. If splitting and chopping were prime functions of these tools, this could suggest that woodworking was one of the more prominent activities, as Huang et al.'s (2003) comments on the environment would imply. Today the region is subtropical, but it borders the tropical monsoon zone and has an annual precipitation of more than 1200 mm (Atlas of China, 2007). During the Middle Pleistocene, South China experienced periods of greater humidity reflected in red clays and vermiculated deposits that are widespread south of the Yangtze River (Yang et al., 1996; Jiang et al., 1997; Yin and Guo, 2006; Yin et al., 2006; Liu et al., 2008; Yuan et al., 2008). These are deeply weathered sediments formed during humid periods of the Pleistocene when conditions were more moist than today (Yin and Guo, 2006). Thus in addition to the constraints imposed by the Bose raw materials, the unique character of the heavy, tongue-shaped Bose LCTs also appears to have a functional link to the prominence of woodlands in regional subsistence ecology. Table 8 shows that the Bose handaxes do indeed show consistently higher values for width and thickness than all of the other Asian handaxe sites for which data are available. The same holds true for handaxe weight, with the exception of one site in India.

Central China: DRR and Luonan are both located in central China (Fig. 1). Lithic raw materials for DRR have already been discussed as cobbles acquired from local river gravels. The DRR lies at the southeastern edge of the Qinling Mountains, an east-west oriented mountain range with an elevation of up to 3000 m. The Qinling Mountains are commonly used to divide North China from central and South China, but elevations east of the Qinling Mountains were low enough that a 'continuous faunal migration corridor' always existed with the North (Norton et al., 2010). The DRR habitat today is subtropical, with evergreen broadleaf forest and with less precipitation than Bose, approximately 900 mm per year, and thus is less humid than the Bose region (Guo et al., 2013), although some red soil development occurred in the mid-Pleistocene (Pei et al., 2008). The earliest tool-bearing deposits of the Han River are T4, ca. 0.8 Ma, where the site of Xuetangliangzi has yielded a large

Table 3
A) Blank types for DRR handaxes. Blanks that are split pieces or bipolar flakes make up 32% of the 72 specimens. B) Student's *t*-test comparing T3-T2 handaxes made on cobbles versus flakes only. The most significant difference is in thickness.

A.	T2 Han River	T2 Dan River	T2 total	T3 Han River	Combined T2–T3	
	Yunxian Basin	Liguanqiao and Xichuan Basins		Junxian Basin		
Blank						
Cobble	4	2	6 (29%)	20 (39%)	26	36%
Split cobble	3	4	7 (33%)	11 (22%)	18	25%
Flake	1	3	4 (19%)	15 (29%)	19	26%
Bipolar flake	2	0	2(10%)	2 (4%)	4	6%
Split tabular piece	1	0	1 (5%)	0	1	1%
Naturally split cobble	0	0	0	2 (4%)	2	3%
Indeterminate	0	0	0	1 (2%)	1	2%
Old artefact	1	0	1 (5%)	0	1	1%
Total	12	9	21 (100%)	51 (100%)	72	100%

B.	N	Cobbles	N	Flakes	*t*-statistic	*p*-value
Weight	24	972.58	18	799.67	1.423	0.163
Length	23	166.22	17	167.18	−0.092	0.927
Width	26	100.54	19	98.21	0.487	0.628
Thickness	26	49.54	19	41.89	2.188	$p < 0.05$
T/W	26	0.50	19	0.43	1.956	0.057
L/W	23	1.67	17	1.71	−0.529	0.600

Table 4
Shaping data for the DRR handaxes. See text for discussion of the formula used. Unifacial pieces either have no flaking on one face or a maximum of flaking in only one sector on the second face. Pieces were excluded if scars were not clearly preserved, even if in only one sector.

	Bifacial	Partly bifacial	Unifacial	N
T2 Han River	9	2	0	11
T2 Dan River	3	3	2	8
	12	5	2	19
Total	63.2%	26.3%	10.5%	100%
T3 Han River	8	29	6	43
Total	18.6%	67.4%	14.0%	100%

assemblage of fauna. The large mammal community corresponds to a wooded environment, with only one species of *Equus* reflecting open habitat (Échassoux et al., 2008). No fauna is preserved in the younger terraces of DRR in this study, but overall the Pleistocene climates of China south of the Qinling Mountains are known to have been relatively warm and wet, stable, and with woodland habitats (Wang, 2005). What is perhaps most interesting for the DRR tools from an ecological perspective is that the LCTs are characterized by some forms that have acute (and often delicate) cutting edges and others that are heavy and robust, such as the unifacial cobble picks, which might be linked to woodworking activities.

The Luonan sites are found in an intermontane basin ca. 70 km long by 30 km wide, with four major terraces of the Luohe River (Wang, 2005). The Luonan Basin lies just north of the Qinling Mountains in the transition zone between the subtropical broadleaf forest of central China and the warm temperate deciduous forest of North China. Annual precipitation today averages 706 mm, and modern habitats consist of a mosaic of grass and re-forested and endemic species (Lu et al., 2011b). Artefacts recovered from the terraces record repeated visits of LCT-using hominids in three periods, by 0.8–0.7 Ma, at 0.4–0.3 Ma, and at 0.2–0.1 Ma (Wang, 2005; Lu et al., 2011a), although most of the open-air LCT-bearing assemblages belong to deposits ca. 0.50–0.25 Ma (Wang and Huang, 2001; Wang, 2005; Lu et al., 2007, 2012). Climates here during the Pleistocene alternated between warmer, more humid periods, when palaeosols formed and pollen profiles record more woody species, and warm temperate to subtropical conditions that were relatively cooler and drier, supporting grassland amenable to human occupations (Xue et al., 1996; Lu et al., 2011b). These cooler periods were mild in the intermontane basins, as the loess deposits record more humid conditions than further north and strong weathering, and overall during the mid-Pleistocene the region was relatively warm and humid (Zhang et al., 2012).

The Luonan Basin deposits that bear LCTs are all open-air and none has yet been found in the local cave sites such as Longyadong, which was occupied by at least 0.35 Ma (Wang, 2005). More than 268 open-air sites have been reported in recent literature and over 13,500 artefacts, including more than 200 LCTs (Lu et al., 2011b). What is remarkable about the Luonan LCTs is their widely acknowledged resemblance to the Acheulean tradition, including an abundance of cleavers (Wang, 2006). In Africa, cleavers are very common in Acheulean open-air sites through time, and they are also found in the handful of later Acheulean cave occupations after ca. 0.6 Ma (Kuman, 2014). The large numbers of cleavers and the technological similarities of the Luonan material with the Acheulean appear to be directly related to the dominant raw materials in the industry, which include some good quality quartzites. As in Africa, good quartzite allows for the production of large flakes and the well-controlled shaping of blanks.

Such a low density of finds for the large area investigated is characteristic of all three of the basins where handaxes are found, and despite differences in excavation methods and the special difficulties of working lateritic deposits in South China, this does seem to be a genuine pattern when compared with Acheulean sites. Table 8 shows that the Luonan handaxes are closest in their metric and weight values and indices to the other East Asian samples. This is interesting given the presence of large numbers of cleavers made in the same technological manner as Acheulean examples. However, no raw material studies are yet published that provide insight into the range of properties of the quartzites used in Luonan. The greater weight and thickness of handaxes compared with the Acheulean samples suggest that the raw materials merit detailed analysis.

Discussion

In the comparison presented in Table 8, African data are organized according to early Acheulean sites (from 1.76 to >1.00 Ma) and subsequent Acheulean from <1 Ma to the Middle Pleistocene. As noted above, means for handaxe thickness and refinement (T/W) in these samples are both similar through time. Perhaps this is due

Table 5
Proportions of flaking coverage for the DRR handaxes. A) Overall flaking coverage calculates flaking in all sectors, whether primary or secondary. B) Secondary flaking coverage calculates only the small scars used to regularise or refine an edge. C) A Student's *t* test shows that there is no statistically significant difference in secondary shaping between the older T3 and younger T2 samples, but the difference in overall shaping is statistically significant.

A. Overall flaking coverage in 12 sectors	T2 Han River	T2 Dan River	Combined T2	T3 Han River	Combined T2 and T3
Mean	0.69	0.64	0.67	0.54	0.58
SD	0.13	0.24	0.18	0.22	0.21
Range	0.33 to 0.83	0.25 to 1.00	0.25 to 1.00	0.00 to 0.83	0.00 to 1.00
	***N* = 11**	***N* = 8**		***N* = 43**	
B. Secondary flaking coverage in 12 sectors	**T2 Han River**	**T2 Dan River**	**Combined T2**	**T3 Han River**	**Combined T2 and T3**
Mean	0.37	0.26	0.32	0.3	0.31
SD	0.16	0.2	0.18	0.15	0.16
Range	0.17 to 0.67	0.00 to 0.50	0.00 to 0.67	0.00 to 0.67	0.00 to 0.67
	***N* = 11**	***N* = 8**		***N* = 43**	

C. Comparison of flaking coverage by terrace	Combined T2 ($N = 19$)	T3 ($N = 43$)	*t*-statistic	*p*-value
Overall shaping	0.67	0.54	2.151	$p < 0.05$
Secondary shaping	0.32	0.30	0.621	0.537

Table 6
Weights and measurements for DRR LCTs, with indices for elongation (L/W) and refinement (T/W).

Terrace 2	N	Weight			Length			Width			Thickness			L/W			T/W		
		Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Handaxes	21 (19L)	848.19	284.45	830.00	170.00	34.76	167.00	103.38	13.53	101.00	51.52	25.15	47.00	1.66	0.25	1.62	0.50	0.23	0.44
Pick-like handaxes	3	1560.67	1021.96	1226.00	200.00	49.69	205.00	114.67	36.20	104.00	57.00	19.08	54.70	1.77	0.19	1.74	0.50	0.06	51.00
Picks	10	966.00	431.85	852.00	167.60	28.18	168.50	93.60	21.21	88.00	54.70	15.55	53.00	1.84	0.38	1.77	0.59	0.16	0.61
Unifacial cobble picks	1	1182.00			154.00			116.00			70.00			1.33			0.60		
Cleavers	2	641.00	287.09	641.00	152.50	31.82	152.50	94.50	12.02	94.50	37.00	4.24	37.00	1.60	0.13	1.60	0.39	0.01	0.39
Broken LCTs	2																		
Total	**39**																		
Terrace 3	N	Weight			Length			Width			Thickness			L/W			T/W		
		Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Handaxes	51 (45W, 44L)	929.07	394.81	844.00	172.70	31.31	174.50	99.88	14.59	101.00	45.45	10.53	45.00	1.73	0.23	1.76	0.46	0.10	0.45
Pick-like handaxes	1	826.00			155.00			98.00			41.00			1.58			0.42		
Picks	11	1107.46	486.97	914.00	189.45	35.81	182.00	96.18	16.84	93.00	51.45	15.64	56.00	2.01	0.41	2.05	0.53	0.13	0.53
Unifacial cobble picks	13 (11L)	1948.62	926.18	2022.00	180.18	34.71	185.00	115.08	18.32	115.00	75.00	19.04	80.00	1.65	0.30	1.61	0.65	0.11	0.69
Cleavers	3	1104.00	258.33	1144.00	188.33	6.66	190.00	112.33	12.66	110.00	48.00	9.00	48.00	1.69	0.23	1.76	0.43	0.06	0.45
Notched Pick	1	678.00			126.00			95.00			36.00			1.33			0.38		
Total	**80**																		
Terrace 4	N	Weight			Length			Width			Thickness			L/W			T/W		
Unifacial cobble pick	1	2128			196			119			78			1.65			0.66		

Table 7
Student's *t* test results for the three main LCT types found in Terrace 3. The unifacial cobble pick (UCP) shows statistically significant differences in most variables with both handaxes and ordinary picks. Handaxes and ordinary picks, however, are only statistically different in the Refinement Index. $N = 51$ handaxes (45We, 44L, 51W, 51T); $N = 11$ picks; $N = 13$ UCP (11L).

	Handaxe versus UCP		Pick versus UCP		Handaxe versus pick	
	t-statistic	*p*-value	*t*-statistic	*p*-value	*t*-statistic	*p*-value
Weight	−3.869	$p < 0.05$	−2.843	$p < 0.05$	−1.283	0.205
Length	−0.694	0.491	0.617	0.544	−1.543	0.129
Width	−3.179	$p < 0.05$	−2.611	$p < 0.05$	0.743	0.461
Thickness	−5.388	$p < 0.05$	−3.269	$p < 0.05$	−1.215	0.248
T/W	−6.067	$p < 0.05$	−2.477	$p < 0.05$	−2.064	$p < 0.05$
L/W	0.977	0.333	2.309	$p < 0.05$	−2.133	0.054

not only to the dominance of flakes as blanks, but also to the large sample of sites. The West European handaxes are, overall, a younger sample than the African examples as all belong to the later Acheulean. Their smaller thickness and refinement values also reflect raw materials that are dominated by flint and chert, some of the best quality rocks to flake. The thickness and refinement values for Indian handaxes are quite close to those in Africa, and it is widely accepted that these industries belong to the Acheulean. Although the average weight of handaxes is higher, the majority of assemblage weights falls within the Acheulean range. For the East Asian data, we call attention to the fact that DRR handaxes in T3 are also close to the African and Indian mean thicknesses, while T/W for both T3 and T2 are small and unlike the other East Asian examples. Only 36% of the DRR LCTs are made directly on cobbles (Table 3a), and the remainder are made on flakes or split pieces.

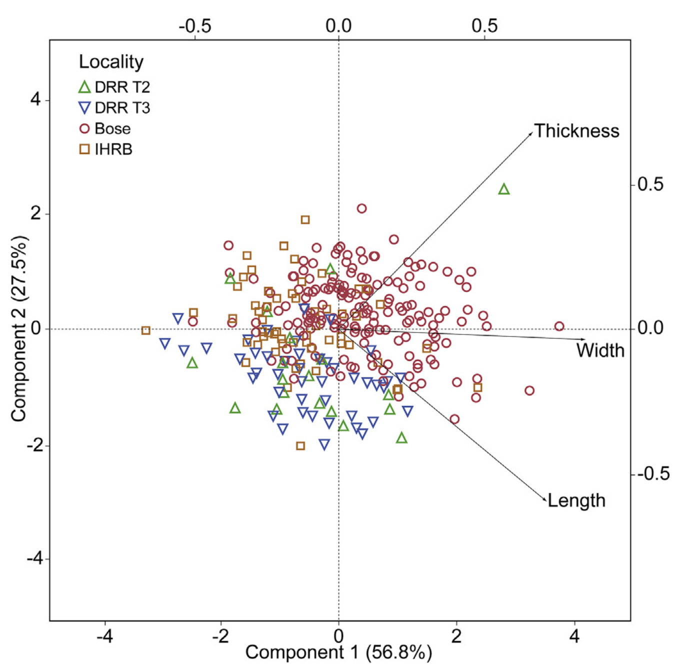

Figure 10. Principal Component Analysis for East Asian handaxe assemblages where individual weights and measurements are available. The first two components make maximum contributions to the variance (84.3%). The loading vector for PC1 places approximately equal weight on the thickness (0.52), length (0.55) and width (0.65), which indicates that handaxes with large thickness tend to have large length and width. The loading vector for PC2 places most of its weight on thickness (0.75) and length (−0.66), with much less weight on width (−0.04). Hence, PC 2 roughly corresponds to the value of thickness and length. Specifically, Bose handaxes, which have prominent positive scores on the second component, are generally thicker than the DRR handaxes (negative scores).

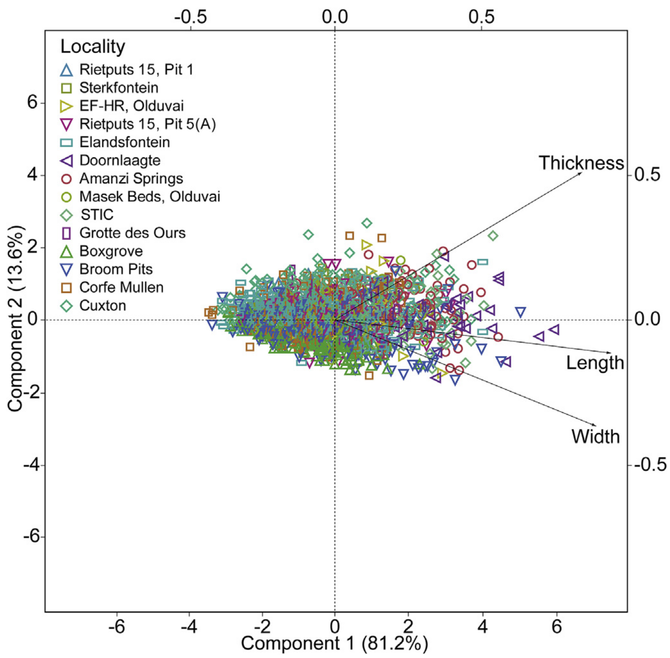

Figure 11. Principal Component Analysis for all Western Acheulean assemblages where raw data were available, showing the principal component scores and the principal component loading vectors. The first two components make maximum contributions to the variance (94.8%). The loading vector for PC1 places approximately equal weight on the thickness (0.55), length (0.61) and width (0.58), which indicates that handaxes with large thickness tend to have large length and width. Specificallly, the site of Doornlaagte has prominent positive scores on the first component, which indicates that these handaxes are generally thicker, longer and wider than those from other sites. The loading vector for PC2 places most of its weight on thickness (0.80) and width (−0.57), with much less weight on length (−0.18). Hence, PC2 roughly corresponds to the value of thickness and width. Overall, most of the Western Acheulean sites are close to zero on both components, which indicates they have approximately average levels of thickness, length and width.

Quartz phyllite dominates the LCTs in both terraces (Table 1), and it is available as flat cobbles that are easy to split and flake with bipolar technique. The overlap of the DRR handaxes with some Acheulean samples thus demonstrates the importance of evaluating the specifics of raw material properties when using morphometric data for comparative purposes.

Making sense of the LCT industries of China in a global context requires a methodology that focuses on technology as much as morphology to reveal more readily the commonalities with Western industries. Raw materials, local ecologies, and the great distances involved are all bound to create important differences in the appearance of Eastern industries. However, as Bar-Yosef and Wang (2012) and Bar-Yosef and Belfer-Cohen (2013) point out, a group's technological tradition, which has long-lasting imprints over numerous generations, is the best means of detecting the cultural markers or 'road signs' of dispersal across Eurasia.

If we apply this perspective to the three major regions in China with early LCT sites, we can see their commonalities. All show the first signs of hominid occupation at about 0.8 Ma, with occupation at DRR and Luonan continuing through time, probably into the Late Pleistocene. Although most developed in South China, woodland habitats were prominent in all three regions during periods of the Pleistocene. Woodlands oscillated with more open conditions in central China, but even glacial periods there were mild and relatively humid, with woodlands persisting to a significant extent. For the Bose Basin, the most wooded environment, subsistence ecology and the poor quality of raw materials can explain the morphology of LCTs that are often heavy, thicker, and with tongue-shaped distals, suggestive of chopping functions. For DRR, some LCTs also suggest heavy-duty activities during the more humid T3 period (e.g., the 13 unifacial cobble picks in T3), but other pieces also suggest that more delicate cutting or knife-like functions were prominent. Certainly the DRR raw materials were mostly of poor quality and put many constraints on the technology that was employed; bipolar splitting of quartz phyllite is frequent and end-struck flakes are more common than side-struck, in contrast with African Acheulean handaxes that are more often made on large side-struck flakes in lavas and quartzites. However, a flaking pattern typical of Acheulean handaxes and cleavers can be argued for the DRR LCTs: handaxes have convergent distals with shaped bodies that employ both primary and secondary flaking, and cleavers possess large working bits and are often shaped by lateral flaking. In contrast with Bose and DRR, the Luonan LCTs are more obviously Acheulean in appearance, which is evident in published figures (Wang, 2005, 2006, 2007b). This is arguably due to the use of quartzite capable of producing large flakes, but the relatively more open habitat may also have influenced the need for this type. In Africa after ca. 0.6 Ma, later Acheulean industries contain LCTs that are in general more well-made than typical examples from the early Acheulean (Roe, 1994; Klein, 2000; Kuman, 2014), although a 'least effort' approach to shaping and significant variability are also characteristic of the later Acheulean (e.g., McNabb et al., 2004). In northern China, the Dingcun and Sanmenxia sites have some examples of fine working, and Dingcun has been argued to be late Acheulean in technological skills (Yang et al., 2014).

Not discussed in this paper are the numerous and widespread Middle Pleistocene sites across China that lack LCTs, some of which have very large assemblages of small tools, fairly sophisticated in their own right (e.g., Zhoukoudian in the North and Longyadong in the Luonan region). Fossils of *Homo erectus* are particularly well known from the Mode 1 site of Zhoukoudian. At the Middle Pleistocene cave site of Longyadong dated from 0.5 to 0.25 Ma (Wang and Huang, 2001; Wang, 2005), a Mode 1 industry co-exists broadly in time with Mode 2 open-air sites in the same region. Although Wang (2005) considers these co-existing assemblages may be due to activity differences, it is unlikely that the very rich collection of artefacts at Longyadong ($N = 18{,}608$) would lack LCTs all together if they were made by the same population.

There are only two sites where hominid fossils are associated with an LCT industry in China. The late Middle Pleistocene site of Dingcun yielded three teeth that were published by Pei et al. (1958) as being more advanced than those of *Sinanthropus* (i.e., *Homo erectus*), and with some morphological traits similar to European Neanderthals. The artefacts from this site, as noted above, have been termed a late Acheulean industry (Yang et al., 2014). The second is the Yunxian hominid site at Xuetangliangzi, where two crania were found in Terrace 4 of the Han River, one on the surface and one from the excavation (Li et al., 1991; Li and Etler, 1992; Li and Feng, 2001). de Lumley and Li (2008) discuss an assemblage of 453 lithics, 70% of which derive from excavation. One handaxe was excavated in situ and the other LCTs are surface finds: five bifaces, one uniface, four cleavers, and three picks. Materials are quartzite, igneous rocks and metamorphosed schist (a rock similar to quartz phyllite), and all of the bifaces are made in the latter material. The sediments consist of fluvial sands and silts, and some artefact refits are present. The site is well dated by fauna, palaeomagnetism and electron spin resonance (ESR) to ca. 0.8 Ma (Yan, 1993; Huang and Li, 1995; Chen et al., 1996, 1997; de Lumley and Li, 2008; Guo et al., 2013).

Table 8
Metric and weight data available for handaxes in Africa, Western Europe and Asia. Measurements for Rietputs 15 have variable sample sizes because of breaks that particularly affected the tool lengths as these LCTs were retrieved from mining operations. The minimum ages published in Gibbon et al., 2009 are used as most accurate due to new statistical modelling available for cosmogenic nuclide burial dating (Gibbon, Personal communication). The EF HR sample from Olduvai measured by Kuman was done in the Kenya National Museum in Nairobi in 2009 and not all handaxes were available. We, L, W and T in the sample size column stand for Weight, Length, Width and Thickness. Weight is in grams and measurements in mm.

Locality	Country	Age (Ma)	*N*	Weight			Length			Width			Thickness			Thickness/Width			Length/Width			References
				Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	
Africa																						
Konso KGA6-A1 Loc.C	Ethiopia	~1.75	4				161.00	37.20								0.41	0.13					A
Rietputs 15 Pit 1	So. Africa	1.72 ± 0.16	9				109.67	16.21	112.00	71.00	11.53	75.00	40.89	6.62	40.00	0.59	0.12	0.59	1.56	0.16	1.57	B,C
Konso KGA4-A2	Ethiopia	~1.6	19				159.80	25.20								0.55	0.13					A
Olduvai EF HR, Bed II	Tanzania	1.6	21L/22W&T				146.05	29.79	141.00	85.55	11.99	82.5	46.91	10.25	45.5	0.56	0.15	0.51	1.64	0.45	1.71	B,D
Olduvai EF HR, Bed II	Tanzania	1.6	29	601.80	210.2																	E,D
Sterkfontein	So. Africa	~1.6	10				123.50	21.63	123.50	76.30	13.92	76.50	47.00	9.51	47.50	0.63	0.13	0.61	1.64	0.28	1.61	B,F,G,H
Canteen Kopje basal EA	So. Africa	>1.5	7	402.90			120.71	30.10		68.57	13.55											I
Canteen Kopje EA	So. Africa	~1.5	30	399.70	225.2		125.38	29.01		71.00	13.02											I
Konso KGA 10-A11	Ethiopia	~1.45	16				164.60	42.90								0.53	0.10					A
Konso KGA7-A1,A2,A3	Ethiopia	~1.4	17				142.40	25.80								0.58	0.11					A
Rietputs 15 Pit 5 (A)	So. Africa	1.32 ± 0.21	62L/74W/78T				127.50	25.12	123.50	78.92	12.59	77.00	42.00	9.70	40.00	0.53	0.10	0.52	1.63	0.21	1.60	B,C,J
Konso KGA 12-A1	Ethiopia	~1.25	30				174.20	24.00								0.54	0.15					A
Canteen Kopje Victoria W.	So. Africa	>1.0 Ma	35	618.00	108		138.00	49.00		79.00	25.00											I
Averages for available data, Early Acheulean				*505.60*			*141.07*			*75.76*			*44.20*			*0.55*			*1.62*			
Olorgesailie M1, FB	Kenya	0.99–0.97	15	180.87	116.11	137.00							34.60	8.44	33.00	0.60	0.14	0.56				K,L
Olorgesailie, M1, I3	Kenya	0.99–0.97	57	225.12	197.48	158.00							33.54	9.28	31.00	0.56	0.12	0.55				K,L
Olorgesailie M6/7, DE89A	Kenya	0.97–0.78	60	877.82	381.80	804.50							46.23	10.43	46.00	0.45	0.11	0.45				K,L
Olorgesailie M6/7, H9AM	Kenya	0.97–0.78	10	770.00	426.54	760.00							36.20	7.53	33.50	0.37	0.09	0.39				K,L
Grotte des Ours	Morocco	~0.4	40	390.40	133.39	383.00	133.14	18.30	133.68	78.45	11.08	79.05	43.81	6.79	43.60	0.57	0.10	0.55	1.70	0.16	1.70	M
STIC	Morocco	<0.7	82	704.68	292.96	677.00	166.02	26.64	164.47	94.61	15.68	95.65	54.64	10.64	54.50	0.59	0.12	0.56	1.77	0.19	1.76	M
Olduvai, Masek Beds	Tanzania	0.7-0.4	125	375.02	153.24	345.00	129.98	17.21	127.10	78.44	10.69	77.60	41.25	7.75	40.70	0.53	0.09	0.51	1.67	0.19	1.69	M
Elandsfontein	So. Africa	probably <0.6	232	355.54	250.65	302.50	122.44	32.86	119.99	75.85	16.82	75.70	40.13	11.19	38.75	0.53	0.10	0.52	1.61	0.22	1.59	M
Amanzi Springs	So. Africa	Middle Pleist?	133	751.41	356.82	730.00	154.50	30.74	155.87	93.38	16.41	95.20	53.69	11.22	53.40	0.58	0.10	0.57	1.66	0.19	1.63	M
Doornlaagte	So. Africa	probably >0.6	44	1147.93	527.55	1038.50	195.87	36.17	201.15	103.90	14.45	103.90	59.03	11.76	59.20	0.57	0.10	0.55	1.88	0.21	1.91	M
Averages for available data, Africa Acheulean ca 1.0 to 0.4 Ma				*577.88*			*150.33*			*87.44*			*44.31*			*0.53*			*1.72*			
West Europe																						
Boxgrove	England	~0.5 Ma	182	288.81	132.42	282.50	122.56	22.67	122.84	80.79	13.27	82.35	30.59	5.66	30.50	0.38	0.05	0.37	1.52	0.12	1.51	M
Broom Pits	England	0.29–0.23 Ma	241	359.90	258.00	292.00	125.06	35.73	118.82	81.11	17.10	78.90	36.22	10.20	35.60	0.45	0.09	0.43	1.54	0.25	1.51	M
Corfe Mullen	England	0.5–0.38 Ma	131	346.63	191.04	299.00	121.64	27.49	118.71	75.54	13.77	75.90	37.94	12.30	34.30	0.51	0.16	0.45	1.62	0.29	1.58	M
Cuxton	England	0.43–0.23 Ma	205	370.32	252.36	304.00	124.05	34.71	120.13	73.04	15.89	70.00	44.15	11.80	43.00	0.61	0.13	0.59	1.70	0.28	1.65	M
Averages for available data, European Later Acheulean				*341.42*			*123.33*			*77.62*			*37.22*			*0.49*			*1.59*			
South Asia																						
Anagwadi	India	Middle Pleist.	15										45.73	6.04	45.00	0.60	0.08	0.58				K,N
Fatehpur V	India	0.35–0.16 Ma	11	455.45	246.74	465.00							40.91	11.36	40.00	0.52	0.13	0.56				K,N
Gulbal II	India	0.35–0.16 Ma	12	902.50	385.84	822.50							47.50	9.65	45.00	0.51	0.06	0.50				K,N
Hunsgi II	India	0.35–0.16 Ma	18	1041.94	551.14	927.50							52.22	10.60	50.00	0.55	0.10	0.58				K,N
Hunsgi V	India	0.35–0.16 Ma	45	669.00	349.60	590.00							48.44	9.99	50.00	0.56	0.11	0.57				K,N
Mudnur VIII	India	0.35–0.16 Ma	9	1302.22	204.56	1245.00							61.11	9.28	60.00	0.58	0.13	0.55				K,N
Teggihalli II	India	Middle Pleist	9	324.56	375.11	215.00							33.86	11.54	28.50	0.47	0.13	0.43				K,N
Yediyapur I	India	0.35–0.16 Ma	10	443.00	230.30	380.00							36.00	5.16	40.00	0.46	0.09	0.44				K,N
Yediyapur IV	India	0.35–0.16 Ma	11	626.82	415.00	415.00							42.73	11.04	40.00	0.54	0.13	0.50				K,N
Yediyapur VI	India	0.35–0.16 Ma	21	591.19	563.49	505.00							42.86	13.09	40.00	0.51	0.11	0.50				K,N
Averages for available data, Indian Acheulean				*706.30*									*45.14*			*0.53*						
East Asia																						
IHRB	So. Korea	<0.35 Ma	58				153.86	30.46	151.00	94.16	13.92	91.50	60.19	12.92	60.00	0.65	0.14	0.63	1.64	0.27	1.64	O
Bose	China	~0.8 Ma	64				167.52	29.09	165.50	120.69	18.61	120.00	73.14	12.26	74.00	0.62	0.13	0.62	1.40	0.20	1.41	P
Bose-Fengshudao excav.	China	~0.8 Ma	5	1105.20	453.97	1054.00	166.77	34.95	161.94	109.91	22.53	118.25	76.69	15.27	76.47	0.71	0.10	0.73	1.56	0.37	1.55	Q
Bose-Fengshudao surface	China	~0.8 Ma	99	1132.33	485.64	1062.00	157.25	27.88	151.93	118.47	19.19	115.59	67.42	14.03	67.43	0.58	0.13	0.57	1.34	0.24	1.31	Q
Luonan	China	<0.5 Ma	236	979.00	470.61	946.50	157.44	39.60	156.51	98.32	18.36	97.84	58.41	13.46	58.91	0.61	0.14	0.60				R
DRR (T3)	China	Middle Pleist	45We/44L/51W&T	929.00	394.81	844.00	172.70	31.31	174.50	99.88	14.59	101.00	45.45	10.53	45.00	0.46	0.10	0.45	1.73	0.23	1.76	S
DRR (T2)	China	Late Pleist	21/19L	848.19	284.45	830.00	170.00	34.76	167.00	103.38	13.53	101.00	51.52	25.15	47.00	0.50	0.23	0.44	1.66	0.25	1.62	S
Lantian	China	70–30,000	4L/5W&T	802.70	521.62	855.70	147.43	13.06		86.91			56.40			0.65			1.60			T
Averages for available data, East Asian Acheulean				*966.07*			*161.62*			*106.40*			*61.83*			*0.59*			*1.56*			

References: A) Beyene et al., 2013; B) recorded by Kuman; C) Gibbon et al., 2009; D) Leakey 1971; E) Roe 1994; F) Kuman 1994; G) Kuman 1998; H) Field 1999; I) Leader 2013; J) Leader 2009; K) Petraglia and Shipton 2008; L) Potts et al., 1999; M) Marshall et al. 2002; N) Szabo et al. 1990; O) Norton et al. 2006; P) Huang e t al. 2003; Q) Wang et al. 2014; R) Wang 2007b; S) current study; T) Wang, S. et al. 2014.

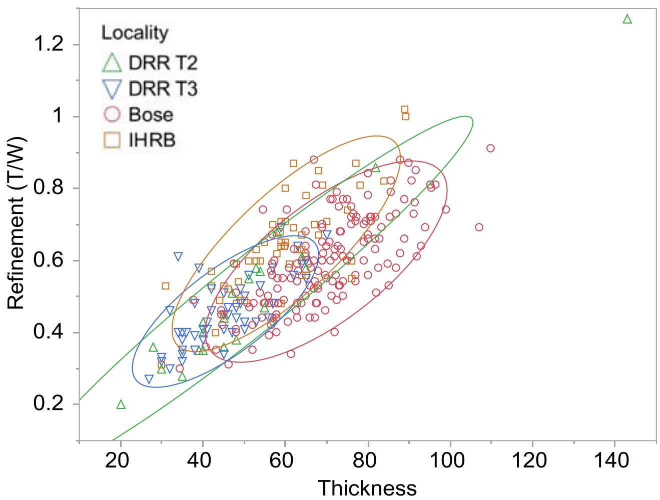

Figure 12. Scatter plot between Thickness and Refinement (T/W) of the East Asian handaxe assemblages. The bivariate normal ellipses encircle 90% of the plotted points in each assemblage. Thickness and Refinement in the four handaxe assemblages are highly correlated, which T2 handaxes from DRR having the highest correlation: Bose ($r = 0.71$, $p < 0.001$); DRR, T2 ($r = 0.97$, $p < 0.001$); DRR, T3 ($r = 0.75$, $p < 0.001$); IHRB ($r = 0.79$, $p < 0.001$).

The Yunxian crania (ca 0.8 Ma) are said to possess features of both *Homo erectus* and *Homo sapiens* (Li and Etler, 1992; Etler and Li, 1994; Vialet et al., 2010), and thus they are more advanced than the *Homo erectus* fossils well represented at Zhoukoudian with Mode 1 artefacts. The cranial capacities of the two specimens (a female and a male) are also relatively large at 1125 and 1152 cc (de Lumley and Li, 2008). Etler and Li (1994: 669) argue that the Yunxian crania are best viewed as “members of an archaic hominid lineage evolving in a regional context toward an Asian variant of later premodern H. sapiens.” On the other hand, Bae (2010) notes that gene flow between Western incoming and Eastern resident populations is receiving greater attention today, and that more researchers are abandoning the extreme versions of both the complete replacement and the multiregional continuity hypotheses. Within China, a popular view is the ‘continuity with hybridization’ model advocated by Wu (2004), which accommodates both the local evolution of *Homo erectus* and admixture with Western populations. The archaeological data we have at present cannot resolve such debates, but it can contribute to a better understanding of the commonalities in technology between East and West.

Conclusions

Despite the value of quantitative data, metric information like that presented in Table 8 is unlikely to settle the debate on whether the Chinese LCTs are an indigenous development or the result of sporadic contact with Western immigrant populations. With the addition of more samples from both sides of the Movius Line, variability increases and more Eastern assemblages overlap in their measurements with the Acheulean. The DRR handaxes are a case in point, with their lower values for Thickness and Refinement (T/W), which are closer to the Acheulean and contrast with the higher values for the other East Asian samples. A technological approach and informed evaluation of lithic raw materials for each assemblage is in our view likely to prove more informative in the long run. However, opinions will continue to vary in these debates, depending on how variables are weighted or linked to features of the technology. Interpretation is complicated by the fact that population movements into eastern Asia would have been complex, limited, and affected by periods of isolation and by the limiting demographic factors of small immigrant communities.

The interpretations based on this study of the DRR LCTs and a review of the main LCT-bearing sites in China may be summarized as follows:

1) LCT-bearing sites have been found in the Bose Basin of South China at ca. 0.803 Ma, in the DRR in central China from ca. 0.800 Ma to the late Middle or Late Pleistocene, in the Luonan Basin of central China during at least three periods from 0.800 to 0.100 Ma, and further north at a number of sites that thus far are only documented at the younger end of the time range: Dingcun (later Middle Pleistocene), Sanmexia (undated but possibly similar to Dingcun) and Lantian (Late Pleistocene). Additional reports of handaxe occurrences, largely published in Chinese, are also noted but need further documentation (Li et al., 2014b). Thus the presence of handaxe-making hominids in China currently appears to be limited and sporadic, with the most continuity present in central China. However, research to date has not been extensive and the reports of new finds are likely to increase with time.
2) All LCT-bearing localities thus far are open-air alluvial sites with overall low densities of artefacts. This pattern is widespread enough to not be explained simply by site formation processes and suggests low population densities.
3) Although some researchers contrast the small number of LCTs in eastern Asia with the larger numbers that occur in many Western Acheulean sites, this difference can be explained as the result of smaller population sizes in the East. This is particularly evident in the small assemblage sizes at open-air sites in southern and central China. There is currently no way to prove that bamboo cutting tools were widespread or persistent enough through time to explain why LCTs are limited in numbers and distribution. Rather the limited distribution of sites can be interpreted as suggesting pathways of movement and/or cultural diffusion.
4) Cleavers are argued to be rare finds in China. However, this is a sampling issue that is being changed with further research (e.g., Wang, 2006; Xie and Bodin, 2007; Li et al., 2014a). It is often forgotten that there is also a paucity of cleavers in European Acheulean sites. Both cultural factors and raw material limitations in some regions are the likely reasons for the limited ‘cleaver phenomenon.’ Typically Acheulean-like cleavers occur in the Luonan sites. In the DRR, both classic and atypical examples of cleavers occur, although side-struck blanks are rarely used because they are difficult to produce in the local raw materials. In the Bose sites where large flakes are also not easily produced on the raw materials, more cleavers are made on cobbles than flakes.
5) There are significant differences in the morphological appearance of LCTs across the three regional industries of Bose, DRR, and Luonan. While these differences are largely driven by raw materials, the LCT sites also extend across a range of vegetation zones that must have influenced adaptations and technology. Bose in southern China has the highest rainfall of the three regions. Its sites are characterized by red clay and vermiculated soils reflecting humid habitats and intense weathering during hominid occupations ca. 0.803 Ma. As one travels northwards to central China and the southern margin of the Qinling Mountains, lower rainfall resulted in less weathered red soils in the DRR region and periodic accumulation of more arid sediments, which we see in the loess-palaeosol sequence. North of the

Qinling Mountains in the Luonan region, annual rainfall is less again and grasslands are more prominent, along with developed loess-palaesol stratigraphic sequences in the Middle Pleistocene. This region is considered a transition zone between subtropical central and temperate northern China. The existence of the Qinling Mountains has influenced these rainfall patterns, particularly as uplift increased during the mid to Late Pleistocene (Xue et al., 1996, 2004).

6) The East Asian handaxes as a whole show greater variability when compared with the Western Acheulean (Figs. 10 and 11). The greater thickness of East Asian handaxes has been argued to be most significant. However, the DRR examples prove to be an exception, due to the flaking properties of the specific raw materials. More studies of the Asian rock types used for LCTs are needed for greater clarity in overall comparisons.
7) The greater average weights of Asian handaxes have no obvious explanation, but some possibilities can be considered. Raw material shapes and sizes will have some influence, particularly as more Chinese LCTs are made on cobbles than is typical for the Acheulean, and a by-product may be larger average handaxe sizes. However, we cannot preclude that both size and weight contrasts could be due to cultural differences and/or subsistence ecology.
8) Variability in bifacial, partly-bifacial and unifacial shaping patterns exists in both the Acheulean and the Chinese assemblages, and this needs clearer documentation on both sides of the Movius Line. We also need greater standardization in classification of types that will allow us to share information more easily.
9) In comparisons with the Acheulean, we should not only focus on Western assemblages of similar age, whether it be 0.8 Ma or later Middle Pleistocene. We must acknowledge that China could have hosted handaxe-making populations that arrived from the West and admixed with local peoples, with mutual influence on adaptations and technology a possibility. We should, in particular, not limit our comparisons to only classic, later Acheulean technology, as Western immigrant populations with an earlier or middle Acheulean technology might have sustained their technology longer in China than was possible in Africa, which was characterized by higher population densities.

In conclusion, we suggest that when the technologies of the Chinese LCT assemblages are examined in detail, the similarities with Acheulean patterns are more striking than the differences. There is bound to be variability in appearance of the LCTs that arises with differences in ecology and raw material flaking properties, and there will undoubtedly be differences based on ‘cultural drift’ affecting such widespread industries. The lack of LCTs in large Mode 1 assemblages excavated from sites like Zhoukoudian and Longyadong suggests that activity differences do not provide a robust explanation for their absence. These Mode 1 sites demonstrate that *Homo erectus* persisted very successfully in China from ca. 0.77–0.30 Ma (Shen et al., 2009). The Yunxian and Dingcun hominid fossils, however, indicate that the hominid species responsible for the LCT industries had some sapient traits that *H. erectus* did not possess, although whether these morphological differences were due to local evolution or admixture is debated. The complexity of cultural traditions in China makes its regional handaxe industries a highly interesting challenge for archaeological interpretation, and we suggest that more weight should be placed on the study of technology and raw material flaking properties to address these challenges.

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Appendix A. Site names for numbered locations in Fig. 1, Danjiangkou Reservoir Region site surveys.

T4
1 Xuetangliangzi (Yunxian hominid site)
T3
2 Beitaishanmiao
3 Hongshikan
4 Dudian
5 Hejiawan
6 Pengjiahe
7 Shuiniuwa
8 Caijiadu
9 Balamiao
10 Longkou
11 Guojialinchang
12 Caojiayuan
13 Tianjialing
14 Zhuangzigou
15 Lianhuacun
16 Qijiayazi
17 Guochachang
T2
18 Hanjiazhou
19 Yuzui
20 Xiaogou
21 Quyuanhekou
22 Liuwan
23 Liujiagou
24 Taizishan
25 Liangjiagang
26 Songwan
27 Chengjiagang
28 Maoping
29 Donggang

Appendix B. Measurements and indices for LCTs. Missing data corresponds with damage.

Artefact	Site	Type	Weight	Mean	SD	Median	Length	Mean	SD	Median	Width	Mean	SD	Median	Th	Mean	SD	Median	L/W	Mean	SD	Median	Th/W	Mean	SD	Median
Terrace 2, HAN RIVER																										
Handaxes																			Elongation				Refinement			
132	Liujiagou	handaxe	1116								112				65								0.58			
142	Hanjiazhou	handaxe	646				96				91				53				1.05				0.58			
60	Xiaogou	handaxe	956								115				40								0.35			
106a	Quyuanhekou	handaxe with conjoining distal	1206				224				105				64				2.13				0.61			
130	Hanjiazhou	handaxe with narrow distal	912				200				102				45				1.96				0.44			
50	Quyuanhekou	handaxe with thin distal	928				150				124				45				1.21				0.36			
110	Liuwan	handaxe with thin distal	1342				228				126				48				1.81				0.38			
129	Hanjiazhou	handaxe with thin distal	964				200				113				143				1.77				1.27			
131	Yuzui	handaxe with thin distal	676				160				93				47				1.72				0.51			
141	Hanjiazhou	handaxe with thin distal	830				179				112				39				1.60				0.35			
143	Yuzui	handaxe with thin distal	1282				217				118				55				1.84				0.47			
133	Xiaogou	handaxe with wide flat distal	1204				190				124				35				1.53				0.28			
		N=12		**1005.00**	**227.44**	**960.00**		**184.40**	**40.38**	**195.00**		**111.25**	**11.58**	**112.50**		**56.58**	**28.75**	**47.50**		**1.66**	**0.33**	**1.75**		**0.51**	**0.26**	**0.45**
106b	Quyuanhekou	handaxe without conjoined distal	1134				191				105				64				1.82				0.61			
Other LCTs			**Weight**	Mean	SD	Median	**Length**	Mean	SD		**Width**	Mean	SD	Median	**Th**	Mean	SD	Median	**L/W**				**Th/W**			
55	Xiaogou	pick-like handaxe	2708				247				155				79				1.59				0.51			
35	Hanjiazhou	LCT distal portion / thin					>216																			
58	Hanjiazhou	LCT proximal portion					>135																			
95	Liuwan	pick	840				164				70				57				2.34				0.81			
46	Quyuanhekou	pick	862				171				78				49				2.19				0.63			
57	Yuzui	cleaver	438				130				86				34				1.51				0.40			
		N=6																								
Terrace 2, DAN RIVER																										
100	Chengjiagang	handaxe	748				152				95				54				1.60				0.57			
134	Songwan	handaxe	1050				148				95				82				1.56				0.86			
137	Taizishan	handaxe	576				138				85				58				1.62				0.68			
40	Liangjiagang	handaxe with thin distal	640				160				99				40				1.62				0.40			
94	Liangjiagang	handaxe with thin distal	546				167				101				30				1.65				0.30			
96	Liangjiagang	handaxe with thin distal	394				145				98				20				1.48				0.20			
103	Taizishan	handaxe with thin distal	340				122				77				28				1.58				0.36			
107	Taizishan	handaxe with thin distal	744				181				93				51				1.95				0.55			
108	Taizishan	handaxe with thin distal	712				173				93				40				1.86				0.43			
		N=9		**638.89**	**211.90**	**640.00**		**154.00**	**18.36**	**152.00**		**92.89**	**7.52**	**95.00**		**47.78**	**18.85**	**40.00**		**1.66**	**0.15**	**1.62**		**0.48**	**0.20**	**0.43**
Other LCTs			**Weight**	Mean	SD	Median	**Length**	Mean	SD	Median	**Width**	Mean	SD	Median	**Th**	Mean	SD	Median	**L/W**	Mean	SD	Median	**Th/W**	Mean	SD	Median
42	Taizishan	pick	842				179				84				48				2.13				0.57			
43	Taizishan	pick	342				127				86				29				1.48				0.34			
47	Maoping	pick	762				167				90				39				1.86				0.43			
48	Liangjiagang	pick	1616				170				119				76				1.43				0.64			
97	Liangjiagang	pick	1222				225				97				75				2.32				0.77			
98	Donggang	pick	954				160				95				70				1.68				0.74			
102	Taizishan	pick	530				127				77				46				1.65				0.60			
109	Songwan	pick	1692				186				140				58				1.33				0.41			
		N=8		**995.00**	**484.77**	**898.00**		**167.63**	**31.90**	**168.50**		**98.50**	**20.90**	**92.50**		**55.13**	**17.47**	**53.00**		**1.73**	**0.35**	**1.67**	**N=8**	**0.56**	**0.16**	**0.58**
33	Songwan	pick-like handaxe	1226				205				104				45				1.97				0.43			
99	Songwan	pick-like handaxe	748				148				85				47				1.74				0.55			
101	Taizishan	unifacial cobble pick	1182				154				116				70				1.33				0.60			
104	Taizishan	cleaver	844				175				103				40				1.70				0.39			
		N=4																								

(continued on next page)

(*continued*)

Terrace 3, HAN RIVER

Handaxes																				Elongation				Refinement		
Artefact	**Site**	**Type**	**Weight**	Mean	SD	Median	**Length**	Mean	SD	Median	**Width**	Mean	SD	Median	**Th**	Mean	SD	Median	**L/W**	Mean	SD	Median	**Th/W**	Mean	SD	Median
49	Guojialingchang	handaxe	1318				212				118				47				1.80				0.40			
64	Hejiawan	handaxe	562				135				91				36				1.48				0.40			
69	Pengjiahe	handaxe									102				35								0.34			
70	Hongshikan	handaxe									79				38								0.48			
71	Caijiadu	handaxe	532				174				95				30				1.83				0.32			
73	Hongshikan	handaxe									87				35								0.40			
74	Pengjiahe	handaxe	1060				156				108				64				1.44				0.59			
75	Beitaishanmiao	handaxe	1404				196				104				70				1.88				0.67			
76	Beitaishanmiao	handaxe									108				38								0.35			
77	Beitaishanmiao	handaxe	1028				145				99				63				1.46				0.64			
79	Beitaishanmiao	handaxe	822				142				91				42				1.56				0.46			
92	Hejiawan	handaxe									85				34								0.40			
116	Beitaishanmiao	handaxe	1564				210				119				65				1.76				0.55			
120	Beitaishanmiao	handaxe	966				171				102				54				1.68				0.53			
123	Dudian	handaxe	812				187				98				38				1.91				0.39			
125	Hongshikan	handaxe	312				106				67				39				1.58				0.58			
127	Hejiawan	handaxe	284				121				69				32				1.75				0.46			
138	Beitaishanmiao	handaxe	826				140				91				51				1.54				0.56			
139	Hongshikan	handaxe	1638				200				118				57				1.69				0.48			
140	Caojiayuan	handaxe									108				48								0.44			
118	Beitaishanmiao	handaxe with squared distal	1398				189				122				53				1.55				0.43			
9	Longkou	handaxe with thin distal	1696				161				81				42				1.99				0.52			
10	Shuiniuwa	handaxe with thin distal	1496				214				109				65				1.96				0.60			
26	Shuiniuwa	handaxe with thin distal	806				179				101				27				1.77				0.27			
31	Dudian	handaxe with thin distal	690				183				109				35				1.68				0.32			
34	Beitaishanmiao	handaxe with thin distal	734				203				108				32				1.88				0.30			
39	Beitaishanmiao	handaxe with thin distal	634				162				101				35				1.60				0.35			
44	Hejiawan	handaxe with thin distal	716				190				89				45				2.13				0.51			
45	Beitaishanmiao	handaxe with thin distal	564				159				96				41				1.66				0.43			
53	Balamiao	handaxe with thin distal	1064				214				109				45				1.96				0.41			
63	Caijiadu	handaxe with thin distal	1268								132				45								0.34			
78	Beitaishanmiao	handaxe with thin distal	584				142				99				41				1.43				0.41			
80	Beitaishanmiao	handaxe with thin distal	482				125				98				40				1.28				0.41			
81	Beitaishanmiao	handaxe with thin distal	230				120				56				34				2.14				0.61			
82	Beitaishanmiao	handaxe with thin distal	1372				183				101				50				1.81				0.50			
84	Beitaishanmiao	handaxe with thin distal	1024				215				101				50				2.13				0.50			
86	Beitaishanmiao	handaxe with thin distal	844				167				85				59				1.96				0.69			
87	Beitaishanmiao	handaxe with thin distal	1018				200				105				40				1.90				0.38			
88	Beitaishanmiao	handaxe with thin distal	844				175				97				46				1.80				0.47			
89	Beitaishanmiao	handaxe with thin distal	1090				178				123				50				1.45				0.41			
90	Shuiniuwa	handaxe with thin distal	444				170				95				49				1.79				0.52			
91	Dudian	handaxe with thin distal	530				150				92				35				1.63				0.38			
93	Balamiao	handaxe with thin distal	264				112				90				30				1.24				0.33			
105	Beitaishanmiao	handaxe with thin distal	1228				213				110				62				1.94				0.56			
117	Hongshikan	handaxe with thin distal	1092				226				103				48				2.19				0.47			
119	Beitaishanmiao	handaxe with thin distal	1700				220				126				56				1.75				0.44			
121	Beitaishanmiao	handaxe with thin distal	1050				181				98				57				1.85				0.58			
122	Dudian	handaxe with thin distal	1060				170				115				50				1.48				0.43			
128	Hejiawan	handaxe with thin distal	782				156				103				49				1.51				0.48			
135	Beitaishanmiao	handaxe with thin squared distal	1228				192				102				46				1.88				0.45			
124	Hongshikan	handaxe with thin wide distal	748				155				99				45				1.57				0.45			
		N=51		**929.07**	**394.81**	**844.00**		**172.70**	**31.31**	**174.50**		**99.88**	**14.59**	**101.00**		**45.45**	**10.53**	**45.00**		**1.73**	**0.23**	**1.76**		**0.46**	**0.10**	**0.45**
Other LCTs																										
11	Shuiniuwa	pick	914				160				76				28				2.11				0.37			
30	Hongshikan	pick	900				178				89				56				2.00				0.63			
32	Shuiniuwa	pick	884				193				93				44				2.08				0.47			
41	Dudian	pick	832				182				94				56				1.94				0.60			
54	Tianjialing	pick	538				174				76				35				2.29				0.46			
65	Hejiawan	pick	544				160				78				27				2.05				0.35			
72	Hejiawan	pick	930				135				118				63				1.14				0.53			
83	Beitaishanmiao	pick	1504				256				91				69				2.81				0.76			

85	Beitaishanmiao	pick	2052				216				105				70				2.06				0.67			
111	Beitaishanmiao	pick	1362				190				120				55				1.58				0.46			
113	Dudian	pick	1722				240				118				63				2.03				0.53			
		N=11		**1107.455**	**486.9695**	**907.00**		**189.45**	**34.56**	**180.00**		**96.18**	**16.84**	**93.00**		**51.45**	**15.64202**	**56.00**		**2.01**	**0.41**	**2.05**		**0.54**	**0.13**	**0.53**
1	Zhuangzigou	unifacial cobble pick	3555								138				90								0.65			
2	Longkou	unifacial cobble pick	2246				187				121				83				1.55				0.69			
3	Longkou	unifacial cobble pick	1588				165				120				72				1.38				0.60			
4	Longkou	unifacial cobble pick	1612				185				116				60				1.59				0.52			
5	Longkou	unifacial cobble pick	2022				195				112				88				1.74				0.79			
17	Liahuacun	unifacial cobble pick	540				113				92				40				1.23				0.43			
51	Qijiayazi	unifacial cobble pick	2426				220				112				85				1.96				0.76			
66	Pengjiahe	unifacial cobble pick	3445								154				111								0.72			
67	Hejiawan	unifacial cobble pick	2264				220				113				80				1.95				0.71			
68	Pengjiahe	unifacial cobble pick	2444				223				115				84				1.94				0.73			
112	Pengjiahe	unifacial cobble pick	1394				172				107				74				1.61				0.69			
114	Longkou	unifacial cobble pick	718				162				79				49				2.05				0.62			
62	Pengjiahe	unifacial cobble pick	1078				140				117				59				1.20				0.50			
		N=13		**1948.615**	**926.18**	**2022.00**		**180.18**	**34.71**	**185.00**		**115.08**	**18.32**	**115.00**		**75.00**	**19.04**	**80.00**		**1.65**	**0.30**	**1.61**		**0.65**	**0.11**	**0.69**
6	Dudian	pick notched & doubled pointed	678				126				95				36				1.33				0.38			
52	Hejiawan	picklike handaxe	826				155				98				41				1.58				0.42			
61	Guochachang	cleaver	1340				181				126				57				1.44				0.45			
136	Dudian	cleaver	828				194				110				39				1.76				0.35			
126	Hongshikan	cleaver	1144				190				101				48				1.88				0.48			
		N=5																								
Terrace 4, HAN RIVER																										
LCT	**Site**	**Type**	**Weight**	Mean	SD	Median	**Length**	Mean	SD	Median	**Width**	Mean	SD	Median	**Th**	Mean	SD	Median	**L/W**	Mean	SD	Median	**Th/W**	Mean	SD	Median
29	Xuetangliangzi	unifacial cobble pick	2128				196				119				78				1.65				0.66			
		N=1																								

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The Middle Pleistocene handaxe site of Shuangshu in the Danjiangkou Reservoir Region, central China

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ABSTRACT

The presence of Acheulean tool types (e.g. handaxes and cleavers) in East Asia has recently attracted considerable attention. They challenge the long lasting concept that the Early Palaeolithic in East Asia is characterized only by Mode 1 technology, and they reflect the diversity and complexity of Palaeolithic culture during hundreds of thousands of years. In this paper, we present a detailed technological analysis of the in situ artifact assemblage at the Shuangshu site (Danjiangkou Reservoir Region, central China), as well as intra- and inter-regional comparisons of some characteristic traits used to test the difference between handaxes in the East and the West. The results show that there are two reduction sequences taking place. One is expressed in the predominant use of quartz in the production the small-to-medium sized artifacts, which is an expedient technology that dominates the whole assemblage, and the other is represented by the predominant use of quartz phyllite and trachyte in the production of Large Cutting Tools (LCTs). The latter displays the technical criteria characteristic of Acheulean technology, although its origins are much debated. In addition, the number of LCTs and total artifacts is generally low for the size of the excavation area, which probably is a result of relatively small population size and the high mobility of hominids. The thickness of handaxes has been shown not to be a reliable variable in demonstrating the difference between the East and the West.

1. Introduction

One of the prominent characteristics of the Acheulean Industrial Complex is its variability across space and time. This is seen in tool type frequencies (Pope, 2002; Sharon et al., 2011), technological strategies (Clark, 2001; Schick and Clark, 2003; McPherron, 2003; Archer and Braun, 2010), and morphology (Gamble and Marshall, 2001; Lycett, 2008). Moreover, some assemblages (e.g., GnJh 42 and GnJh 50 sites in the Middle Pleistocene Kapthurin Formation of Kenya) actually lack the typical tool types of the Acheulean, such as handaxes and cleavers (Diez-Martín and Eren, 2012; Johnson and McBrearty, 2012). This has led some researchers to recognize the need to form a more balanced focus on exploring a truly holistic version of the Acheulean concept (Tryon and Potts, 2011; Diez-Martín and Eren, 2012; Johnson and McBrearty, 2012). Current emphasis on the small-medium sized débitage component at Acheulean sites exemplifies this more holistic approach, as it helps our understanding of the overall technological innovations and adaptations at these sites (de la Torre and Mora, 2005; Tryon and Potts, 2011; Diez-Martín and Eren, 2012; Johnson and McBrearty, 2012; Gallotti, 2013). However, the study of handaxe-bearing assemblages in China has been constrained by an initial focus on surface collections and the Large Cutting Tools (LCTs) within them (Hou et al., 2000; Norton et al., 2006; Petraglia and Shipton, 2008). This has impeded the reconstruction of complete technological strategies, which are necessary to this more holistic approach.

In this paper, we will present a detailed study of the in situ stone artefact assemblage excavated at the Shuangshu site in the Danjiangkou Reservoir Region (DRR), central China. At the time of the

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construction of the national South-to-North Water Transfer Project, the field team of IVPP (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences) conducted several investigations along the banks of the Han and Dan Rivers in the DRR (Fig. 1). The survey results show that LCTs are associated with three terraces (T4, T3 and T2) of the Han and Dan Rivers and are estimated to date from the late Early Pleistocene (T4) to the Late Pleistocene (T2) (Zhu, 1955; Shen, 1956; Yan, 1993; Huang and Li, 1995; Chen et al., 1996, 1997; Huang et al., 1996; Li et al., 2009, 2012, in press-a; Kuman et al., in press). Since intensive work began in 2006, more than 20 Palaeolithic sites have been excavated (Pei et al., 2008; Zhou et al., 2009; Niu et al., 2012, 2014; Fang et al., 2012; Li et al., 2013; Chen et al., 2014). Of all the excavated sites, Shuangshu contains the largest number of LCTs on the third terrace (T3) of the DRR, and it is one of the few sites where systematic dating work has taken place. The purpose of this study is to have a closer look into the complete technological strategy of handaxe makers in the DRR. Furthermore, we discuss its implications for understanding the handaxe phenomenon in China within a comparative approach.

2. Geological setting and palaeoenvironment

The Shuangshu site is located in the Junxian Basin in the upper valley of the Han River (E111°07′19″, N32°40′24″). Some parts of the basin have been submerged because of the construction of the Danjiangkou Reservoir (Fig. 1). Geologically, the Shuangshu site is located in the southern Qinling tectonic belt. Due to the Yanshan movement in the Mesozoic era, northwest-southeast intermontane fault basins formed (e.g. Junxian Basin, Yunxian Basin in Fig. 1)

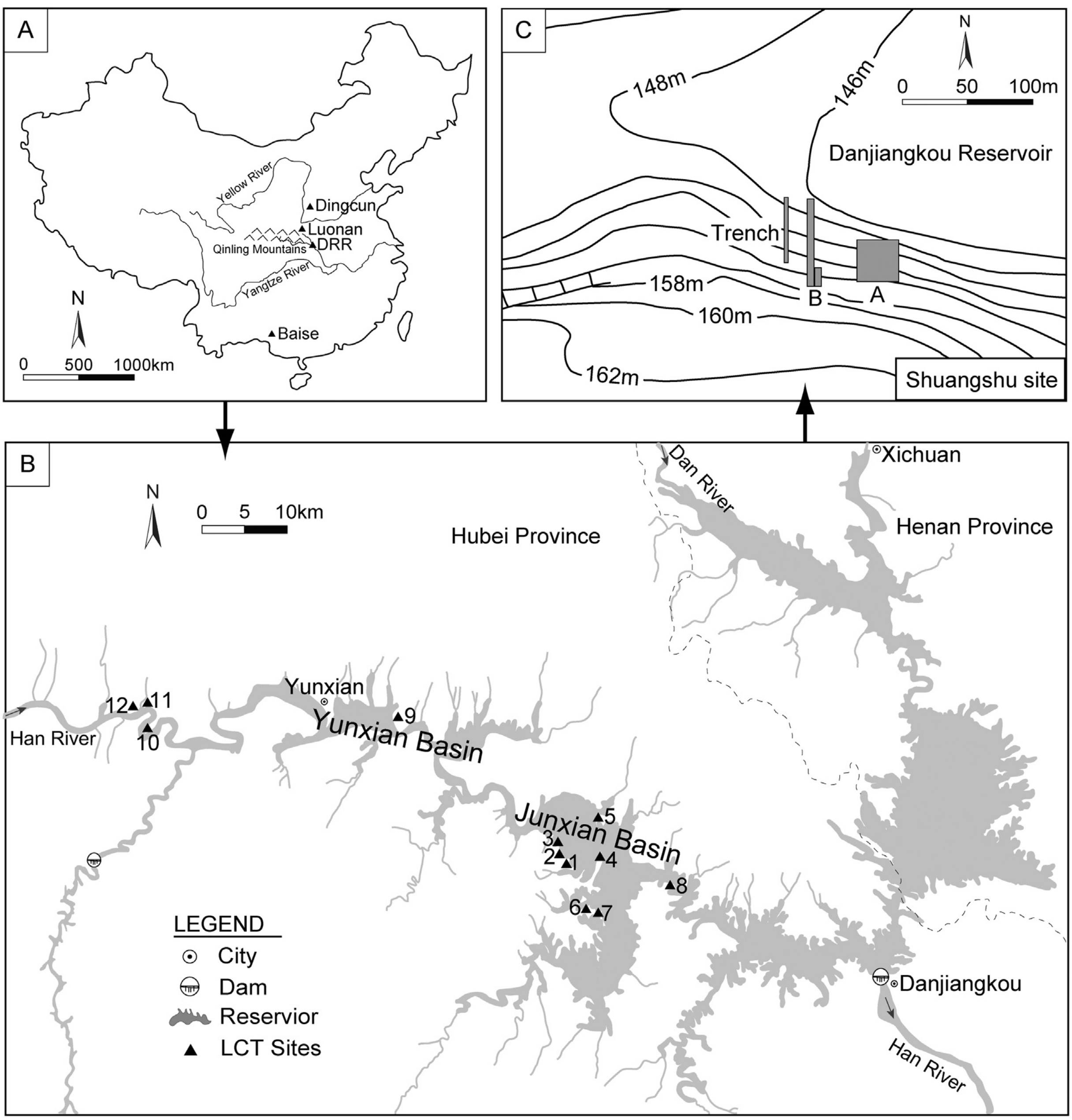

Fig. 1. Handaxe regions of China. A) geographic location of the main handaxe-bearing regions. B) the Danjiangkou Reservoir Region (DRR) with the Palaeolithic sites mentioned in this paper: 1. Shuangshu; 2. Shuiniuwa; 3. Beitaishanmiao II; 4. Beitaishanmiao; 5. Guochachang II; 6. Datubaozi; 7. Waibiangou; 8. Pengjiahe; 9. Liuwan I; 10. Houfang; 11. Dishuiyan; 12. Xuetangliangzi (or Yunxian hominid site). C) the Shuangshu site excavation areas and trench noted in the text.

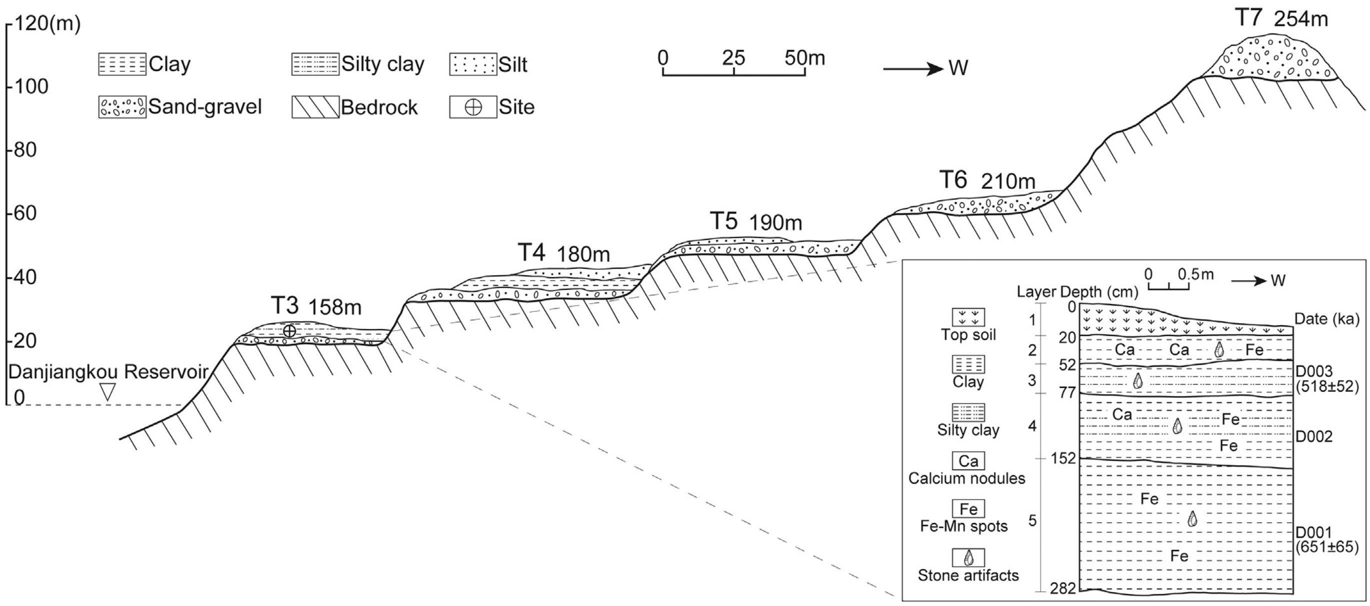

Fig. 2. The fluvial terrace sequence at Shuangshu, with stratigraphic profile (bottom right) for terrace three recorded in the Trench.

along the early deep fracture in this area (Zhang et al., 1988; Xue et al., 1996). The area today is dominated by the canyon geomorphology of the upper valley of the Han River as it flows through the Qinling Mountains, with steep slopes, turbulent water, and undeveloped terraces. However, when the Han River flowed through the basins, the valley was broad and developed several river terraces (Zhu, 1955; Shen, 1956).

The field survey around the site indicates that there are seven terraces in this area. Of these, terraces one and two are the youngest and are submerged, while the others terraces are currently exposed. The Shuangshu site is located on the third terrace of the south bank of the Han River, and is composed of two distinct stratigraphic units: the upper clay layer and the lower cobble layer. It is an extensively developed and well preserved terrace, with most farmlands and villages in the region located on this terrace. The elevation of terrace three is about 158 m and the terrace floor is about 25 m higher than the water surface of the Danjiangkou Reservoir (Fig. 2).

From the palaeoenvironmental perspective, the Qinling Mountains form the boundary between North and South China and separate the temperate and subtropical zones. This boundary area currently receives ca 800 mm of annual precipitation (Atlas of China, 2007). The Shuangshu site is located in the extreme southeastern part of the Qinling Mountains, and analyses of the fossils from the late Early Pleistocene to the Late Pleistocene levels indicate that the fauna were typical of southern China (Ailuropoda-Stegodon fauna) at the time (Qiu et al., 1982; Li and Feng, 2001; Wu et al., 2008, 2009). Some northern Chinese species (*Equus ferus przewalskii*, *Crocuta crocuta ultima*, *Ursus arctos*) do appear in the Late Pleistocene, although their proportion is lower than in the contemporary northern China fauna (Huang et al., 1987; Wang,

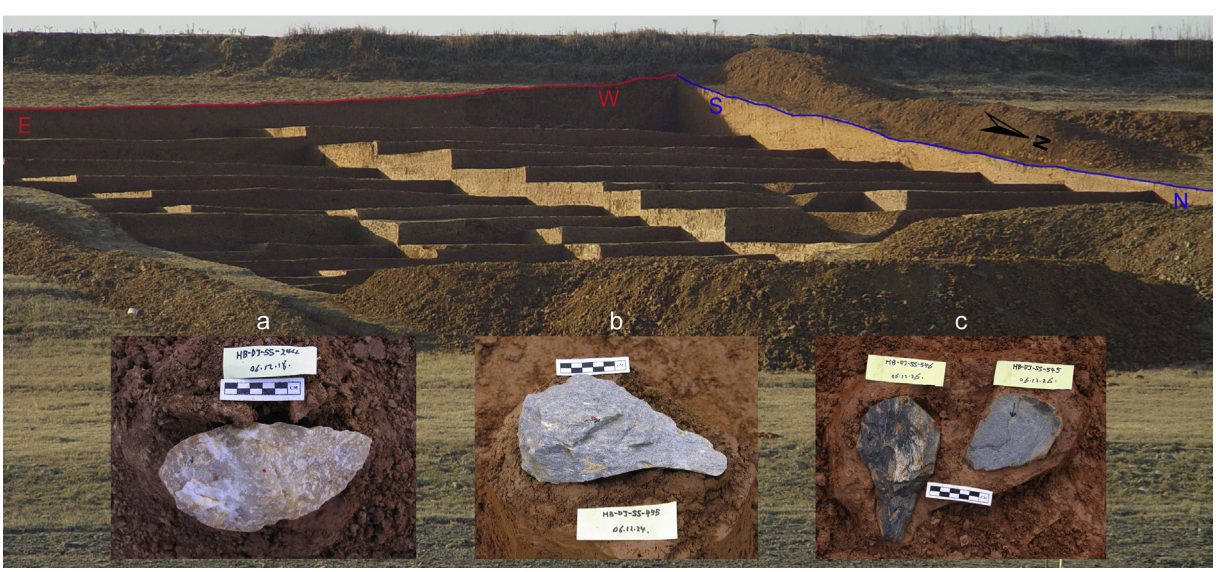

Fig. 3. Area A of the Shuangshu site and the in situ artifacts exposed during the excavation: a) handaxe on quartz, SS-244; b) handaxe on trachyte, SS-495; c) two handaxes made on quartz phyllite, SS-546 (left) and SS-545 (right). The red line shows the East-West direction and the blue line shows the North-South direction. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

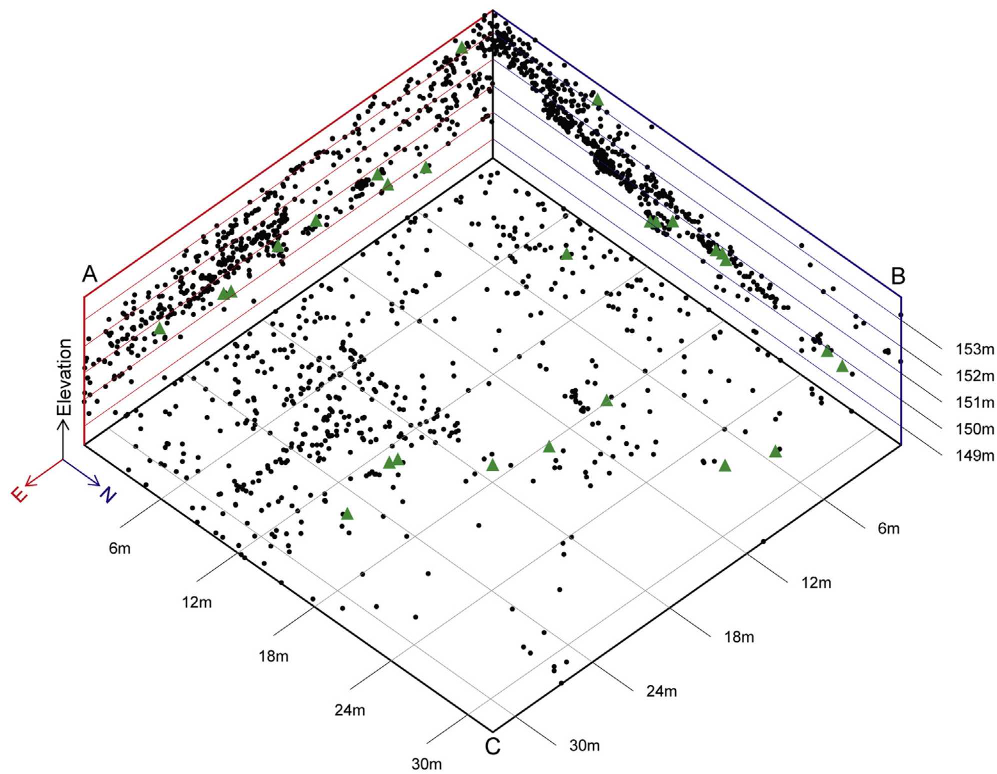

Fig. 4. The plan and cross-section distributions of lithics excavated in Area A. The red lines (A) show the East-West cross-section; the blue lines (B) show the North-South cross-section; the gray lines (C) show the lithics in plan view. Green triangles represent LCTs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1988; Wu et al., 2006, 2007). In the Pleistocene, this area experienced a relatively stable subtropical environment, with abundant animal and plant resources providing good subsistence opportunities for the survival of early humans.

3. Site stratigraphy and chronology

3.1. Stratigraphy

The Shuangshu site was discovered in 2004, and excavations were conducted from November 2006 to January 2007 by IVPP. The total excavation area was 1435 m^2. There were three excavation areas (see right top map in Fig. 1): a trench 50 m long and 1.5 m wide (75 m^2); the Area A excavation 1024 m^2 in size (see Fig. 3); and the Area B excavation 336 m^2 large. In total, 706 lithics were excavated from the Shuangshu site: $N = 21$ from the trench, including four handaxes; $N = 592$ from Area A, including six handaxes, two picks and one atypical cleaver; and $N = 93$ from Area B. The average density was 0.49 specimen/m^2 within all three areas. The plan and sectional distributions of lithics excavated from the Area A are shown in Fig. 4.

The stratigraphy of the site was divided into five layers, as follows (from the upper to the lower, see right bottom map in Fig. 2):

Layer 1: Brown clay, top soil (~20 cm);
Layer 2: Reddish-brown clay, containing stone artifacts, black Fe-Mn spots, and more calcium nodules (~32 cm);
Layer 3: Reddish-yellow clay, with silt, containing stone artifacts (~25 cm);
Layer 4: Reddish-brown clay, with silt, friable, containing stone artifacts, black Fe-Mn spots and fewer calcium nodules (~75 cm);
Layer 5: Reddish-brown clay, strong cohesive, stiff, containing stone artifacts and more black Fe-Mn spots (~130 cm) (the bottom is not obtained).

The cultural finds at Shuangshu are distributed throughout most levels in the clay layers (Fig. 2), which correspond to low energy deposition.

3.2. Chronology

Currently, the most extensive dating work has been conducted on the fourth terrace (T4) of the Han River, because of the discovery of two hominid crania (evolved *Homo erectus* or archaic *Homo sapiens*) at the Xuetangliangzi site (Fig. 1). The base of this terrace is about 180 m above sea level, which lies ca. 45 m above the current water level in the Danjiangkou Reservoir. Relative dating based on paleomagnetism, faunal chronology, and comparison with the loess-palaeosol sequence from the Luochuan profile on the Loess Plateau all indicate that Xuetangliangzi site falls in MIS19-MIS20 (814–761 kya) (Yan, 1993; Huang and Li, 1995; Chen et al., 1996, 1997; Li and Feng, 2001; De Lumley and Li, 2008; Guo et al., 2013).

In contrast to this higher and older terrace (T4) in the DRR, terraces one and two at the site are now submerged. However, a survey in the 1950s, prior to construction of the Danjiangkou Reservoir, indicates that terrace one is no more than 10 m higher than the riverbed and is composed of yellow sandy silt (Zhu, 1955; Shen, 1956). Recently in western Yunxian County, OSL dating of the earliest loess on terrace one indicates that it was deposited from 18.0 kya (Gu et al., 2012). Terrace two in the DRR was 10–15 m above the riverbed before construction of the reservoir, with the base of this terrace at 140 m above sea level, characterized by yellow clayey silt (Zhu, 1955; Shen, 1956). The age of terrace two is estimated to the middle or late Pleistocene based on its sediments and on height compared with other terraces. Currently, the only published date for terrace two is from the Dishuiyan site (800 m east of Xuetangliangzi), with a result of ca. 100–50 kya using the OSL and TT-OSL methods (Liu and Feng, 2014). The Shuangshu site of terrace three in the DRR sequence is considered on sedimentological grounds to be younger than the terrace four Xuetangliangzi site, but older than the second terrace sites in the DRR. The deposits of the Shuangshu site are strongly weathered red clay, which formed in a humid period, and these acid sediments did not preserve fossils. Both the calcium carbonate nodules and the Fe-Mn spots in the red clay (see Fig. 2) are good indicators of intense weathering and pedogenesis process at the time. The study of red clay development in Pleistocene South China has revealed that the Qinling Moutains form the northern boundary of the red clay deposits formed during the most humid period (Zhao and Yang, 1995; Yang et al., 1996; Yuan et al., 2008). The Shuangshu site is located in this boundary area of the red clay, which means the formation of red clay in this region should fall within the most humid period of the Pleistocene (Yuan et al., 2008; Pei et al., 2008; Zhou et al., 2009; Niu et al., 2012; Li et al., 2013). The study of the loess-palaeosol sequence in China is well established and shows that palaeosol S5–S4 (equal to MIS15-11, 621–374 kya) represents a most intense humid stage in the Pleistocene, best suited for the formation of the red soil in the DRR region (Zhao and Yang, 1995; Yang et al., 1996; Huang et al., 1999; Zhao et al., 2004; Yin and Guo, 2006; Yuan et al., 2008).

The Electron Spin Resonance (ESR) dating method is now commonly used to obtain accurate ages for Pleistocene fluvial sediments, especially using the confirmed quartz titanium (Ti)-center as a reliable ESR signal for dating (Beerten et al., 2006; Beerten and Stesmans, 2006, 2007; Bahain et al., 2007; Tissoux et al., 2007; Rink et al., 2007; Liu et al., 2009, 2010, 2011). For example, applying the ESR dating method to the sandy layer (layer I-26a) of the Ubeidiya Early Acheulean site in the Jordan Valley of Israel, it was shown that this method is suitable and reliable for dating older deposits that exceed the dating range of OSL or TL (<0.5 Ma). The dating results using this method are consistent with the relative palaeomagnetic and faunal dates for Ubeidiya (1.0–1.4 Ma) (Rink et al., 2007). The systematic application of the ESR optical dating method has also been applied to fluvial deposits in the Somme Valley of France, where the Acheulean was first defined, revealing that the first human settlement here began in MIS 16/15 (ca. 0.6 Ma) (Bahain et al., 2007; Voinchet et al., 2010). In China, this method was recently used to date archaeological sites in the Nihewan Basin. The reliability of ESR optical dating of quartz was first examined for reference sample collected near the Brunhes/Matuyama (B/M) boundary at the Donggutuo site, where the presence of the B/M boundary as well as the Jaramillo subchron in the silty sequence of this site have been confirmed (Wang et al., 2005). ESR dating on this sample yielded an age of 750 ± 88 kya, which suggested that the method is reliable for estimating the age of lacustrine and fluvial sediments at least until this age (Liu et al., 2010). This dating method was then applied to the Majuangou, Banshan and Dongpo sites, where the dates are consistent with the previous magnetostratigraphic and geomorphological estimations (Liu et al., 2010, 2013, 2014).

Given these successes with ESR dating, we decided to apply the method to fluvial deposits at Shuangshu. ESR dating samples were collected from layers 5, 4 and 3 of the site and were numbered D001, D002 and D003 from the lower to upper layers. The lithology of the samples was clay. The State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, analyzed the samples. The paleodose of D001 was 2499 ± 250, and the annual dose was 3.841. Therefore, the age of D001 was 651 ± 65 ka. The signature of D002 was poor, thus the age was undeterminable. The paleodose of D003 was 1792 ± 180, and the annual dose was 3.457. This indicates that the age of D003 sample was 518 ± 52 ka (Table 1). From the ESR dating, the age of the Shuangshu site appears to belong to the first half of the Middle Pleistocene.

Table 1
ESR dating of terrace three clay samples collected from the profile in Area A at Shuangshu.

Sample number	Stratigraphic unit	Lithology	Paleo-dose (Gy)	Annual dose (Gy/ka)	Age (ka)
D001	Layer 5	Clay	2499 ± 250	3.841	651 ± 65
D002	Layer 4	Clay	–	3.255	–
D003	Layer 3	Clay	1792 ± 180	3.457	518 ± 52

A detailed magnetostratigraphic analysis was also carried out on the profile of the Shuangshu site. The paleomagnetic sample section began at the top of terrace three and sampled down the western wall of the excavation in Area A to near the surface of the water. To ensure that we obtained fresh and original outcrops of samples, ~50 cm of the wall was first cut back. Samples were then collected at 10 cm intervals, resulting in a total of 86 oriented block samples. Then, two parallel samples with a volume of $2 \times 2 \times 2$ cm^3 were cut out of each block in the laboratory for rock magnetic and magnetostratigraphic studies. The analyses were conducted at the Paleomagnetism and Geochronology Laboratory, Institute of Geology and Geophysics, Chinese Academy of Sciences. The samples were heated to maximum 690 °C using MMTD80 Thermal Demagnetizer, with 25°–50 °C temperature increments below 600 °C and 10°–20 °C temperature increments above 600 °C. Remanence measurements were made using a 2G-760 cryogenic magnetometer at a magnetically shielded space (<300 nT). The high-stability natural remanent magnetization was separated above ca. 300 °C and adopted as characteristic remanent magnetization. Principal component analysis of the magnetic components (Jelinek, 1978) showed that all 86 samples provided reliable characteristics of remnant magnetization. Except for the sample from 3.4 m deep, all samples were of normal polarity (Fig. 5). Considering the ESR dating results and combined with the international polarity time scale (Cande and Kent, 1995), it is likely that the site was formed in the "Brunhes normal chron" which means the site was not formed earlier than 0.78 Ma.

The dating results from ESR and the paleomagnetism measurements therefore indicate that the Shuangshu site likely belongs to an early to middle stage of the Middle Pleistocene. This is consistent with the former geomorphological and sedimentary observations. Nevertheless, dating work on the third terrace sites of DRR is still very limited, and the application of additional dating methods on more samples is a top priority for future research.

4. Lithic assemblage

4.1. Assemblage component

Flakes (complete and incomplete flakes) comprise a dominant proportion ($n = 269$), or 38.1% of the whole assemblage (see Fig. 6 for artifacts number of each category). Chunks and debris (<25 mm) were the second and third largest proportions ($n = 149$ and $n = 116$ respectively), or 21.2% and 16.4% respectively. There were 67 cores in total, or 9.5% of the assemblage. There were 55 retouched pieces, or 7.8% of the assemblage. LCTs totaled 13 pieces, or 1.9% of the assemblage. Among them, 10 were handaxes, 2 were picks and 1 was an atypical cleaver. Five hammerstones and two

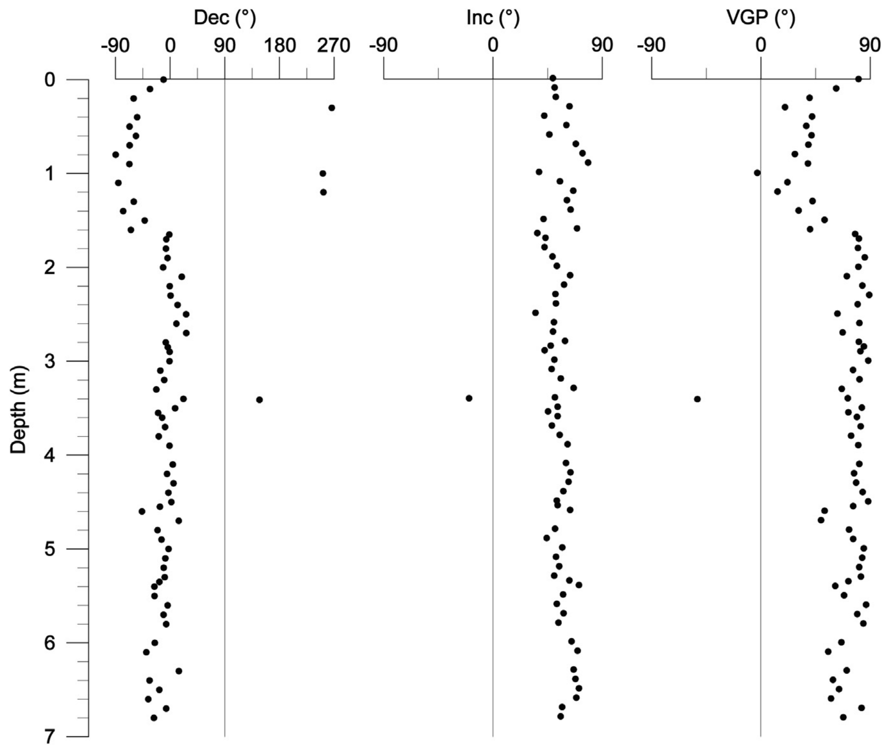

Fig. 5. Magnetic readings of the Shuangshu site: declination (Dec); inclination (Inc); virtual geomagnetic pole (VGP) latitude. The samples were collected from the N–S wall in the Area A excavation.

anvils were also unearthed. In addition, there were 30 unmodified pieces called manuports. With regard to the size, flakes, chunks, debris, cores and the retouched pieces were predominately small to medium size (0–10 cm), while LCTs were of large size (>10 cm) (Fig. 6). By putting different types of artifacts together, we can see that 47.6% of lithic length is < 40 mm and 71.0% of lithic length is < 60 mm (Fig. 7). In general, the size profile of the assemblage indicates a relatively stable taphonomic environment when deposited on the clay surface. However, there could have been moderate sheet wash along the ancient natural slope that winnowed some of the smallest artifacts from the site, as only 10.6% of lithic length is < 20 mm (Fig. 7).

4.2. Raw materials

Raw materials investigation at the site shows that the lower cobble layer on the third terrace provided a locally available source of raw materials. The thickness of the cobble layer is approximately 6 m. Cobbles are dominated by sub-rounded shapes, along with rounded and sub-angular shapes. The sub-angular cobbles can provide the natural facets which may be used as striking platforms in the initial stage of knapping. The size of cobbles is concentrated in 2–20 cm range, with the maximum size up to 30 cm. Rock lithology is dominated by quartz, quartz phyllite and trachyte, with a smaller number of sandstone, quartzite and other igneous rocks. In the Shuangshu site, raw materials were mainly quartz ($n = 587$; 83.1%), quartz phyllite ($n = 88$; 12.5%), and trachyte ($n = 26$; 3.7%). Quartzite and sandstone were only occasionally used and constitute 0.4% and 0.3% of the assemblage respectively (Table 2). It is obvious that the availability of local raw materials plays an important role in the tool makers' selectivity.

The proportion of various raw materials used in the manufacture of different sized artifacts is clearly defined (Table 2). Quartz was mainly employed in the production of small to medium sized artifacts. It accounted for 83.8% in the cores, 86.6% in the flakes, 81.2% in the chunks, 100% in the debris and 87.3% in the retouched pieces. In contrast, of the 13 LCTs, only one is made of quartz, eight of quartz phyllite and four of trachyte. Fig. 8 shows our investigation of raw materials at a quarry sorting factory on the bank of the Han River. The three enlarged images clearly demonstrate the size variation of cobbles from small to large, which is consistent with previous observations of the third terrace cobble layer. The dark gray color generally represents quartz phyllites, the dark green color indicates trachytes, while the light white and brown colors mainly indicate quartz, quartzites and sandstones. It is notable that different colors of rocks repeatedly appeared in all three images, which indicates there is no lithological selection by size. However, considering the selection of raw materials in making different types of artefacts, it is apparent that the Shuangshu toolmakers had a skillful understanding of the quality of different raw materials. Regarding small to medium sized débitage, the makers may have aimed to acquire sharp-edged flakes which can be used directly, as experimental and use-wear studies have revealed that flakes may not simply represent debitage or “waste” but rather a central component of the toolkit (Toth, 1982, 1985; Sussman, 1985, 1988; Schick and Toth, 2006). To this end, the quality of the local quartz, which can provide sharp, and can fracture easily, could be more favorable in this requirement. On the other hand, although quartz phyllite and trachyte cobbles are also abundant in the river bank, they were mainly used to make LCTs. Both of these raw materials are not homogenous and show internal fractures (see the experimental flaking in Fig. 12: a1, a2, a3 and b1, b2, b3). Nevertheless, they were still better for some tasks than the brittle quartz, which was less predictable for knapping large flakes or for directly making large-sized tools on cobbles. However, if suitable quartz was available, LCT makers did on occasion use it (see Fig. 12: 1).

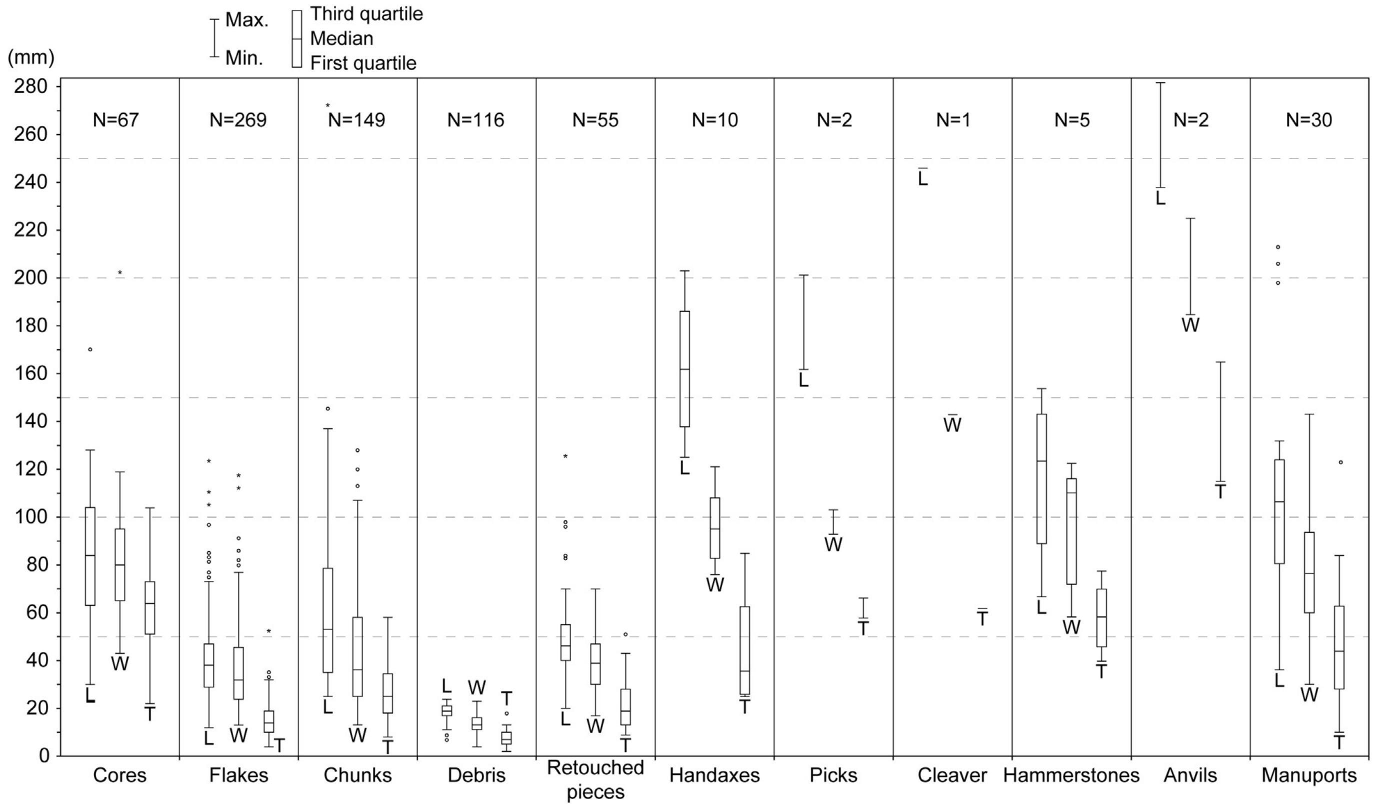

Fig. 6. Box plot of the length (L), width (W) and thickness (T) for different types of artifacts.

4.3. Small-medium sized débitage

4.3.1. Cores

In total, 67 cores were excavated from the site, 57 of them made of quartz (85.1%). The size of the cores was predominately small to medium, with average dimensions of 82.6L × 81.8 W × 61.7 T (mm) and an average weight of 591.7 g. The dominant flaking technique was free hand percussion, with only one bipolar core identified. Among the 66 free hand percussion cores, 46 (69.7%) are chopper (or chopper-like) cores, with 36 flaked on the cortical surface or on simply flaked surfaces (Fig. 9: 1–2), and with ten flaked on two unadjacent platforms. The other 20 (30.3%) cores show bifacial alternating flaking, in which the removals were struck on two adjacent surfaces with negative scars used alternatively as a striking platform to flake the other plane (Fig. 9: 3–4). A total of 98 platforms are present on the 67 cores. Among them, 40 are on natural cobble surfaces and 58 are on flaked surfaces, which supplied a flatter surface for flaking without the need of preparation (Fig. 9: 1–2). The high proportion of natural surfaces shows, however, that hominids tended to select cobbles that had suitable flaking surfaces from the beginning. This is demonstrated in Fig. 8, which shows that some raw materials are sub-angular in shape. The natural facets on these cobbles provide advantageous angles to facilitate the initiation of removals. Flake scars on the cores were low, with an average number of 3.8 scars per core, which reflects the abundance of raw material. Twenty-one cores had one to two flake scars, which makes them casual cores (Fig. 10). This technological data shows that the exploitation of cores was low and generally random.

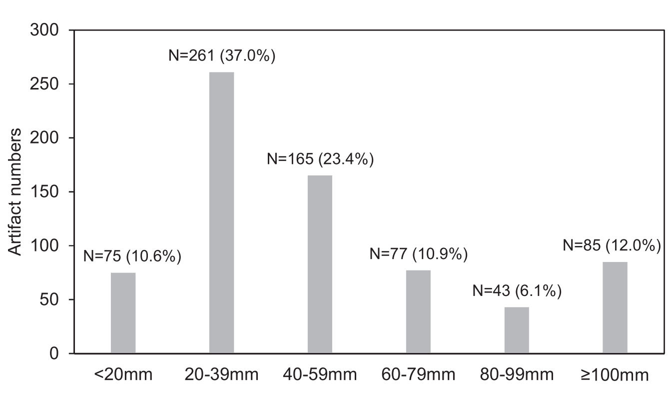

Fig. 7. Size profile for the Shuangshu assemblage.

4.3.2. Flakes

Of the 269 flakes recovered from the site, 232 are made of quartz (86.2%) (Fig. 9: 6–9). The size of flakes is generally small, with average dimensions of 40.7L × 36.4 W × 15.3 (mm) and an average weight of 31.0 g. The dominant flaking technique is free hand percussion, with only 17 bipolar flakes identified. Among the free hand percussion flakes ($n = 252$), 126 (50.0%) have cortical platforms, 124 (49.2%) have plain platforms, and only two (0.8%) have simple faceted platforms. With regards to the dorsal surface of the flakes, six (2.4%) are totally cortical, 150 (59.5%) have flake scars but lack cortex, and 96 (38.1%) show a mix of scars and cortex. A classification of flakes using Toth's (1985) method is shown in Fig. 11. Accordingly, about half of the flakes were likely in the advanced stages of flaking (type V, 20.6%; type VI, 29.0%), which is inconsistent with the low degree of flaking on the cores. However, the local quartz has natural fractures, causing it to break into chunks during the knapping process. If these chunks were used as cores, then flakes from advanced stages of production would be produced. This idea is supported by the numerous chunks from the site which will

Table 2
Tool types and raw materials.

Type	Quartz	Quartz phyllite	Trachyte	Quartzite	Sandstone	Total	%
Cores	57	5	4	1		67	9.5
Flakes	232	26	11			269	38.1
Chunks	121	23	4	1		149	21.2
Debris	116					116	16.4
Retouched pieces	48	7		1		55	7.8
Handaxes	1	5	4			10	1.4
Picks		2				2	0.3
Cleaver		1				1	0.1
Hammerstones	4				1	5	0.7
Anvils		1			1	2	0.3
Manuports	8	19	3			30	4.2
Total	587	88	26	3	2	706	100
%	83.1	12.5	3.7	0.4	0.3	100	

be described below. The total flake number ($n = 269$) is close to the flake scar number on all the cores ($n = 253$) confirming our technological observation of the cores and showing that extensive transportation of cores or flakes out of the site was not likely. One rejuvenation flake is present (Fig. 9: 12), showing the removal of the distal end of a handaxe (i.e., a tranchet flake that removes the convergent end of the piece).

4.3.3. Chunks

One hundred forty-nine chunks were found on site with 121 being made of quartz. The average size of chunks is small to medium, with average dimensions of 61.9L × 44.1 W × 29.2 T (mm) and an average weight of 178.9 g. These numerous quartz chunks reveal the easily-broken nature of the quartz. On average, cortex covered 65.3% of the chunks, showing that most were in the preliminary stages of production.

4.3.4. Debris

There were 116 pieces of debris (<25 mm) from the site, all of them made of quartz. Experimental results have shown that, if the proportion of small flaking debris (<20 mm) is 60–75%, the site should be regarded as in primary context without disturbance (Schick, 1986, 1997). Quartz debris at the Shuangshu site, however, only comprises 19.8% ($n = 116$) of the total quartz artifacts ($n = 587$), indicating the site was modified to a certain degree during the formation of the site.

4.3.5. Retouched pieces

In total, 55 retouched pieces were unearthed from the site, 48 made of quartz (Fig. 9: 10–11). The size of retouched pieces is small to medium, with average dimensions of 51.1L × 39.8 W × 21.3 T (mm) and an average weight of 53.0 g. On average, cortex covers 22.5% of each piece. Forty-eight pieces are made on small to medium flake blanks, five on chunks, and two on cores. The retouch is simple and the intensity is low. Single retouched edges dominate the assemblage. Among them, 24 are straight edges, 16 are convex edges and eight are concave, although four have double edges and three have edges retouched along the whole circumference of the flake. Retouched pieces form part of the small-medium artifacts' reduction sequence in terms of their raw materials, size and blanks. Hominids procured quartz from the local cobble layers and transported them into the site, then conducted simple flaking and retouch. Quartz phyllite and quartzite were also used in this sequence, but in a lower frequency (see Table 2).

Fig. 8. Lithic raw materials collected from gravels are sorted by size at a quarry on the bank of the Han River. The three enlarged images clearly demonstrate the size variation of cobbles from small to large. See details in the text.

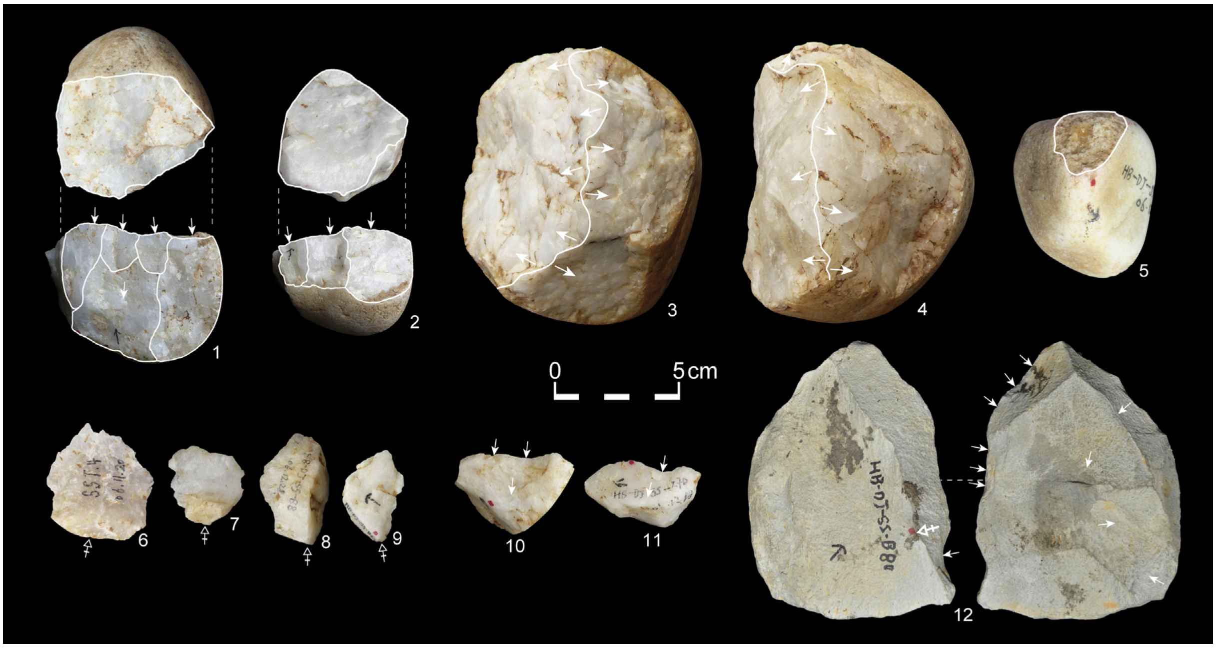

Fig. 9. Artifacts from Shuangshu: (1–2) SS-220, SS-392B: cores with simply flaked surface; (3–4) SS-376, SS-208: cores with bifacial alternating flaking; (5) SS-285, hammerstone; (6–9) SS-T4, SS-T19, SS-B8, SS-B64: flakes; (10–11) SS-119, SS-270: retouched pieces; (12) SS-B80, rejuvenation flake. White arrows show direction of the flake scars, and the hollow triangles indicate the strike direction (Black arrows record cardinal directions of excavated pieces).

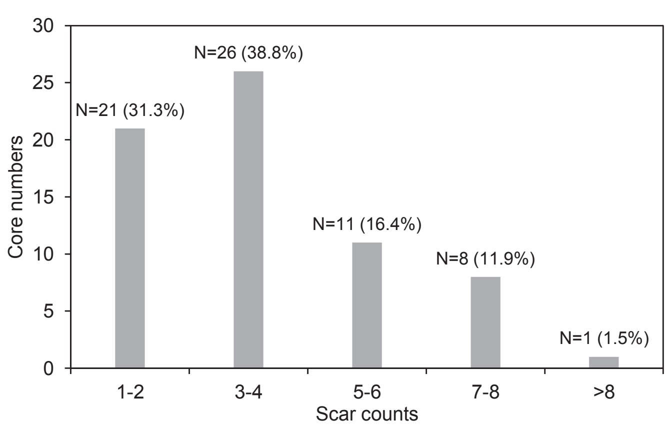

Fig. 10. The scar counts on cores.

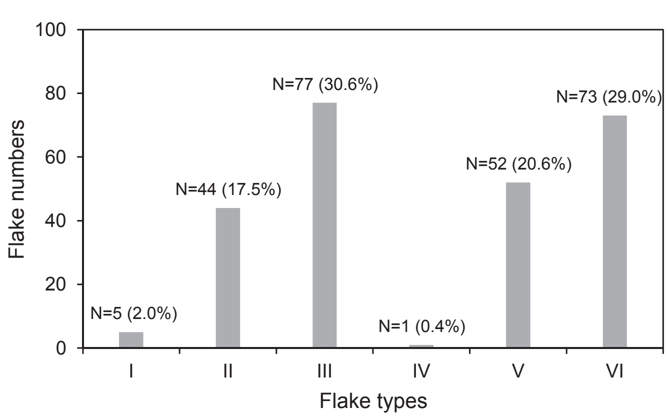

Fig. 11. The classification of flakes using Toth's (1985) method.

4.4. Large Cutting Tools production

Altogether, 13 LCTs were excavated. Ten of them are handaxes, two are picks and one is an atypical cleaver as it has a wide unretouched bit. Because of the importance of the in situ findings of LCTs in the Shuangshu site, individual information is provided for these 13 artifacts, together with the surface collected LCTs from Shuangshu for the comparative purpose in the section below (Table 3). The average dimensions of handaxes are 162.5L × 96.5 W × 44.0 T (mm) and the average weight is 749.6 g. Cortex averages 34.0% per piece. The average dimensions of picks are 181.5L × 98.0 W × 62.0 T (mm) and the average weight is 1165.0 g. The cortex average is 45.0% per piece. The dimension of the single cleaver is 246.0L × 143.0 W × 62.0 T (mm) and its weight is 2088.0 g. Cortex covers 30.0% of the tool surface. Two indices, Length/Breadth (elongation) and Thickness/Breadth (refinement) are thought to be useful variables for characterizing and discriminating LCT assemblages (Wynn and Tierson, 1990; White, 1998; Shipton and Petraglia, 2010). The average L/B (elongation) of handaxes and picks is 1.69 and 1.85 respectively, and the average for T/B (refinement) is 0.45 for handaxes and 0.63 for picks.

Five handaxes are made of quartz phyllite, four of trachyte and one is made of quartz. The two picks and single cleaver are both made of quartz phyllite. These facts reveal that the raw materials being exploited for the production of LCTs were different to the raw materials used to make small to medium sized artifacts.

Four handaxes are made on cobbles (Fig. 12: 1–4; Fig. 14: 1, 3, 5), five on large flakes (>10 cm) (Fig. 13: 1–4; Fig. 14: 2, 4, 6–8, 10), and one is indeterminate because of the intense weathering of this specimen. Of the two picks, one is made on a flake blank and the other on a split cobble blank (Fig. 14: 9). The solitary cleaver is made on a flake blank (Fig. 14: 10). The striking platforms of flake blanks are dominated by cortex, with an average of 40% of the dorsal face being cortex. These features show that most flake blanks are likely the primary flake, also called the cobble opening flake. This same situation occurs at the Ternifine site in North

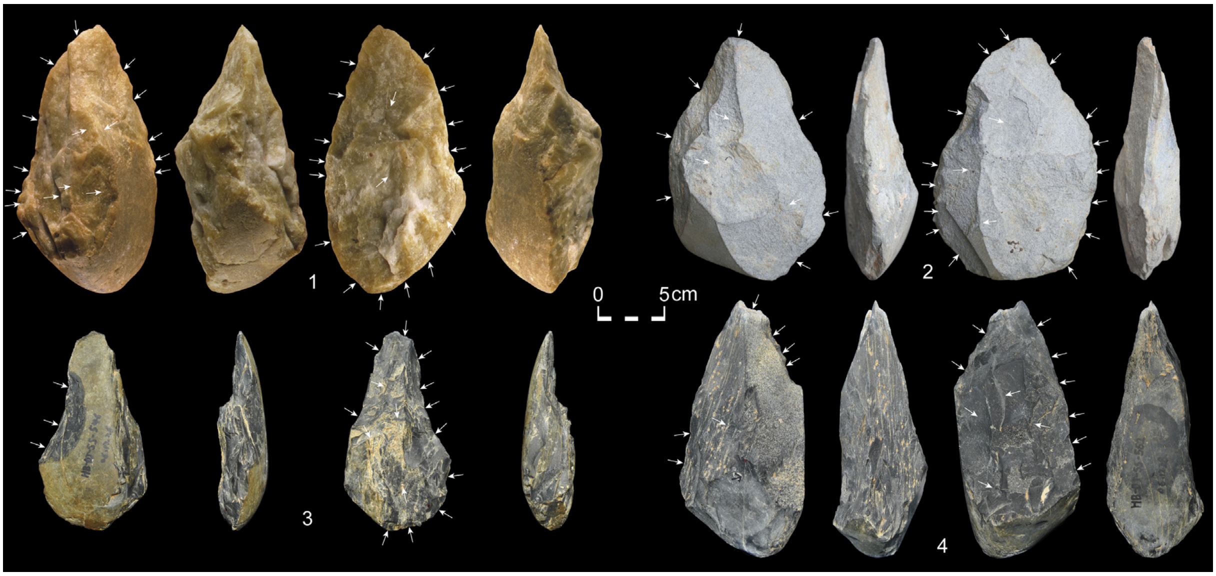

Fig. 12. Handaxes made on cobble blanks: (1) SS-244, quartz handaxe; (2) SS-T21, trachyte handaxe; (3) SS-546, quartz phyllite handaxe; (4) SS-562, quartz phyllite handaxe.

Africa, and the El Sartalejo site in Spain (Sharon, 2007). These kinds of blanks are typical and are regarded as an adaptation to the local raw materials. Comparisons were made with experimentally flaked stones (see Fig. 13: a1-3, b1-3 for the bipolar technique; Fig. 13: c1-3 for the throwing technique), which suggest the archaeological assemblages contains one bipolar flake (Fig. 13: 3; Fig. 14: 7) and one throwing flake (a cobble thrown against an anvil stone, Fig. 13: 4; Fig. 14: 4). This shows that various flaking techniques were used depending on the quality of raw material.

On the topic of shaping patterns, two handaxes are bifacially shaped, five are partly bifacial and two are unifacial. The picks and cleaver are all partly bifacial, indicating that partly bifacial was the main shaping pattern. There is an average of 19.1 shaping scars per piece, with a range between 35 and seven scars for individual pieces, showing a relatively high degree of variation (see Table 3). This also shows that toolmakers may employ intensive shaping sometimes. Secondary scars (with focus on the edges) are on average higher in number than primary shaping scars (with focus on the whole body), with a ratio of 13.0:6.3 secondary to primary scars (Table 4). This demonstrates that shaping was mainly focused on the edges of LCTs, although invasive flaking was conducted to obtain a predetermined form. Moreover, for the LCTs made on large flake blanks, average shaping scars on the ventral surface (usually flatter than the dorsal face) are almost twice as numerous as scars on the dorsal surface with a ratio of 11.0:5.2 (ventral to dorsal) (Table 4). This indicates sophisticated shaping technology compared with the relatively easier shaping of a convex surface into a flat one observed by Boëda et al. (1990) and de la Torre (2009).

Table 3
Data for LCTs from both excavation and surface collection at the Shuangshu site. Weight in grams, measurements in mm.

Number	Type	Weight	Length	Breadth	Thickness	L/B	B/L	T/B	Raw material	Blank	Scar counts
Excavated											
SS-244	Handaxe	1724.00	203.00	108.00	85.00	1.88	0.53	0.79	Quartz	Cobble	35
SS-495	Handaxe	828.00	179.00	101.00	60.00	1.77	0.56	0.59	Trachyte	Flake	29
SS-545	Handaxe	310.00	141.00	76.00	25.00	1.86	0.54	0.33	Quartz phyllite	Bipolar flake	12
SS-546	Handaxe	424.00	151.00	82.00	37.00	1.84	0.54	0.45	Quartz phyllite	Cobble	18
SS-562	Handaxe	1186.00	195.00	97.00	70.00	2.01	0.50	0.72	Quartz phyllite	Cobble	19
SS-576	Handaxe	456.00	147.00	83.00	35.00	1.77	0.56	0.42	Quartz phyllite	Flake	16
SS-T1	Handaxe	356.00	128.00	97.00	25.00	1.32	0.76	0.26	Trachyte	Flake	15
SS-T3	Handaxe	566.00	173.00	108.00	30.00	1.60	0.62	0.28	Quartz phyllite	Flake	7
SS-T10	Handaxe	426 (min)	125 (min)	92.00	26.00			0.28	Trachyte	Inderterminate	Inderterminate
SS-T21	Handaxe	1220.00	183.00	121.00	47.00	1.51	0.66	0.39	Trachyte	Cobble	28
SS-13	Pick	946.00	162.00	93.00	58.00	1.74	0.57	0.62	Quartz phyllite	Split cobble	12
SS-487	Pick	1384.00	201.00	103.00	66.00	1.95	0.51	0.64	Quartz phyllite	Cobble	22
SS-493	Cleaver	2088.00	246.00	143.00	62.00	1.72	0.58	0.43	Quartz phyllite	Flake	16
Surface											
10	Handaxe	494.00	135.99	81.27	47.54	1.67	0.60	0.58	Quartz phyllite	Cobble	15
19	Handaxe	318.00	126.33	78.10	32.41	1.62	0.62	0.41	Quartz phyllite	Bipolar flake	14
23	Handaxe	604.00	131.42	82.94	50.23	1.58	0.63	0.61	Quartz phyllite	Split cobble	20
26	Handaxe	572.00	134.61	77.22	57.07	1.74	0.57	0.74	Quartz phyllite	Cobble	29
28	Handaxe	760 (min)	141 (min)	100.33	49.88			0.50	Quartz phyllite	Bipolar flake	22
30	Pick	522	129.72	90.47	52.55	1.43	0.70	0.58	Quartz phyllite	Cobble	16
40	Pick	1284	193.26	127.95	58.33	1.51	0.66	0.46	Quartz phyllite	Flake	18
55	Cleaver	674 g	154.17	79.16	47.50	1.95	0.51	0.60	Quartz	Flake	30

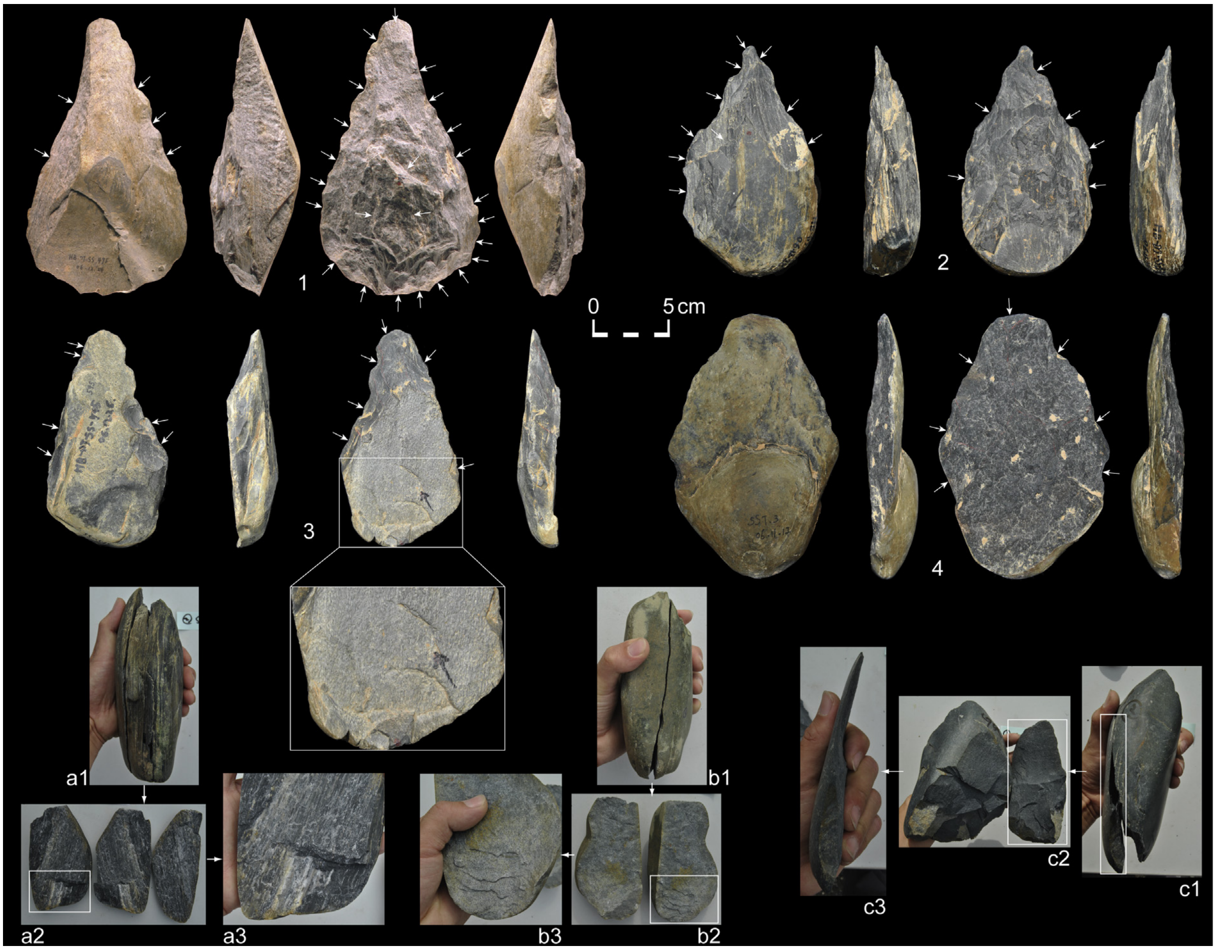

Fig. 13. Nos. 1–4 are Shuangshu handaxes made on flake blanks: (1) SS-495, trachyte handaxe; (2) SS-576, quartz phyllite handaxe; (3) SS-545, quartz phyllite handaxe made on a bipolar flake; (4) SS-T3, quartz phyllite handaxe made on a thrown flake. a and b represent the experimental bipolar technique using quartz phyllite and trachyte respectively, with crushing visible at the bottom of two bipolar flakes (a3 and b3). c represents the experimental throwing technique (a cobble thrown against an anvil stone) using quartz phyllite; note the small thickness of the flake.

4.5. Hammerstones and anvils

There were five hammerstones, four in quartz and one in sandstone. The average dimensions are 116.8L × 97.6 W × 58.4 T (mm) and the average weight 979.6 g. Hammerstones are mainly oval-shaped with flat-convex or double-convex cross sections. The use traces are small pits that are always concentrated on the convergent part of the cobble surfaces, indicating the skillful control of striking direction (Fig. 9: 5).

Two anvils were also found. One is quartz phyllite and the other is sandstone. The average dimensions of the two anvils are 260.0L × 205.0 W × 140.0 T (mm) and they have an average weight of 9976.0 g. The giant anvils at the site were likely not placed there by hydraulic processes, but rather they reflect the intentional transport of raw materials by hominids.

4.6. Manuports

Thirty manuports were discovered on site. Among them, 19 are quartz phyllite, eight are quartz and three are trachyte. The average dimensions are 108.4L × 79.2 W × 47.1 T (mm) and the average weight is 783.5 g. The size of the manuports is similar to the size of the cores and hammerstones, indicating that the manuports may have been wanted for cores or hammerstones. To a certain degree, the appearance of manuports combined with the hammerstones and anvils unearthed from the site suggest that the small-medium sized lithics were probably produced on-site.

5. Discussion

5.1. Technological strategies and attributes of the Shuangshu lithic assemblage

Analysis of the technology at the Shuangshu site show that there are two reduction sequences taking place. One is expressed by the small-medium sized artifact production, and the second reduction sequence is represented by the LCTs that are usually seen as the diagnostic implement of the Acheulean technocomplex. Raw materials, which were abundant in the nearby river banks, were procured by hominids and did not require long distance transport. There is a clear dichotomy in the raw material exploitation strategies in the two sequences, which demonstrates the preferences in the raw materials selectivity. Quartz was commonly used in the first sequence, while quartz phyllite and trachyte were predominately used in the making of LCTs.

The technology utilized in the small-medium artifacts production is simple and opportunistic, as seen through the technological analysis of flakes, cores and retouched pieces. The scar number on cores is low (3.8 on average) and most cores are simple chopper-cores, with the flaking platforms dominated by cortex or

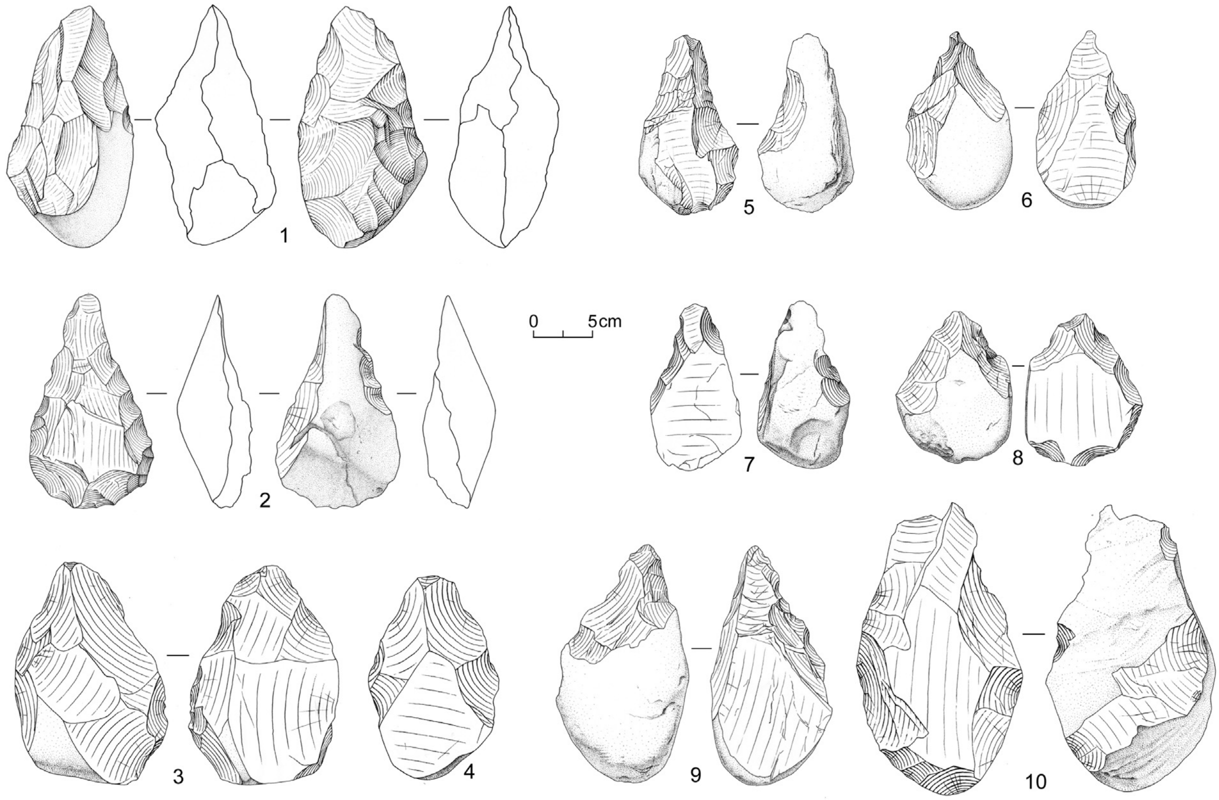

Fig. 14. LCTs from Shuangshu: (1–7) handaxes (see Fig. 12 and 13 for piece numbers); (8) SS-T1, trachyte handaxe made on a flake; (9) SS-487, quartz phyllite pick made on a split cobble; (10) SS-493, quartz phyllite cleaver made on a flake.

unprepared flaking surfaces. With regards to flakes, most have cortical or plain platforms, with irregular scar patterning dominating on the dorsal surface. For retouched pieces, the number of retouch scars is low and these can be regarded as the informal tools in the assemblage. All of these represent an expedient technological strategy used in the production of small-medium sized artifacts, which may be related to the abundant raw materials near the site. Meanwhile, the presence of all varieties of detached pieces–flakes, chunks and debris, the cores, the hammerstones, the anvils, and the manuports–indicates that the production, use and discard of small-medium sized artifacts was conducted on-site, and therefore represents a complete reduction sequence. In contrast, the technology of making LCTs is different to the small-medium sized artifact production. The blanks for making LCTs are large flakes, cobbles and split cobbles, among which large flakes are the most common blank (58.3%), although the occurrence of several blank types shows flexibility in the flaking techniques. The features of flake scars retained in the LCTs allow us to deduce that there was no core preparation before flaking occurred. The flaking was directly carried out on the carefully selected cobbles, and primary (or cobble opening) flakes were used to make LCTs. With respect to shaping, the number of secondary scars (13.0 on average) is higher than the number of primary shaping scars (6.3 on average), indicating that flaking was concentrated on the margins of the LCTs and these hominids paid more attention to getting effective edges.

Table 4
Mean and SD (in parentheses) of scar counts according to the type of shaping. PS means the number of primary scars; SS means the number of secondary scars; DFS means the number of scars on the dorsal face (for cobble blanks, convex face is treated as the dorsal); VFS means the number of scars on the ventral face.

Type	PS	SS	DFS	VFS
Handaxes ($N = 9$)	6.3 (2.8)	13.8 (6.8)	7.1 (4.9)	13.0 (6.7)
Picks ($N = 2$)	7.5 (2.8)	12.5 (4.2)	6.5 (2.1)	10.5 (4.9)
Cleaver ($N = 1$)	6	10	5	11
Combined ($N = 12$)	6.3 (2.5)	13 (6.1)	6.8 (4.3)	12 (6.0)

Table 5
Comparison of scar counts of handaxes from Chinese sites with western Acheulean sites.

	Scar counts				
	Age	*N*	Mean	SD	Reference
China					
DRR-Shuangshu	Middle Pleist	9	19.9	9.0	This paper
Baise-Fengshudao	ca. 803 ka	104	27.0	8.5	Wang et al., 2014b
Baise	ca. 803 ka	33	24.7	10.5	Hou et al., 2000
India					
Hunsgi	Middle Pleist	38	22.1	10.3	Sharon, 2007
Chirki	Middle Pleist	40	21.6	7.26	Sharon, 2007
West Asia					
Gesher Benot Ya'aqov II-6	<0.78 Ma	203	26.0	11.2	Sharon, 2007
Africa					
KGA6-A1 Locus C	~1.75 Ma	4	12.3	5.7	Beyene et al., 2013
KGA4-A2	~1.6 Ma	19	12.3	7.5	Beyene et al., 2013
KGA10-A11	~1.45 Ma	16	10.6	5.7	Beyene et al., 2013
KGA7-A1,A2,A3	~1.4 Ma	17	17.1	7.7	Beyene et al., 2013
KGA12-A1	~1.25 Ma	30	18.2	7.3	Beyene et al., 2013
KGA20-A1,A2	~0.85 Ma	19	30.4	10.9	Beyene et al., 2013
STIC	<0.7 Ma	70	24.8	11.3	Sharon, 2007
Ternifine	~0.7 Ma	48	19.1	10.5	Sharon, 2007
Grotte des Ours	~0.4 Ma	51	21.6	9.9	Sharon, 2007
Olorgesailie	0.7–0.4 Ma	[a]	25.4	9.1	Isaac, 1977

[a] Isaac (1977) only provides a table for the range of handaxe numbers utilized for scar counts (343–666).

Table 6
Comparisons between excavated and surface collected handaxes at the Shuangshu site. Weight in grams, measurements in mm.

	Excavated		Surface		*t*-statistic	*p*-value
	N	Mean	*N*	Mean		
Weight	9	785.56	4	497.00	1.077	0.313
Length	9	166.67	4	132.09	3.615	<0.05
Breadth	10	96.50	5	83.97	1.811	0.093
Thickness	10	44.00	5	47.43	−0.343	0.737
L/B	9	1.73	4	1.65	0.678	0.515
T/B	10	0.45	5	0.57	−1.250	0.233
Scar counts	9	19.9	5	20.0	−0.025	0.981

Table 7
Comparisons between excavated handaxes at the Shuangshu site and the surface collected handaxes from the DRR. Weight in grams, measurements in mm.

	Excavated		Surface		*t*-statistic	*p*-value
	N	Mean	*N*	Mean		
Weight	9	785.6	77	823.4	−0.266	0.791
Length	9	166.7	77	165.6	0.099	0.922
Breadth	10	96.5	86	96.5	−0.005	0.996
Thickness	10	44.0	86	46.5	−0.371	0.718
L/B	9	1.7	77	1.7	0.039	0.969
T/B	10	0.5	86	0.5	−0.583	0.573
Scar counts	9	19.9	75	18.0	0.604	0.561

However, the primary shaping, i.e. the invasive flaking, did play an important role in shaping of the whole body of LCTs, which is well demonstrated by the convergent distals and the shaped bodies of handaxes and picks. Table 5 presents a preliminary comparison of flake scar numbers of handaxes from Chinese sites and western Acheulean sites. It shows that the mean scar count of the Shuangshu handaxes ($n = 19.9$) is close to that of other sites, but at the lower end of the range. The mean scar counts on handaxes at Ternifine (ca 0.7 Ma) and five Early Acheulean localities (>1.0 Ma) at KGA are lower than at Shuangshu (Table 5).

Although the number of excavated LCTs at the Shuangshu site is low, we argue that they are an important type purposefully made by toolmakers and not a fortuitous development related to choppers. To demonstrate this, we conducted statistical comparisons between excavated handaxes and those from systematic surface collection in the DRR (Kuman et al., in press; Li et al., in press-b). If there are no statistically significant differences, it would support our argument that even if excavated examples are smaller in number, they are a consistent tool type, and probably penecontemporaneous with the more numerous surface-collected examples. At Shuangshu, five surface collected handaxes (see Table 3 for individual data) are compared with the 10 excavated handaxes from the site (Table 6). To further demonstrate the provenience of handaxes collected from the whole DRR, we then compare the 86 handaxes collected from the third terrace of the DRR with the ten handaxes excavated from the Shuangshu site (Table 7). In the comparative study, weight, length, breadth, thickness and the indices of L/B and T/B are used. In addition, the numbers of scars are considered. The Student's *t*-statistic in Table 6 shows that there is no significant difference in most cases between handaxes from excavation and from surface collection at Shuangshu. The only significant variation ($p < 0.05$) is the length, which is probably due to the small size of the sample. If a larger sample used, it is clear that there would be no significant difference (Table 7). Thus, it is reasonable to infer that the surface collected handaxes are penecontemporaneous with the excavated examples and, therefore, that handaxes excavated from the Shuangshu site were not an occasional production. Rather they reflected intentional type, most probably used for functions different to those for which the hominids used the small-medium sized artifacts.

The characteristic traits used to define typical Acheulean technology include (1) the ability to knock off large flake, (2) the ability to flake invasively and shape tools purposefully with predetermination or preconception of form, and (3) the standardization of tool technique (Isaac, 1969; Semaw et al., 2009; Beyene et al., 2013). Technological analysis of LCTs at the Shuangshu site on these traits

Table 8
Artifact numbers and densities for individual sites in China. LCT numbers are provided, with handaxe densities calculated by square meter.

Region	Site	Age	Excavation area	Artifacts		LCTs		LCTs from surface collection of the site	References
				N	Density (/m2)	*N*	Handaxe density (/m2)		
DRR (T3)	Shuangshu	Middle Pleist	1435 m^2	706	0.492	13 (10 handaxes, 2 picks and 1 cleaver)	0.007	8 (5 handaxes, 2 picks and 1 cleaver)	This paper; Li et al., in press-a
DRR (T3)	Beitaishanmiao	Middle Pleist	800 m^2	277	0.346	7 picks	[a]	27 (24 handaxes, 3 picks)	Zhou et al., 2009; Kuman et al., in press
DRR (T3)	Shuiniuwa	Middle Pleist	675 m^2	301	0.446	1 handaxe	0.001	5 (3 handaxes, 2 picks)	Chen et al., 2014; Kuman et al., in press
DRR (T3)	Pengjiahe	Middle Pleist	600 m^2	264	0.440	8 picks	[a]	7 (3 handaxes, 4 picks)	Pei et al., 2008; Kuman et al., in press
DRR (T3)	Beitaishanmiao II	Middle Pleist	500 m^2	159	0.318	9 (4 handaxes, 5 picks)	0.008	–	Fang et al., 2012
DRR (T3)	Guochachang II	Middle Pleist	500 m^2	150	0.300	4 (3 handaxes, 1 pick)	0.006	17 (6 handaxes, 9 picks and 2 cleavers)	Li et al., 2013; Kuman et al., in press; Li et al., in press-a
DRR (T3)	Waibiangou	Middle Pleist	500 m^2	121	0.242	1 handaxe	0.002	2 (1 handaxe, 1 pick)	Li et al., 2011; Recorded by H. Li
DRR (T3)	Datubaozi	Middle Pleist	300 m^2	58	0.193	1 handaxe	0.003	3 picks	Li et al., 2011; Recorded by H. Li
DRR (T2)	Liuwan I	Late Pleist	500 m^2	177	0.354	5 (3 handaxes, 2 picks)	0.006	5 (1 handaxe, 3 picks and 1 cleaver)	Feng et al., 2012; Recorded by H. Li
DRR (T2)	Houfang	Early Late Pleist	400 m^2	162	0.405	3 (2 handaxes, 1 pick)	0.005	–	Li and Sun, 2013
DRR (T2)	Dishuiyan	100–50 ka	–	>600	–	>20 handaxes	–	–	Liu and Feng, 2014
Baise Basin	Nanbanshan	ca. 803 ka	2500 m^2	176	0.070	11 (2 handaxes, 9 picks)	0.0008	7 handaxes	Wang et al., 2008; Huang, 2003
Baise Basin	Fengshudao	ca. 803 ka	49.3 m^2	155	3.144	6 (5 handaxes, 1 pick)	0.101	99 handaxes	Wang et al., 2014b

[a] At Beitaishanmiao, two of these picks were reclassified as handaxes (Kuman et al., in press); and at Pengjiahe, one handaxe was identified (Kuman et al., in press).

Table 9
Comparison of the thickness (in mm) of East Asian handaxes with western Acheulean examples.

Locality	Age	*N*	Mean	SD	CV	References
East Asia						
DRR	Middle Pleist	96	46.25	12.48	26.98	Li et al., in press-a
Baise	~0.8 Ma	168	69.87	13.67	19.56	Huang, 2003; Wang et al., 2014b
Luonan	<0.5 Ma	236	58.41	13.46	23.04	Wang, 2007
IHRB	<0.35 Ma	58	60.19	12.92	21.46	Norton et al., 2006
South Asia						
Anagwadi	Middle Pleist	15	45.73	6.04	13.21	Szabo et al., 1990; Petraglia and Shipton, 2008
Fatehpur V	0.35–0.16 Ma	11	40.91	11.36	27.77	Szabo et al., 1990; Petraglia and Shipton, 2008
Gulbal II	0.35–0.16 Ma	12	47.50	9.65	20.32	Szabo et al., 1990; Petraglia and Shipton, 2008
Hunsgi II	0.35–0.16 Ma	18	52.22	10.60	20.30	Szabo et al., 1990; Petraglia and Shipton, 2008
Hunsgi V	0.35–0.16 Ma	45	48.44	9.99	20.62	Szabo et al., 1990; Petraglia and Shipton, 2008
Mudnur VIII	0.35–0.16 Ma	9	61.11	9.28	15.19	Szabo et al., 1990; Petraglia and Shipton, 2008
Teggihalli II	Middle Pleist	9	33.86	11.54	34.08	Szabo et al., 1990; Petraglia and Shipton, 2008
Yediyapur I	0.35–0.16 Ma	10	36.00	5.16	14.33	Szabo et al., 1990; Petraglia and Shipton, 2008
Yediyapur IV	0.35–0.16 Ma	11	42.73	11.04	25.84	Szabo et al., 1990; Petraglia and Shipton, 2008
Yediyapur VI	0.35–0.16 Ma	21	42.86	13.09	30.54	Szabo et al., 1990; Petraglia and Shipton, 2008
West Asia						
Azraq Lion Spring	Middle Pleist	42	43.97	9.68	22.02	Petraglia and Shipton, 2008
Dawadmi 207–76	Middle Pleist?	27	52.04	22.02	42.31	Petraglia and Shipton, 2008
Wadi Fatima	Middle Pleist?	15	49.67	9.80	19.73	Petraglia and Shipton, 2008
West Europe						
Boxgrove	~0.5 Ma	182	30.59	5.66	18.51	Marshall et al., 2002
Broom Pits	0.29–0.23 Ma	241	36.22	10.20	28.16	Marshall et al., 2002
Corfe Mullen	0.5–0.38 Ma	131	37.94	12.30	32.42	Marshall et al., 2002
Cuxton	0.43–0.23 Ma	205	44.15	11.80	26.73	Marshall et al., 2002
North Africa						
Grotte des Ours	~0.4 Ma	40	43.81	6.79	15.50	Marshall et al., 2002
STIC	<0.7 Ma	82	54.64	10.64	19.47	Marshall et al., 2002
East Africa						
Olduvai EF-HR, Bed II	1.6Ma	22	46.91	10.25	21.85	Recorded by K. Kuman; Leakey, 1971
Olduvai Masek Beds	0.7–0.4 Ma	125	41.25	7.75	18.79	Marshall et al., 2002
South Africa						
Sterkfontein	~1.6 Ma	10	47.00	9.51	20.23	Recorded by K. Kuman; Kuman 1994, 1998; Field 1999
Rietputs 15 Pit1	1.72 ± 0.16 Ma	9	40.89	6.62	16.19	Recorded by K. Kuman; Gibbon et al., 2009
Rietputs 15 Pit5 (A)	1.32 ± 0.21Ma	77	41.58	9.70	23.33	Recorded by K. Kuman; Gibbon et al., 2009; Leader, 2009
Elandsfontein	1.0–0.6 Ma	232	40.13	11.19	27.88	Marshall et al., 2002
Amanzi Springs	Middle Pleist	133	53.69	11.22	20.90	Marshall et al., 2002
Doornlaagte	1.0–0.5 Ma	44	59.03	11.76	19.92	Marshall et al., 2002
Cave of Hearths	0.45/0.5 Ma	32	45.11	10.01	22.19	Marshall et al., 2002

indicates that all three are present at the site. Thus, it is sound to suggest that the attributes of Shuangshu site can be described as Acheulean, although its origins are much debated. However, regarding the attributes of handaxe-bearing sites in China, there are arguments that they cannot be classified as typical Acheulean, mainly because of their low frequencies and their noticeably morphological difference with western Acheulean handaxes (Norton et al., 2006; Lycett, 2007; Norton and Bae, 2008; Lycett and Bae, 2010; Lycett and Norton, 2010; Wang et al., 2012, 2014b). In following sections, we focus our discussions on these two points.

5.2. The meaning of the low number of handaxes in the Chinese handaxe-bearing sites

It is argued that one of the characteristic traits of the East Asian handaxe-bearing sites lies in the low number of handaxes from excavation sites (Norton et al., 2006; Norton and Bae, 2008). This argument is further supported by the Shuangshu site in this paper. Only 13 LCTs (including ten handaxes) were unearthed. However, the total number of artifacts (706) is also low for the size of the excavation area (1435 m^2). This can be seen as a pattern, as sites excavated at different handaxe-bearing regions in East Asia display the same quality. In Table 8, we provide the available information of the excavated handaxe sites from terrace three and terrace two of the DRR (eight sites on terrace three and three sites on terrace two), and from the Baise Basin (two sites). It shows clearly that both the number of handaxes and the overall size of complete assemblages is low for the size of the excavation area. The highest density of handaxes occurred at the Fengshudao site in the Baise Basin, where six LCTs including five handaxes were unearthed and the density of handaxes is 0.101/m^2. Nevertheless, the total number of artifacts is low, with only 155 specimens excavated from an area of 49.3 m^2 (Wang et al., 2014b). In contrast, the lowest density of handaxes (0.001/m^2) was found at the Shuiniuwa site in the DRR, with only one handaxe unearthed. The total number of artifacts at the Shuiniuwa site was low, with 301 specimens excavated from a 675 m^2 area (Chen et al., 2014). The Nanbanshan site in the Baise Basin had the lowest density of total artifacts; only 176 specimens were unearthed from an area of 2500 m^2. Of these, two were handaxes and nine were picks (Wang et al., 2008).

The comparative data provided here comfortably supports Norton et al.'s (2006), Norton and Bae (2008) observation. But, contrary to their argument that the low number of handaxes in the sites would not support the label true Acheulean to describe the East Asian handaxe-bearing sites, we suggest that the number of handaxes in a site is not the key criterion to judge if the site is true Acheulean or not. Rather it is the consideration of technological elements. We have proposed elsewhere that the proportion of LCTs in sites can be understood as a by-product of behavioral (or social) processes (Li et al., in press-b). The demographic model, for instance, has recently been considered as one of the most potent explanatory factors (Lycett and von Cramon-Taubadel, 2008; Lycett and Norton, 2010; Lycett and Bae, 2010; Kuman et al., in press). Based on the theory of genetic drift in population genetics, Lycett and Norton (2010) predict that the relatively smaller effective population size, which likely results from a combination of bio-

Table 10
Student's *t*-test comparing handaxe thickness. *p*-value <0.05 indicate significant differences and *p*-value <0.001 indicates very significant differences. Detailed information of the handaxe sites are given in Table 9.

	DRR	Baise	IHRB	Boxgrove	Broom Pits	Corfe Mullen	Cuxton	Grotte des Ours	STIC	Olduvai EF-HR, Bed II	Olduvai Masek Beds	Sterkfontein	Rietputs 15 Pit1	Rietputs 15 Pit5 (A)	Elandsfontein	Amanzi Springs	Doornlaagte	Cave of Hearths
DRR	–	<0.001	<0.001	<0.001	<0.001	<0.001	0.158	0.145	<0.001	0.819	<0.001	0.855	0.054	<0.05	<0.001	<0.001	<0.001	0.640
Baise	<0.001	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
IHRB	<0.001	<0.001	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.641	<0.001
Boxgrove	<0.001	<0.001	<0.001	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Broom Pits	<0.001	<0.001	<0.001	<0.001	–	0.173	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.175	<0.001	<0.001	<0.001	<0.001	<0.001
Corfe Mullen	<0.001	<0.001	<0.001	<0.001	0.173	–	<0.001	<0.001	<0.001	<0.05	<0.05	<0.05	0.253	<0.05	0.085	<0.001	<0.001	<0.05
Cuxton	0.158	<0.001	<0.001	<0.001	<0.001	<0.001	–	0.802	<0.001	0.293	<0.05	0.453	0.197	0.065	<0.001	<0.001	<0.001	0.662
Grotte des Ours	0.145	<0.001	<0.001	<0.001	<0.001	<0.001	0.802	–	<0.001	0.212	0.064	0.227	0.248	0.152	<0.05	<0.001	<0.001	0.531
STIC	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	–	<0.05	<0.001	<0.05	<0.001	<0.001	<0.001	0.540	<0.05	<0.001
Olduvai EF-HR, Bed II	0.819	<0.001	<0.001	<0.001	<0.001	<0.05	0.293	0.212	<0.05	–	<0.05	0.981	0.116	<0.05	<0.05	<0.05	<0.001	0.524
Olduvai Masek Beds	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.05	0.064	<0.001	<0.05	–	<0.05	0.892	0.799	0.268	<0.001	<0.001	<0.05
Sterkfontein	0.855	<0.001	<0.001	<0.001	<0.001	<0.05	0.453	0.227	<0.05	0.981	<0.05	–	0.127	0.100	0.057	0.069	<0.05	0.602
Rietputs 15 Pit1	0.054	<0.001	<0.001	<0.001	0.175	0.253	0.197	0.248	<0.001	0.116	0.892	0.127	–	0.835	0.840	<0.001	<0.001	0.242
Rietputs 15 Pit5(A)	<0.05	<0.001	<0.001	<0.001	<0.001	<0.05	0.065	0.152	<0.001	<0.05	0.799	0.100	0.835	–	0.308	<0.001	<0.001	0.090
Elandsfontein	<0.001	<0.001	<0.001	<0.001	<0.001	0.085	<0.001	<0.05	<0.001	<0.05	0.268	0.057	0.840	0.308	–	<0.001	<0.001	<0.05
Amanzi Springs	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.540	<0.05	<0.001	0.069	<0.001	<0.001	<0.001	–	<0.05	<0.001
Doornlaagte	<0.001	<0.001	0.641	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.05	–	<0.001
Cave of Hearths	0.640	<0.001	<0.001	<0.001	<0.001	<0.05	0.662	0.531	<0.001	0.524	<0.05	0.602	0.242	0.090	<0.05	<0.001	<0.001	–
Significant differences (%)	**64.7**	**100.0**	**94.1**	**100.0**	**88.2**	**82.4**	**58.8**	**52.9**	**94.1**	**64.7**	**76.5**	**47.1**	**35.3**	**58.8**	**70.6**	**88.2**	**94.1**	**58.8**

geographical, topographical and dispersal factors, may be an underlying cause of the sporadic occurrences of handaxe technology both geographically and temporally. According to the pattern of numbers revealed in Table 8, we are in agreement with Lycett and Norton's opinion that the relatively small effective population size in East Asia is probably the reason for the low number of handaxes, as well as the small size of assemblages in the sites. However, we suggest (contra Lycett and Norton) that although the population size is relatively small, the (handaxe) technological transmission from generation to generation was uninterrupted and finally formed a stable social or cultural tradition in a given region. The findings of handaxes on different terraces of the DRR offer evidence for this (Pei et al., 2008; Zhou et al., 2009; Feng et al., 2012; Li and Sun, 2013; Li et al., 2013; Liu and Feng, 2014; Chen et al., 2014; Kuman et al., in press). The systematic dating of handaxe-bearing sites on different terraces in the future will further test this assumption.

In addition to the demographic explanation, the usage strategy of the sites and the high mobility of hominids are also probable factors in the low number of handaxes and total artifacts (Gao and Pei, 2006; Gao, 2013). The relatively uniform river terrace habitat and the stable sub-tropical climate and resources of DRR in the Pleistocene provided a good environmental setting for frequent mobility from one site to another homogeneous site, and therefore the occupation of the terrace sites could be ephemeral. The expansive intermountain basin area and the developed and mutually related water system appear to have provided space and routes for high mobility. This explanation is supported by the recent discovery of handaxe sites in the vicinities of the DRR, for example, the Hanzhong Basin in the upper valley of the Han River and the Shangdan Basin in the upper valley of the Dan River (Wang et al., 2013; 2014a). However, greater concentration of handaxes did seem to happen at some sites, such as the Beitaishanmiao site in the DRR (27 LCTs including 24 handaxes were retrieved; see Kuman et al., in press) and the Fengshudao in the Baise Basin (99 handaxes were retrieved; see Wang et al., 2014b). Hou et al. (2000) also argued that there is a biased spatial distribution of LCTs in the Baise Basin, with Acheulean-like forms limited to the western third of the basin. Whether this a place-specific pattern or just sample bias is the question that needs to be addressed in future research, especially combined with the geographic and raw material features around the sites.

5.3. *The inter-regional comparison of handaxe thickness*

We argued above that the handaxe industry in the DRR can be considered true Acheulean, although the numbers of handaxes are relatively small. Here, we further demonstrate this through the inter-regional comparison of one measurement, thickness, which is widely considered to be another characteristic variable when comparing handaxes from the East and the West (Norton et al., 2006; Norton and Bae, 2008; Petraglia and Shipton, 2008; Shipton and Petraglia, 2010; Lycett and Bae, 2010; Wang et al., 2014b). The East Asian materials used here are from the DRR and the Luonan Basin in central China (Li et al., in press-a; Wang, 2005, 2007), the Baise Basin in South China (Huang, 2003; Wang et al., 2014b), and the IHRB in South Korea (Norton et al., 2006). The western Acheulean sites are from South Asia (India), West Asia (Arabia and Jordan), West Europe (Britain) and Africa (Morocco, Tanzania, South Africa) (Marshall et al., 2002; Petraglia and Shipton, 2008). The ages of these handaxe assemblages span from the beginning of Acheulean technology (~1.72 Ma) to the final stage of the Acheulean (~0.3 Ma).

The mean thickness of handaxes from each region or site is given in Table 9. We can see that the East Asian sites of Baise, Luonan and IHRB have higher mean thickness than most of the western Acheulean sites, whereas the mean thickness of the DRR handaxes (46.25 mm) overlaps considerably with some western Acheulean sites (both early and late Acheulean sites). Student's *t*-statistic of the mean thickness of handaxes between pairs of regions or sites in Table 10 indicates that the three East Asian handaxe assemblages, i.e. DRR, Baise and IHRB, are significantly different from each other ($p < 0.001$), showing distinct variability within the East Asian sites. Of these, the Baise handaxes are significantly different from all other handaxe assemblages from the East and the West, while the IHRB handaxes have a 94% difference, and the DRR handaxes have a lower difference of 64.7%. This means the thickness of DRR handaxes is much closer to that of the western Acheulean examples (Table 10). Detailed examination of mean thickness among western Acheulean sites, however, also indicates considerable variability. Of the 15 western Acheulean sites, nine of them (60%) show the same or an even higher percentage ($\geq$64.7%) of significant difference when compared with other sites (Table 10). According to the statistical results presented here, we argue that thickness is likely not a reliable variable to demonstrate the difference between the East and the West. As we have discussed elsewhere (see Li et al., in press-a), some factors, such as the quality of raw materials, the blank types or the extent of reduction could easily result in significant variability of handaxe thickness, regardless of geographical differences.

6. Conclusions

In this paper, the detailed technological analysis of the in situ artifact assemblage in the Shuangshu site, as well as the intra- and inter-regional comparisons on some characteristic traits of handaxes allow the reconstruction of full technological strategies and behaviors of early hominids. The features revealed in the study are as follows:

- the procurement of raw materials were from the locally available river cobbles;
- the preferential selection of different raw materials for different technical processes, which indicates a good knowledge of raw material properties;
- the predominant use of quartz in the production of small-to-medium sized artifacts, which dominates the whole assemblage and shows an expedient technological strategy;
- the predominant use of quartz phyllite and trachyte in the production of LCTs, which displays the technical criteria required to define Acheulean technology;
- the co-existence of two distinct reduction sequences at the site indicates flexible technological strategies and the diverse survival needs;
- the comparative analysis of the number of handaxes indicates that both the LCTs and the total artifacts are generally low in numbers when compared with the large excavation area, and this was probably due to the relatively smaller population size and the high mobility of hominids;
- the comparative analysis on the thickness of handaxes indicates that it is not a reliable variable in demonstrating the handaxe differences between the East and the West.

In conclusion, the Shaungshu site provides us a window to research the technology and behavior of the hominids that lived in the Middle Pleistocene in central China. Given the importance of these materials, further work in the Danjiangkou Reservoir Region is still needed, especially on dating, site formation process, landscape use and the technological strategy contained in the in situ assemblages. These in-depth analyses in this region will give us a better understanding of the technological and behavioral evolution of the Middle Pleistocene's populations in China.

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Re-examination of the morphological variability of East Asian handaxes from a comparative perspective

Re-examination of the morphological variability of East Asian handaxes from a comparative perspective

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Abstract

In this article, we report on a re-examination of the morphological variability of East Asian handaxes through study of handaxes from sites generally considered to be Middle Pleistocene in age and by carrying out detailed small-scale comparisons. In particular, we add data for a new handaxe assemblage found in the Danjiangkou Reservoir Region, central China. We begin with an analysis of the range of handaxe morphological variability in different regions (Africa, West Europe and East Asia) and conclude that the variability in the East Asian sites is not significantly different from that found in the western Acheulean. Moreover, the variability present in East Asian handaxes reflects the flexible adaptation strategies of Acheulean hominids. In explaining the morphological variability of East Asian handaxes, we adopt a stepwise approach for a comprehensive analysis, from the most fundamental level factors, such as raw material and reduction intensity, to higher-level factors like cultural tradition and cognitive ability. The results indicate that East Asian handaxe variability was influenced by multiple factors, to be discussed in this article. Also through comparative morphological analysis, we argue that there are specific regional influences that have explanatory value. The analysis of such regional factors is necessary for a better understanding of this subject.

Keywords

Acheulean; handaxe; East Asia; morphological variability; stepwise approach.

Introduction: an overview of hypotheses on handaxe morphological variability

Following the cultural history paradigm focused on the typological approach, the handaxe was distinguished from other tool types by its distinctive morphology and became representative of the Acheulean industrial complex (Bordes 1961). In addition, because of the simultaneous emergence of the handaxe and *Homo ergaster* (or *Homo erectus*), the handaxe, as the first purposely shaped stone tool, was regarded as an important expression of early human cognition

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and the ability of humans to follow a mental template to create the handaxe shape (e.g. Gowlett 1986; Wynn 2002; Pelegrin 2009; Goren-Inbar 2011; Stout 2011). Thus the investigation of handaxe morphology has been of prime interest since its first discovery, particularly as handaxes are usually the most intensively shaped types in an Acheulean assemblage.

In the course of this research, methods developed by Bordes and Roe for study of handaxe shape played a landmark role. Their methods, developed in the middle of the last century, led the transition from qualitative morphological analysis to one that was quantitative (Bordes 1961; Roe 1964, 1968). The measurement system and indices are still extensively used by today's researchers. However, confined by the cultural history paradigm of that time, the quantitative methods of Bordes and Roe were mainly used for the classification of handaxes, with very little discussion of the reasons for their morphological variability. With the development of Palaeolithic studies, many scholars were not satisfied with simple typological studies and the view of the Acheulean as a single cultural tradition, and hence they began to search for other hypotheses to explain the morphological variability of handaxes.

Ashton and McNabb (1994) were the first to question Roe's hypothesis that different traditions were the explanation for two distinctive morphological handaxe types – ovate and pointed – in the British Palaeolithic. They argued that the existence of the two different morphologies in Britain was not the result of different knapping traditions but was more likely to have been influenced by the type, size and quality of raw materials. The raw materials of ovate handaxes were the large flint or chert nodules often found in a primary geological context. The large size provided enough volume for the application of shaping technology, and these nodules (or the large flakes detached from nodules) could therefore be used to make ovate and other well-made handaxes. On the other hand, the raw materials used to make pointed handaxes derived from river gravels, which were smaller and generally of poorer flaking quality, and so the handaxes made from these materials usually had a pointed distal end and thick cortical butt. Through the continued analysis of handaxe assemblages in Britain, White (1995, 1998) confirmed that raw material was the main factor influencing the variability in handaxe morphology. Knappers adopted flexible technological solutions in response to the raw material, and the final goal was to obtain the lengthiest usable edge with the minimal time and energy.

Subsequent to this raw material hypothesis, McPherron (1995, 1999, 2000) proposed another hypothesis based on the re-sharpening model proposed by Dibble (1987). Reduction intensity was regarded by McPherron as the main factor influencing the morphological variability of British handaxes. In particular, McPherron hypothesized that the different morphologies presented in handaxes were a reflection of different reduction intensity or reduction stages. At the beginning of the reduction, the morphology of handaxes was dominated by their being pointed and thick. In the process of reduction, handaxe morphology moved from pointed to ovate forms with less thickness. Thus, rather than being the result of a mental template in the mind of tool knappers, the morphological differences in handaxes were a by-product of the reduction process, which was remarkably similar in various parts of the Old World and at various times in the Middle and Late Pleistocene. In a similar hypothesis, Davidson and Noble (1993) proposed that differences in handaxe morphology were merely the result of a repertoire of flaking habits used by Acheulean people and do not prove the existence of mental templates. In other words, the concept of the intended final form of a handaxe was an assumption by archaeologists.

Evidence for both the raw material and reduction intensity hypotheses can be found in the British materials. However, both hypotheses denied the cultural tradition hypothesis proposed by Roe (1968), which led some researchers to reconsider the probable role of cultural factors in handaxe morphology. From a study of handaxe assemblages at the Red Barns and Cuxton sites in Britain, Wenban-Smith, Gamble and Apsimon (2000; Wenban-Smith 2004) came to the conclusion that cultural tradition or mental templates in the knapper's head did influence the morphology to a great extent. They posited that the correlation of handaxe morphology with raw materials was probably the result of the intentional selection of rocks according to existing mental templates. In addition, *contra* the raw material hypothesis proposed by Ashton and McNabb (1994) and White (1995, 1998) that pointed handaxes cannot be made ovate because of the material restrictions. Wenban-Smith, Gamble and Apsimon (2000) provide some examples of very refined pointed handaxes, such as the symmetrical shoulder pointed handaxes. They argued that their production was not limited by raw material but was the deliberate choice of knappers. Their findings also contradicted the reduction intensity hypothesis because of the refined and symmetrical morphology of these pointed handaxes, which showed intensive reduction.

The ongoing discussions and debates on British handaxe morphology led to important inspirations on the interpretations of the morphological variability of handaxes in other parts of the Old World. Crompton and Gowlett (1993; Gowlett and Crompton 1994; Gowlett 2006) examined morphological variability at two East African sites, Kariandusi and Kilombe. They concluded that size-related allometry is a major factor in the variability of handaxe morphology and this allometry was probably imposed in response to the functional requirements of handaxes. Moreover, through an analysis of the relative breadth and length of handaxes from Africa and Europe, Gowlett (2011) concluded that a ratio of 1:2 was preferred for long handaxes, which implied that a sense of proportion was possessed by Acheulean people. This sense of proportion was presumably formed over a long period of social transmission through the search for technological success. In contrast, McNabb, Binyon and Hazelwood (2004) analysed handaxes from several Acheulean sites in South Africa and argued that the influence of strong social learning that imposes communally sanctioned practices in manufacture and end product was absent. They concluded that no cultural requirement of form or practice existed among manufacturers. In addition, in Noll and Petraglia's (2003) comparative study of Acheulean assemblages from the Hunsgi-Baichbal Valleys in India and Olorgesailie in East Africa, they detected an overlap in overall size range and a preferential selection of large outcrops for acquisition in both regions, indicating to them some shared patterns in behaviour. However, there was also some variability in morphology mainly due to the raw material type and flaking intensity. For example, at Olorgesailie, the inter-assemblage comparison showed that the older handaxes from Member 1 (I3) were smaller than all the younger Member 6/7 handaxes, which also showed less rejuvenation. And at the Hunsgi-Baichbal Valleys, limestone handaxes from the Hunsgi Valley are larger than granite and dolerite handaxes from the Baichbal Valley.

With the development of evolutionary psychology and research objectives shifting from the materials to the person, some anthropological archaeologists have put effort into explaining the variability of handaxe morphology with reference to people. One such attempt is the identification of individual influence on morphology (Gamble 1999; Gamble and Porr 2005). It is believed that there was a range of different skills and abilities among different knappers, with the talented makers successfully manufacturing more refined and symmetrical forms (Stout 2002; Petraglia 2006). Although it is still difficult to link a particular form with an individual, it does provide a new perspective to seek small-scale human behaviour within well-preserved site contexts. In addition, the gender of makers might also play a role because of the sexual dimorphism between male and female (Kohn and Mithen 1999; Mithen 2005), such as the different degree of muscularity (Petraglia 2006). As Petraglia (2006) said, certain types of stone-tool reduction were probably carried out mostly by adult males, who would have possessed the manual strength needed for the consistent and frequent production of large side-struck flakes in making handaxes and cleavers. Overall, although the exploration of handaxe morphological variability from these anthropological perspectives is difficult to determine compared with factors such as group adaptation and social tradition (which equates to a large time-averaged assemblage), they do give us new perspectives in the interpretations of morphological variability.

Through this short review of various hypotheses on variability in handaxe morphology, we can envision different explanations in different regions, and there could even be different explanations in different sites within the same region. No single explanation can account for morphological variability across the Old World, and sometimes no single explanation is satisfactory even for one region since that could be influenced by multiple interconnected factors. Therefore, we should conduct specific analysis according to each site or region.

Current knowledge of morphological variability of East Asian handaxes

The handaxes found in East Asia, which is regarded as a broad geographical unit at the other end of the Old World from Africa and Eurasia, definitely play an important role in understanding variability in the morphology of these tools. Through a comparison of handaxe morphology among the Imjin/Hantan River Basins (IHRB) in South Korea, the Hunsgi-Baichbal Valleys in India and Olorgesailie in Kenya, East Africa, Norton et al. (2006) observed that IHRB handaxes have a distinctive morphological difference from typical western Acheulean handaxes, especially in their thickness. The authors posited that the large thickness could be a result of the original shape of the clasts and blanks used, as handaxes from East Africa were mostly produced on large flakes, while in general the IHRB handaxes were produced on thick river cobbles. Subsequently, Lycett and Bae's (2010) analysis of East Asian handaxes included material from the Luonan Basin, which is located in Central China. The results of the comparative morphological analysis with western Acheulean handaxes still showed that both Luonan and IHRB handaxes are thicker than western Acheulean handaxes. Lycett and Bae (2010) consider such thickness differences to be significant enough to suggest technological convergence. In addition, Wang et al. (2012) analysed the handaxes from the Bose Basin in South China. The results of their multivariate morphometric comparative analysis of the Bose handaxes and with western Acheulean examples showed that the morphology of western handaxes is different from the Bose examples to a statistically significant degree. This is consistent with the results from Luonan and IHRB in that some researchers consider such shape differences suggestive of a convergent technology in East Asia. However, Petraglia and Shipton's (2008) comparative analysis of handaxes from three regions of East Asia (IHRB, Bose and Luonan) and from sites in Africa, Europe, the Middle East and India drew a slightly different conclusion: that the East Asian handaxes overlap morphologically with the thickest and least refined western Acheulean localities. However, given the lack of cleavers and the predominance of core and flake industries in IHRB and

Bose, the potentially younger age of localities in IHRB and the rarity of bifacial flaking together with the much thicker and heavier handaxe body in Bose, the similarity between the two regions was regarded as a product of technological convergence. Although the handaxes in Luonan are also slightly thicker and less refined than most western Acheulean assemblages, the identification of a large number of typical cleavers in this region allows us to conjecture that they are probably the result of hominids with knowledge of Acheulean tool-making strategies dispersing into East Asia from a western location (Petraglia and Shipton 2008; Shipton and Petraglia 2010).

In terms of the concept of the 'Movius Line', which considered East Asia as a backwater in technological development, having only a Mode 1 core and flake industry and no genetic or cultural contacts with outsiders (Movius 1948, 1969), these studies on East Asian handaxes give us a new view of the diversity and complexity of the Early Palaeolithic in this vast region. Moreover, they provide more evidence for our understanding of the Acheulean populations' adaptive and survival strategies in different regions of the Old World. There were, however, some limitations to the morphological analyses conducted, which to some degree affected explanations of handaxe morphology. First, Lycett and Bae's (2010) comparison of handaxe morphology on both sides of the 'Movius Line' adopted the coarse averaged values of western Acheulean handaxes from different continents. This kind of comparison masks potential variability among the different regions, and therefore it cannot reveal the morphological characteristics or explain the regional morphological variability fully. Second, different types of large cutting tools have sometimes been combined when conducting comparisons. For instance, handaxes and cleavers from Luonan Basin were combined as bifaces in Shipton and Petraglia's (2010) analysis, while, handaxes, cleavers, knives and picks were combined in Noll and Petraglia's (2003) analysis, and these data were then directly quoted by Norton et al. (2006). Third, although Petraglia and Shipton (2008) were aware of these problems and made their comparative analysis at the local level and exclusively on handaxes, consideration of the age of the localities was still lacking in their analysis. Earlier studies have revealed that there is a relatively clear development process in the Acheulean industrial complex, from the early to middle and later Acheulean stages (Kuman 2014). Changes in technology and morphology happened in stages. Thus, because of the large age range of the handaxe assemblages selected by Petraglia and Shipton (2008), this is disadvantageous for our understanding of East Asian handaxes, all of which are probably located in the Middle Pleistocene (Hou et al. 2000; Wang 2005; Norton et al. 2006; Li et al., forthcoming). Finally, the studies focused primarily on the emergence of handaxes to explain the morphological variability. Technological convergence or spread was thought to be the main factor in the morphological variability of East Asian handaxes (Petraglia and Shipton 2008; Shipton and Petraglia 2010; Lycett and Bae 2010). Although other factors, such as the raw material, the selection of blanks, flaking intensity and tool functions, were also mentioned, these more fundamental factors were not systemically compared and discussed in their analyses (Norton et al. 2006; Petraglia and Shipton 2008).

By studying only the handaxe sites generally considered to be Middle Pleistocene in age and by carrying out a detailed small-scale comparison, especially adding a new handaxe assemblage found in the Danjiangkou Reservoir Region (DRR), Central China, this article focuses on interpreting the morphological variability of East Asian handaxes in a comparative perspective with handaxes from the western part of the Old World.

Materials and methods for re-examination

This regional comparison benefits greatly from the 'Bifaces Database' built by Marshall et al. (2002). According to the requirements of our analysis, we have chosen ten handaxe sites from Africa and Europe for comparison with East Asian sites (see Table 1 for detailed information on each locality or region). All of these sites are considered to be Middle Pleistocene. The four sites from Europe are slightly younger, i.e. middle and late Middle Pleistocene, while the sites from South Africa are less well dated and some may be slightly earlier than the Middle Pleistocene (Table 1). The handaxe sites in East Asia are from four regions: IHRB, Bose Basin, Luonan Basin and DRR (Fig. 1). The age of handaxe sites in the IHRB, South Korea, has been regarded as mid-Middle Pleistocene (Norton et al. 2006; Bae, Bae and Kim 2012), and the age of three handaxe-bearing regions in China has generally been considered to be Middle Pleistocene (Hou et al. 2000; Wang and Huang 2001; Wang 2005; Lu et al. 2007; Wang, Mo and Huang 2008; Li. Li and Kuman 2013; Wang et al. 2014; Li et al., forthcoming). Further dating work on these three regions would construct a sounder age framework for the Chinese handaxe industries. The handaxes in the DRR are from both surface collections and excavations (Fig. 2; see Appendix for raw data). Given the significant role of Marshall et al.'s (2002) database, individual information on the DRR handaxes is provided in an appendix for other researchers' utilization. It should be noted that, because of the small number of handaxes in the East Asian localities, it made less sense to do the statistical comparison at the locality level. Therefore, the data from each region of East Asia were regarded as a whole and compared with the data from each western Acheulean locality.

With regard to the selection of measurements and indices, although the 'Bifaces Database' (Marshall et al. 2002) supplies very detailed morphological attributes, our comparative attributes from East Asian sites are currently limited by the available published data, except for the DRR data which are already in hand. Therefore, we chose measurements and indices available for both sides of the 'Movius Line', namely weight, length, width, thickness, L/W (elongation) and T/W (refinement). The breakdown of the information is given in Table 2.

Quantitative methods are used to reveal the morphological correlations of different localities. The measurements and indices of handaxe morphology are analysed with descriptive statistics (e.g. means, standard deviations) and multivariate statistics (e.g. principal components analysis, hierarchical cluster analysis). For better interpretation of morphological variability, the stepwise approach, which is a concept borrowed from Isaac (1986), will be adopted to explain morphological variability. In this concept, morphology is influenced by several factors, such as raw material, shaping technology, subsistence ecology, mental template or cultural tradition. All these factors will be assessed in sequence (Fig. 3). The fundamental level includes mainly factors which are readily visible in lithics, such as raw material, blank type and reduction intensity. After the detailed analysis of the lowest level, we then move on to the middle level which includes palaeoecology and functional activities carried out by hominids. The analysis of these influences will benefit our understanding of adaptations to the local environment. Finally, the top level includes such factors as cultural tradition (or mental template) and cognitive ability, which are less obvious and require more cautious interpretation. With this stepwise approach, we will conduct specific analysis of the most controversial factors in the earlier studies to see which have influenced East Asian handaxe morphological variability.

Table 1 Sites used in comparative analysis

Locality	*Continent*	*Country*	*Number*	*Age*	*Sedimentary context*	*References*
Grotte des Ours	North Africa	Morocco	40	~0.4Ma	Cave deposits	Biberson 1961; Raynal et al. 2001
STIC*	North Africa	Morocco	82	<0.7Ma	Cave deposits	Biberson 1961; Raynal et al. 2001
Olduvai Masek Beds	East Africa	Tanzania	125	0.7–0.4Ma	Aeolian tuff and detrital deposits	Leakey and Roe 1994
Elandsfontein	Southern Africa	South Africa	232	1.0–0.6Ma	Thin palimpsests in dune sands formed on land surface near waterhole	Malan 1962; Klein 1978; Klein et al. 2007; Kuman 2007
Amanzi Springs	Southern Africa	South Africa	133	Middle Pleistocene	Disturbed spring mound	Inskeep 1965; Sampson 1974; Kuman 2007
Doornlaagte	Southern Africa	South Africa	44	1.0–0.5Ma	Pan margin sands: a lag of multiple occupations	Butzer 1974; Mason 1966; Kuman 2007
Boxgrove	West Europe	England	182	~0.5Ma	Sands, gravels, lagoonal silts and palaeosols	Pitts and Roberts 1998; Roberts and Parfitt 1998
Broom Pits	West Europe	England	241	0.29–0.23Ma	Gravels and fine-grained deposits	Roe 1981; Wymer 1999
Corfe Mullen	West Europe	England	131	0.5–0.38Ma	Terrace deposits of the extinct Solent River drainage system	Roe 1981; Wymer 1999
Cuxton	West Europe	England	205	0.43–0.23Ma	Gravel and sand deposits, overlain by a thick loam layer	Roe 1981; Wymer 1999
IHRB*	East Asia	South Korea	58	<0.35Ma	Fluvial and/or lacustrine deposits	Norton et al. 2006; Bae, Bae and Kim. 2012
Bose	East Asia	China	64	~0.8Ma	River terrace deposits of vermicular red soil	Hou et al. 2000; Huang 2003
Luonan	East Asia	China	236	<0.5Ma	Alternating river terrace deposits of loess and palaeosols	Wang 2005, 2007
DRR*	East Asia	China	105	<0.78Ma	River terrace deposits of red soil	Kuman, Li and Li, forthcoming; this article

Note
STIC = Société de Transformation Industrielle et de Construction; IHRB = Imjin/Hantan River Basin; DRR = Danjiangkou Reservoir Region

Figure 1 The geographic distribution of Acheulean sites discussed in this article

Results and discussions

The factor of raw material

Differences in raw materials have been regarded as the main factor influencing the morphological variability of British handaxes (Ashton and McNabb 1994; White 1995, 1998). Through the Kruskall-Wallis test of four British handaxe assemblages (Table 3), significant differences ($p < 0.001$) among the sites in the measurements and indices were observed, with the exception of length, although the handaxes were exclusively made of flint or chert (flint at Boxgrove, Corfe Mullen and Cuxton and chert predominantly at Broom Pits). The most notable difference is in thickness, between the Boxgrove and Cuxton sites (30.59mm and 44.15mm respectively). As White's (1995) study revealed, Boxgrove exploited mainly the raw material of fresh chalk flints, uneroded large nodules from primary (bedrock) context. The large nodules provide enough volume to produce ovate, thin and well-refined handaxes. However, the lithic resources of Cuxton were cobbles from fluvial deposits (gravels), which resulted in the long and pointed form, as well as the thick cortical butt. Meanwhile, other site assemblages are primarily in quartzite. The Kruskall-Wallis test of five African quartzite sites showed that significant differences occurred in all the measurements and indices (Table 4). One probable reason for these differences was the different original contexts of the quartzite. Amanzi Springs in South Africa and STIC in North Africa mainly exploited cobbles and the handaxes are thickness

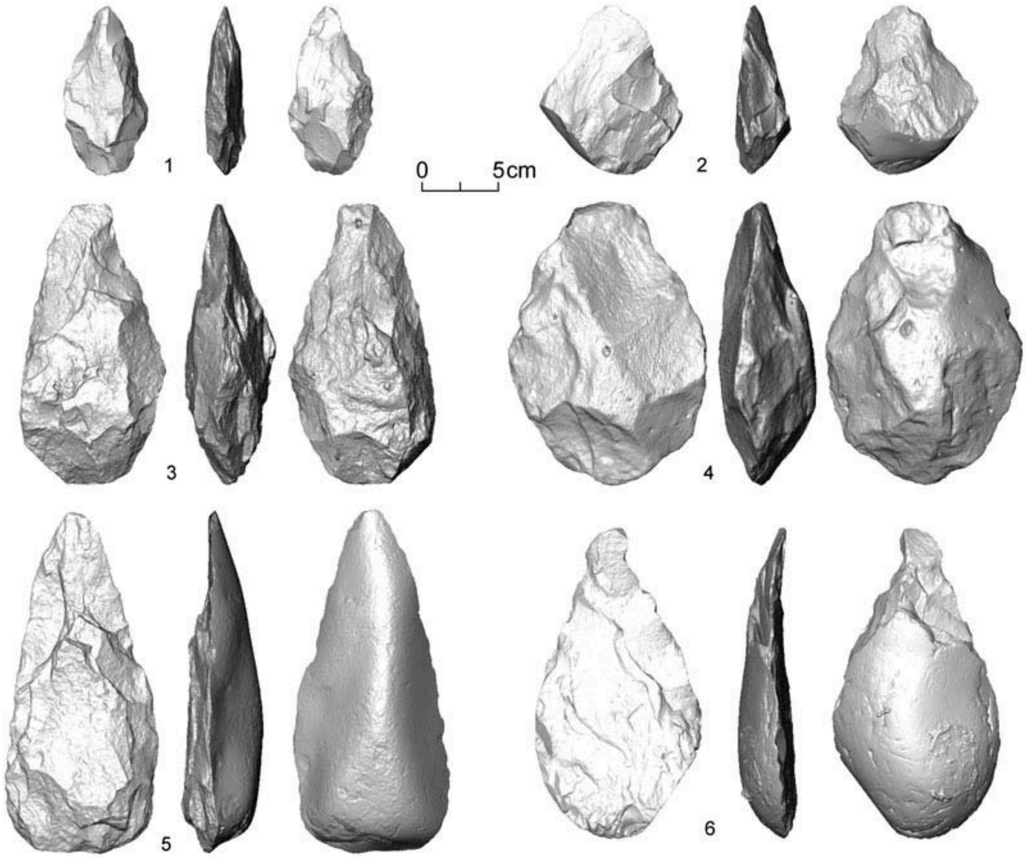

Figure 2 3D scans of handaxes in the DRR. See Appendix for individual data as follows: 1. Niuchangmatou (Recent investigation, 11); 2. Balamiao (1994, 93); 3. Majiazui (Recent investigation, 1); 4. Dudian (Recent investigation, 66); 5. Hongshikan (1994, 117); 6. Beitaishanmiao (1994, 34).

(53.69mm and 54.64mm respectively), while the raw materials of Elandsfontein in South Africa and the Olduvai Masek Beds in East Africa were from outcrops in primary context, which led to less thick handaxes (36.78mm and 40.76mm respectively).

Considering the predominant use of quartzite cobbles in East Asian sites, such as 74.2 per cent in the Luonan Basin (Wang 2007), 48.4 per cent in the Bose Basin (Huang 2003) and a large percentage in the IHRB (the exact proportion was not given) (Norton et al. 2006), it is logical to suggest that the large thickness of handaxes in these regions was influenced by the cobble raw material (see next section for the ratio of cobble to flake blank). The round and smooth surface of river cobbles provides a natural butt for handling, which was probably a reason for leaving the cortex on butts, which generated the thick profile.

In addition, the various raw materials adopted in the DRR and Elandsfontein provide a chance to examine the influence of the different types of raw materials in one region. The Student's t-test of handaxes made of quartz phyllite and trachyte in the DRR (Table 5) and the Kruskall-Wallis test of handaxes made from silcrete, quartzite and quartz porphyry in

Table 2 Mean values of measurements and indices of handaxes adopted in the comparative analysis. Weight in gram, measurements in mm.

	Weight			*Length*			*Width*			*Thickness*			*T/W*			*L/W*		
Locality	*Mean*	*SD*	*CV*	*Mean*	*SD*	*CV*	*Mean*	*SD*	*CV*	*Mean*	*SD*	*CV*	*Mean*	*SD*	*CV*	*Mean*	*SD*	*CV*
Africa																		
Grotte des Ours	390.40	133.39	34.17	133.14	18.30	13.74	78.45	11.08	14.12	43.81	6.79	15.50	0.57	0.10	17.69	1.70	0.16	9.39
STIC	704.68	292.96	41.57	166.02	26.64	16.05	94.61	15.68	16.57	54.64	10.64	19.47	0.59	0.12	20.45	1.77	0.19	10.75
Olduvai Masek Beds	375.02	153.24	40.86	129.98	17.21	13.24	78.44	10.69	13.63	41.25	7.75	18.79	0.53	0.09	17.00	1.67	0.19	11.38
Elandsfontein	355.54	250.65	70.50	122.44	32.86	26.84	75.85	16.82	22.18	40.13	11.19	27.88	0.53	0.10	18.83	1.61	0.22	13.64
Amanzi Springs	751.41	356.82	47.49	154.50	30.74	19.90	93.38	16.41	17.57	53.69	11.22	20.90	0.58	0.10	17.26	1.66	0.19	11.45
Doornlaagte	1147.93	527.55	45.96	195.87	36.17	18.47	103.90	14.45	13.91	59.03	11.76	19.92	0.57	0.10	17.54	1.88	0.21	11.15
Western Europe																		
Boxgrove	288.81	132.42	45.85	122.56	22.67	18.50	80.79	13.27	16.42	30.59	5.66	18.51	0.38	0.05	13.15	1.52	0.12	7.92
Broom Pits	359.90	258.00	71.69	125.06	35.73	28.57	81.11	17.10	21.08	36.22	10.20	28.16	0.45	0.09	20.10	1.54	0.25	16.28
Corfe Mullen	346.63	191.04	55.11	121.64	27.49	22.60	75.54	13.77	18.23	37.94	12.30	32.42	0.51	0.16	31.51	1.62	0.29	17.88
Cuxton	370.32	252.36	68.15	124.05	34.71	27.98	73.04	15.89	21.76	44.15	11.80	26.73	0.61	0.13	21.36	1.70	0.28	16.50
East Asia																		
IHRB				153.86	30.46	19.80	94.16	13.92	14.78	60.19	12.92	21.46	0.65	0.14	21.65	1.64	0.27	16.44
Bose	1534.00	766.00	49.93	167.52	29.09	17.37	120.69	18.61	15.42	73.14	12.26	16.76	0.62	0.13	21.05	1.40	0.20	14.30
Luonan	979.00	470.61	48.07	157.44	39.60	25.15	98.32	18.36	18.67	58.41	13.46	23.04	0.61	0.14	22.95			
DRR	804.45	391.93	48.72	164.28	31.31	19.06	96.19	15.25	15.85	46.33	12.19	26.31	0.49	0.12	24.71	1.72	0.23	13.38

Notes

Data for Africa and western Europe are from Marshall et al. (2002); IHRB data are from Norton et al. (2006); Bose data are from Huang (2003) and Hou et al. (2000); Luonan data are from Wang (2007).

Data for sites are based on individual specimens, with the exception of Luonan and Bose. For Luonan the data are from publications. For Bose, all data except for weight (35 specimens, Hou et al., 2000) are based on individual specimens.

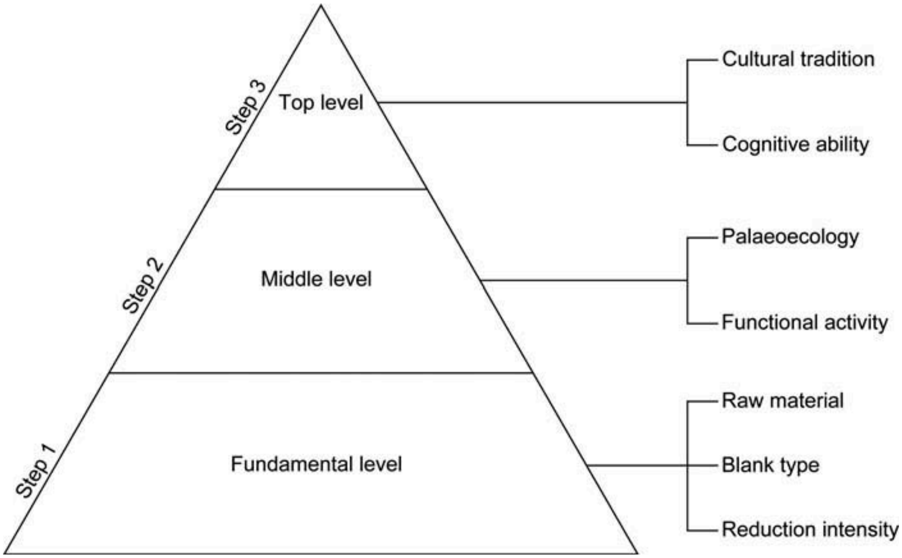

Figure 3. Stepwise approach adopted in the analysis of morphological variability.

Table 3 Kruskall-Wallis test of mean values of four flint/chert handaxe assemblages in Britain. Measurements in mm.

	Boxgrove	*Broom Pits*	*Corfe Mullen*	*Cuxton*	*Chi-square*	*p-value*
Length	122.56	125.06	121.64	124.05	0.791	0.852
Width	80.79	81.11	75.54	73.04	38.596	$p < 0.001$
Thickness	30.59	36.22	37.94	44.15	142.475	$p < 0.001$
L/W	1.52	1.54	1.62	1.70	59.531	$p < 0.001$
T/W	0.38	0.45	0.51	0.61	316.122	$p < 0.001$

Table 4 Kruskall-Wallis test of mean values of five quartzite handaxe assemblages in Africa. Measurements in mm.

	Grotte des Ours (100%)	*STIC (100%)*	*Olduvai Masek Beds (92.8%)*	*Elandsfontein (12.9%)*	*Amanzi Springs (100%)*	*Chi-square*	*p-value*
Length	133.14	166.02	128.84	119.80	154.50	121.373	$p < 0.001$
Width	78.45	94.61	78.06	73.08	93.38	105.262	$p < 0.001$
Thickness	43.81	54.64	40.76	36.78	53.69	147.889	$p < 0.001$
L/W	1.70	1.77	1.66	1.64	1.66	20.498	$p < 0.001$
T/W	0.57	0.59	0.53	0.51	0.58	32.534	$p < 0.001$

Elandsfontein (Table 6) revealed no significant differences ($p > 0.05$) for handaxes made from different raw materials in a certain region. This might provide evidence for an Acheulean cultural tradition in a specific region, as, although the raw materials were different, tool-makers could still make handaxes of similar morphology.

Table 5 Student's t-test of mean values of measurements and indices based on two different raw materials in DRR. Measurements in mm.

	Quartz phyllite (73.3%)	*Trachyte (19%)*	*t-statistic*	*p-value*
Length	162.46	163.96	−0.177	0.860
Width	95.59	96.44	−0.222	0.825
Thickness	45.80	45.58	0.074	0.942
L/W	1.72	1.69	0.331	0.744
T/W	0.48	0.48	0.082	0.935

Table 6 Kruskall-Wallis test of mean values of measurements and indices based on three different raw materials in Elandsfontein.

	Silcrete (64.2%)	*Quartzite (12.9%)*	*Quartz porphyry (12.5%)*	*Chi-square*	*p-value*
Length	120.79	119.80	128.67	1.446	0.485
Width	74.83	73.08	80.70	3.674	0.159
Thickness	40.61	36.78	43.39	4.610	0.100
L/W	1.61	1.64	1.58	4.550	0.103
T/W	0.54	0.51	0.54	1.106	0.575

However, the raw material type did play a role in the morphological variability across different regions. The principal component analysis of five raw materials used in different regions of the Old World indicated that flint and chert, which was exclusively used in four West Europe sites, largely concentrated on the negative side of Component 1 (Fig. 4). The loading matrix of Component 1 (Fig. 4) shows that thickness and length are the main factors influencing the distribution pattern. The linear measurements of west European handaxes presented in Table 2 clearly show small values of thickness and length. Compared with flint and chert, quartzite (see Table 4 for the names of the sites) is mainly found on the positive side of Component 1 (Fig. 4), which means that quartzite handaxes show relatively high values of thickness and length. The other three raw materials, quartz phyllite (used in the DRR), trachyte (used in DRR) and andesite (exclusively used in Doornlaagte site), are primarily located on the positive side of Component 1 and negative side of Component 2, with the andesite much more in this area. The linear measurements in Table 2 show that the Doornlaagte site had higher values of length, width and thickness (195.87mm, 103.90mm and 59.03mm respectively) than other African quartzite sites, West Europe sites and the DRR in East Asia.

Overall therefore, we can conclude that raw materials did play a role in the morphological variability of handaxes. The original context from which the raw materials are acquired is regarded as a factor influencing the morphological variability of handaxes in Europe and Africa, and it was also important for the handaxes in East Asia. The type of raw material has a clear influence on the morphology if we take a broad view. It is easily perceived that flint or chert in western Europe has a better quality for flaking than many other raw materials. And the lack of a statistically significant difference between different raw materials used in a certain region might imply the existence of a cultural tradition in that region.

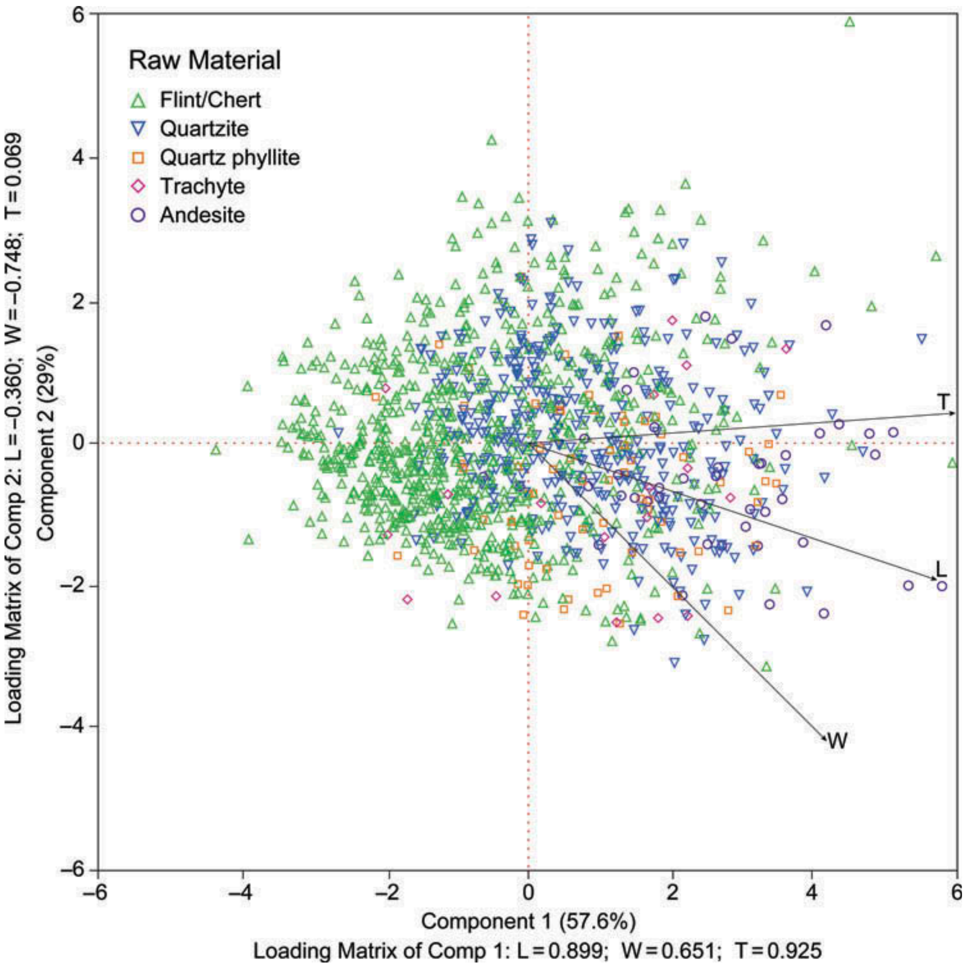

Figure 4. Principal component analysis of handaxes made on different raw materials (W = width).

The factor of the blank

Using cobble as blanks has been regarded as a factor that influenced handaxe morphology in the IHRB when compared with Olorgesailie handaxes which were produced on large flakes (Norton et al. 2006). Petraglia and Shipton's (2008) study confirmed this when they compared the average value of refinement between the IHRB and Anagwadi (India). Anagwadi handaxes, which were made of thick quartzite cobbles, had a refinement value close to that of IHRB handaxes (0.60 in Anagwadi and 0.68, 0.61 and 0.60 in three localities in the IHRB). Although the information on each handaxe blank in East Asia, except for the DRR, is unavailable due to the limited published data, the general statistical results still indicate that a considerable proportion of handaxes were made on cobble blanks, 72 per cent in Bose Basin (Huang 2003), 36.19 per cent in the DRR (see Appendix) and 22.46 per cent in Luonan Basin (Wang 2007). The relatively high proportion of handaxes on cobbles could be regarded as a feature of the East Asian Acheulean which had a significant influence on handaxe morphology, especially on thickness.

The Student's t-test shows that the significant difference between DRR handaxes made on cobbles (n = 38) and flakes (n = 50) is mainly seen in the thickness and T/W ($p < 0.05$), while cobble handaxes are slightly higher than flake handaxes in length, width and L/W (Table 7). The situation for the west European handaxes, however, is much more complex. The four sites in western Europe have a different proportion of cobbles to flakes, twelve to fourteen in Boxgrove, ten to 115 in Broom Pits, forty-six to fourteen in Corfe Mullen and 127 to twenty-two in Cuxton. We can see that many more cobble blanks were used in Corfe Mullen and Cuxton than flake blanks and the Student's t-test shows that significant differences ($p < 0.05$) occurred not only in thickness and T/W, but also in length and L/W (Table 7). And at Broom Pits, which had a low number of handaxes on cobbles, significant differences occurred in all measurements and

Table 7 Student's t-test of mean values for handxes made on cobble v. flake blanks.

		Cobbles	*Flakes*	*t-statistic*	*p-value*
Length	STIC	175.57	167.01	0.879	0.385
	Amanzi Springs	153.47	154.72	−0.159	0.874
	Boxgrove	116.57	125.69	−1.034	0.311
	Broom Pits	158.55	129.72	2.338	<0.05
	Corfe Mullen	128.79	113.99	2.501	<0.05
	Cuxton	126.41	106.25	2.551	<0.05
	DRR	170.49	158.56	1.679	0.097
Width	STIC	104.56	98.27	1.044	0.303
	Amanzi Springs	96.31	92.90	0.840	0.403
	Boxgrove	76.38	82.29	−0.977	0.338
	Broom Pits	97.44	83.40	2.408	<0.05
	Corfe Mullen	73.95	74.50	−0.139	0.890
	Cuxton	72.32	68.01	1.220	0.224
	DRR	97.94	94.65	0.949	0.345
Thickness	STIC	60.60	52.42	2.624	<0.05
	Amanzi Springs	57.34	52.67	1.712	0.090
	Boxgrove	27.85	30.09	−0.977	0.338
	Broom Pits	51.31	37.37	4.022	<0.05
	Corfe Mullen	43.45	35.05	2.203	<0.05
	Cuxton	46.98	34.17	4.918	<0.05
	DRR	51.44	43.19	3.149	<0.05
L/W	STIC	1.69	1.71	−0.341	0.735
	Amanzi Springs	1.60	1.67	−1.279	0.204
	Boxgrove	1.52	1.54	−0.362	0.720
	Broom Pits	1.63	1.55	0.994	0.322
	Corfe Mullen	1.76	1.54	2.479	<0.05
	Cuxton	1.75	1.56	2.902	<0.05
	DRR	1.75	1.69	1.225	0.224
T/W	STIC	0.59	0.54	1.518	0.138
	Amanzi Springs	0.60	0.57	1.172	0.245
	Boxgrove	0.37	0.37	−0.121	0.905
	Broom Pits	0.54	0.45	2.866	<0.05
	Corfe Mullen	0.59	0.47	2.546	<0.05
	Cuxton	0.66	0.50	5.486	<0.05
	DRR	0.53	0.46	2.849	<0.05

indices, except L/W (Table 7). However, the situation for Boxgrove is unique, as there are no significant differences in any measurements or indices and meanwhile the average values for length, width and thickness in cobble handaxes are even lower than in flake handaxes, which shows that the original size of the flint cobbles was quite small (Table 7). In addition, the Student's t-test analysis of two African sites, STIC (with an 8:31 ratio of cobbles to flakes) and Amanzi Springs (with a 19:89 ratio of cobbles to flakes), shows no significant differences in any measurements or indices ($p > 0.05$) (Table 7), which means that blanks were probably not the factor for African handaxe morphological variability.

In summary, the blank might play a different role in different regions of the Old World. Generally, handaxes on cobbles have higher values of measurements and indices than handaxes made on flakes. In East Asia, the influence of the blank is clearly seen on the thickness and T/W. With regard to the sites in western Europe, besides thickness and T/W, the influence of blank is also seen on the length and L/W. For African sites, the influence of the blank is not seen in the two sites (Amanzi Springs and STIC) analysed here.

The factor of reduction intensity

Reduction intensity is also regarded as an important factor in explaining the morphological variability of handaxes (McPherron 1995, 1999, 2000). This hypothesis uses the relationship between length and elongation (L/W) to infer the reduction intensity employed. Generally, larger handaxes will have a greater elongation index and thicker and shorter ones will have a smaller elongation index and thickness (McPherron 1995, 1999, 2000). The Pearson's correlation (r) analyses between length and L/W, length and thickness, and width and L/W show that the western European sites have a relatively significant correlation between length and L/W ($r = 0.4$), and a strong correlation between length and thickness ($r = 0.7$), which to some degree supports the reduction intensity hypothesis (Table 8). In addition, the correlation between width and L/W at western European sites is low ($r < 0.4$), which also supports McPherron's (2000, 2006) opinion that width is conserved, or changed less than length. From the blank analysis which showed that cobble handaxes usually have greater length, thickness and L/W than flake handaxes, we can infer that cobble handaxes probably have a low reduction intensity, while flake handaxes are probably located at the higher end of the reduction intensity scale. Therefore, both the selection of blanks and the reduction intensity seem to have a significant influence on the morphological variability.

Compared to those found in western Europe, the correlations of length and L/W and of length and thickness for African sites are relatively low and also show distinctive variability among the sites, such as the low correlation of Grotte des Ours (0.32 and 0.39) in northern Africa compared with the significant correlation of Doornlaagte (0.65 and 0.62) in South Africa (Table 8). The high variability of correlations in African sites probably shows that the influence of reduction intensity is different at different sites, and that not all the sites conform to the hypothesis of reduction intensity. When we look at the correlations for East Asian sites, we see a low correlation of width and L/W, which is similar to sites in western Europe and Africa. And meanwhile, the correlation of length and thickness is low in the IHRB (0.21) and Bose (0.28), and slightly higher than the significant level ($r = 0.4$) in the DRR (0.47). However, the correlation of length and L/W in three regions of East Asia is significant (0.65 in the IHRB,

Table 8 Analysis of the Pearson's correlation (r)* between the different measurements and indices for each site or region.

Locality	*Length and L/W*	*Length and thickness*	*Width and L/W*
Africa			
Grotte des Ours	0.32	0.39	−0.35
STIC	0.25	0.49	−0.39
Olduvai Masek Beds	0.34	0.66	−0.48
Elandsfontein	0.55	0.75	0.04
Amanzi Springs	0.47	0.57	−0.13
Doornlaagte	0.65	0.62	0.08
Western Europe			
Boxgrove	0.48	0.75	0.08
Broom Pits	0.64	0.78	0.12
Corfe Mullen	0.59	0.70	−0.23
Cuxton	0.61	0.77	0.02
East Asia			
IHRB	0.65	0.21	−0.19
Bose/Baise	0.54	0.28	−0.34
DRR	0.55	0.47	−0.17

Note

$r<0.4$ indicates a weak correlation; $0.4\leq r<0.7$ indicates a significant correlation; $0.7\leq r<1$ indicates a strong correlation

0.54 in Bose and 0.55 in the DRR), which may demonstrate the effect of reduction intensity in the morphological variability of East Asian handaxes.

The Pearson's correlation analyses indicate that reduction intensity probably influenced morphological variability to some degree. To estimate the extent of this influence, we will need to carry out more detailed technological analysis. As far as reduction is concerned, the more we do on the technology, the more convincing our conclusion regarding morphological variability will be.

The factor of tool function in relation to environment

Environment is related to tool function through subsistence ecology. Environment affects the species of animal and plant resources, and therefore the exploitation and utilization of these different kinds of resources need tools which can perform different functions. These different functions may lead to morphological variability. The three handaxe regions in China are good examples to demonstrate the relationship between the environment and morphological variability.

Handaxes from these three regions (Bose, Luonan and DRR) are generally located in the Middle Pleistocene, a period which has been proved to be a climatic optimum in the Quaternary (Cao 1995; Yuan et al. 2008). The Bose Basin, which is located in southern China, passed through a tropical forest environment and developed strongly weathered vermicular red soil in the stratigraphy (Zhao and Yang 1995; Yang et al. 1996; Yin and Guo 2006). The plant resources were abundant in this kind of environment. The handaxes from Bose are much heavier and thicker than those from the DRR and Luonan Basin (Table 2), which probably suggests a different tool function (Petraglia and Shipton 2008; Wang et al. 2012). The stress analysis of Bose handaxes has showed that these handaxes were more suited to splitting and chopping behaviours, which correspond with the local tropical environment in the Middle Pleistocene (Yuan et al. 2008). The DRR and Luonan Basin, which are located in central China, however, had a somewhat different environment from Bose Basin. The Middle Pleistocene deposits in the DRR are red soil containing ferrum and manganese spots, the products of weathering in the warm, humid stage. However, this red soil did not reach the degree of weathering that created the vermicular red soil found in southern China, which points to a less tropical environment in the DRR (Zhou, Wang and Gao 2009; Li, Li and Kuman 2013). The deposits in Luonan Basin, however, presented loess-palaeosol sequences in the stratigraphy, which indicates the alternation of warm and cold climates in this region, although the development of loess is not as distinctive as its development on the loess plateau in northern China (Wang 2005; Lu et al. 2012). Generally, the DRR and Luonan Basin were in a sub-tropical environment during the Middle Pleistocene. The weight and thickness of handaxes are therefore lower than those of the handaxes in the Bose Basin (Table 2). Nevertheless, the appearance of considerable numbers of picks in both regions may also indicate the exploitation and utilization of plant resources because of the possible digging function of picks with their distinct robust points (Li, Feng and Li 2009; Li, Li and Feng 2012; Wang 2005, 2007).

It is thus clear that Acheulean hominids could choose relevant adaptive strategies to fit the changeable environment and types of raw materials. Further use-wear and experimental analyses of handaxe functions will increase our understanding of the relationship between the factors of environment and function and the morphological variability.

The factor of cultural tradition

To a certain degree, cultural tradition is consistent with a mental template in terms of the formation process of the latter. A mental template represents a stable concept existing in the group, which is created by systematic teaching. It is then transmitted rigidly within the mating system of a social entity from generation to generation, finally forming a stable social or cultural tradition (Mithen 1999; Petraglia, Shipton and Paddayya 2005; Bar-Yosef and Wang 2012). As a factor at the top level of our stepwise approach, the analysis of cultural tradition is highly controversial among researchers. Wynn and Tierson (1990) and Gowlett (1986) chose to adopt cultural tradition to explain the morphological variability of handaxes. In contrast, McPherron (2000) and McNabb, Binyon and Hazelwood (2004) denied the effect of cultural tradition and argued that the end morphology of a handaxe was a variable idea in the mind of the knapper or the effect of raw materials, functions and reduction intensity.

The regional comparison conducted in this article supports the existence of cultural tradition, mainly expressed in the similar knowledge of making handaxes in different regions, despite geographic separation, a difference in raw materials, environmental diversity and so on. And we should note that the morphological variability of handaxes in different regions does not preclude the idea of separate cultural traditions; instead it may imply the flexible adaptations of Acheulean people when faced with different raw materials and environments. This is probably why Acheulean technology can be seen in most parts of the Old World. Moreover, the analysis of the morphological variability of handaxes made on different raw materials in any one region has shown that there were preferred morphological patterns, which means that early hominids living in this region shared a common cultural tradition of handaxe making. In addition, the hierarchical cluster analysis shows that, although Bose shows extreme clustering, the IHRB are classified in the same group as STIC and Amanzi Springs, the DRR is grouped with the western

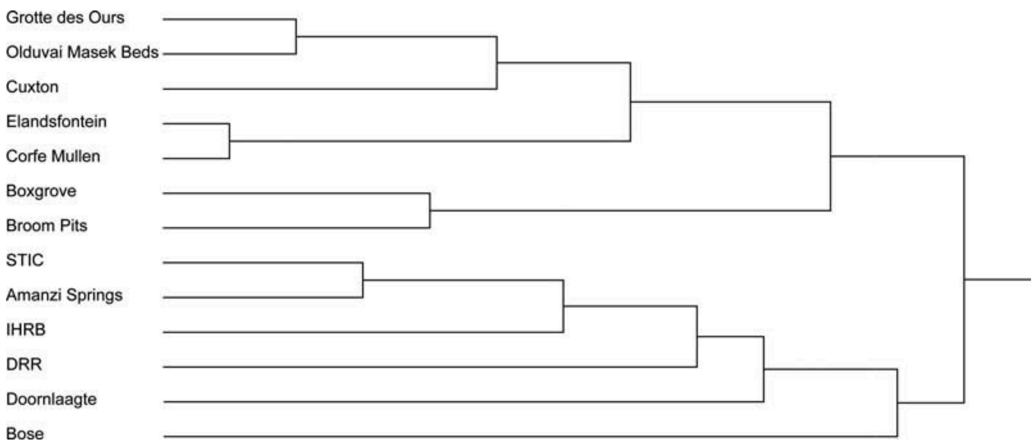

Figure 5. Hierarchical cluster analysis of Acheulean localities or regions discussed in this article.

Acheulean, and Doornlaagte is less similar (Fig. 5). Therefore, we have reasons to believe that East Asian handaxes have an affiliation with the western Acheulean.

The factor of cognitive ability

The study of early hominids' cognition is an important aspect of handaxe research. In terms of the long-term technological and morphological development of handaxes from the early to late Acheulean, it provides us with significant evidence on the cognitive evolution of early hominids (McHenry and Coffing 2000; Wynn 2002; Mithen 2005). However, when the study materials are confined to the same time period, we should be more cautious in conclusions, because there is great variability in technology and morphology of handaxes seen in the same period.

The analysis of the relationship between morphological variability and cognitive ability in this article is based on the premise of limiting the time range of the selected sites to the Middle Pleistocene. Through the comparison of sites from Africa, western Europe and East Asia, we can observe that inter-site variability is ubiquitous. Taking the African sites, for example, the greatest variability is seen between two South African sites, Elandsfontein and Doornlaagte, with an average length of 122.44mm and 195.87mm, an average width of 75.85mm and 103.90mm and an average thickness of 40.13mm and 59.03mm. However, because of the similar age of the two sites, it is difficult to infer that this great morphological variability was caused by the different cognitive ability of the hominids concerned. On the contrary, it is much more likely that the variability itself reflects the flexible adaptation strategies of Acheulean hominids when they faced different situations. Therefore, when looking at East Asia, we can deduce that the existence of the morphological variability in the East Asian sites is normal. On the other hand, the detailed technological analyses of handaxes from the IHRB, Bose and Luonan have also shown that East Asian hominids had the ability to produce sophisticated stone tools, which implies similar technical, cultural and cognitive capabilities on both sides of the 'Movius Line' (Hou et al. 2000; Wang 2005; Norton et al. 2006; Huang, Hou and Gao 2009; Zhang, Huang and Wang 2010). More recent technological analyses of the DRR handaxes also confirm this conclusion in greater detail (Li, Li and Kuman, forthcoming; Kuman, Li and Li, forthcoming), and further studies, which we anticipate will provide additional support, are ongoing. Hence, it seems unlikely that cognitive ability influenced the morphological variability of East Asian handaxes.

Conclusion

Researchers are beginning to pay more attention to handaxes in East Asia. This vast region has been traditionally regarded, in the influential concepts about human evolution, as geographically isolated. However, the continuous reports of handaxes in this region are gradually enriching our understanding of early humans' migration and evolution. In this context, we are conducting a re-examination of the morphological variability of East Asian handaxes. Contrary to mainstream opinion which emphasizes the difference in handaxe morphology between east and west (Norton et al. 2006; Norton and Bae 2008; Petraglia and Shipton 2008; Lycett and Bae 2010; Shipton and Petraglia 2010), we began with an analysis of the handaxe morphological variability range in different regions and conclude that the variability in the East Asian sites is not significantly different from those in the western Acheulean; what we see from our analysis is in fact the similarity with some of the western Acheulean sites. Although greater thickness was regarded as the primary morphological difference between east and west (Norton et al. 2006; Norton and Bae 2008), the analysis of the handaxe materials from the DRR shows that the average thickness of these handaxes fits comfortably within the western Acheulean range of variability. Therefore, the thickness deduction is not suitable for the whole group of handaxe assemblages in East Asia. Our conclusion on the morphological similarity between east and west is also supported by the technological analyses, which showed no technical, cultural or cognitive differences on either side of the 'Movius Line' (Hou et al. 2000; Wang 2005; Norton et al. 2006; Zhang, Huang and Wang 2010; Li, Li and Kuman, forthcoming; Kuman, Li and Li, forthcoming). Moreover, the variability presented in East Asian handaxes may indicate the flexible adaptation strategies of Acheulean hominids.

In explaining the morphological variability of East Asian handaxes, researchers have tended to discuss the origin of these handaxes and to think that technological convergence sufficiently explained morphological variability (Petraglia and Shipton 2008; Shipton and Petraglia 2010; Lycett and Bae 2010). However, some fundamental factors, such as the raw materials and reduction intensity, were not systematically considered. Given this, we adopted a stepwise approach (Isaac 1986; McPherron 2000) to the comprehensive analysis, from the fundamental-level factors to the factors at the top level. The results indicate that the morphological variability of East Asian handaxes is influenced by multiple factors, including the raw materials, selection of blanks, reduction intensity and cultural tradition. Also, through comparative morphological analysis, we find that the morphological variability in different regions might have different explanations. The analysis of specific regions or localities is necessary for a better understanding of this subject.

In a future study, we hope that more elaborate comparisons at the local level can be done with the increasingly available published data and a more accurate chronological range. In addition to developing further the value of morphological analysis, we also need the aid of new technology, such as the 3D scanning technique (Archer and Braun 2010; Bretzke and Conard 2012), to do in-depth analyses and comparisons. Beyond the technological analysis, we believe that the detailed morphological analysis will also open another window into the investigation of the behavioural evolution of early hominids. As an important component of this evolution, the materials from East Asia will surely give us more surprises, and more challenges as well.

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Appendix: Handaxes from the DRR. Missing data correspond with damage. Weight in gram, measurements in mm

For the 1994 specimens, see Kuman, Li and Li (forthcoming). For recent investigations, see Li. Li and Kuman (forthcoming). Handaxes from excavations are recorded by HL.

Artefact number	*Site*	*Weight*	*Length*	*Width*	*Thickness*	*L/W (Elongation)*	*T/W (Refinement)*	*Raw Material*	*Blank*
1994									
9	Longkou	1696.00	161.00	81.00	42.00	1.99	0.52	Quartz phyllite	Flake
10	Shuiniuwa	1496.00	214.00	109.00	65.00	1.96	0.60	Quartz phyllite	Flake
26	Shuiniuwa	806.00	179.00	101.00	27.00	1.77	0.27	Quartz phyllite	Cobble
31	Dudian	690.00	183.00	109.00	35.00	1.68	0.32	Quartz phyllite	Cobble
34	Beitaishanmiao	734.00	203.00	108.00	32.00	1.88	0.30	Quartz phyllite	Flake
39	Beitaishanmiao	634.00	162.00	101.00	35.00	1.60	0.35	Quartz phyllite	Split cobble
44	Hejiawan	716.00	190.00	89.00	45.00	2.13	0.51	Quartz phyllite	Split cobble
45	Beitaishanmiao	564.00	159.00	96.00	41.00	1.66	0.43	Quartz phyllite	Split cobble
49	Guojialingchang	1318.00	212.00	118.00	47.00	1.80	0.40	Quartz phyllite	Split cobble
53	Balamiao	1064.00	214.00	109.00	45.00	1.96	0.41	Quartz phyllite	Flake
63	Caijiadu			132.00	45.00		0.34	Quartz phyllite	Flake indet
64	Hejiawan	562.00	135.00	91.00	36.00	1.48	0.40	Quartz phyllite	Indeterminate
69	Pengjiahe			102.00	35.00		0.34	Quartz phyllite	Cobble (naturally split)
70	Hongshikan			79.00	38.00		0.48	Igneous rock	Flake
71	Caijiadu	532.00	174.00	95.00	30.00	1.83	0.32	Igneous rock	Flake
73	Hongshikan			87.00	35.00		0.40	Quartz phyllite	Cobble
74	Pengjiahe	1060.00	156.00	108.00	64.00	1.44	0.59	Quartz phyllite	Cobble
75	Beitaishanmiao	1404.00	196.00	104.00	70.00	1.88	0.67	Quartz phyllite	Cobble
76	Beitaishanmiao			108.00	38.00		0.35	Quartz phyllite	Cobble
77	Beitaishanmiao	1028.00	145.00	99.00	63.00	1.46	0.64	Quartz phyllite	Cobble
78 *in situ*	Beitaishanmiao	584.00	142.00	99.00	41.00	1.43	0.41	Quartz phyllite	Flake
79	Beitaishanmiao	822.00	142.00	91.00	42.00	1.56	0.46	Quartz phyllite	Flake
80 *in situ*	Beitaishanmiao	482.00	125.00	98.00	40.00	1.28	0.41	Quartz phyllite	Flake
81	Beitaishanmiao	230.00	120.00	56.00	34.00	2.14	0.61	Quartz phyllite	Cobble
82	Beitaishanmiao	1372.00	183.00	101.00	50.00	1.81	0.50	Quartz phyllite	Cobble
84	Beitaishanmiao	1024.00	215.00	101.00	50.00	2.13	0.50	Quartz phyllite	Split cobble
86	Beitaishanmiao	844.00	167.00	85.00	59.00	1.96	0.69	Trachyte	Cobble
87	Beitaishanmiao	1018.00	200.00	105.00	40.00	1.90	0.38	Quartz phyllite	Split cobble

(*continued*)

(*Continued*).

Artefact number	*Site*	*Weight*	*Length*	*Width*	*Thickness*	*L/W (Elongation)*	*T/W (Refinement)*	*Raw Material*	*Blank*
88 *in situ*	Beitaishanmiao	844.00	175.00	97.00	46.00	1.80	0.47	Igneous rock	Flake
89 *in situ*	Beitaishanmiao	1090.00	178.00	123.00	50.00	1.45	0.41	Quartz phyllite	Cobble
90	Shuiniuwa	444.00	170.00	95.00	49.00	1.79	0.52	Quartz phyllite	Flake
91	Dudian	530.00	150.00	92.00	35.00	1.63	0.38	Quartz phyllite	Flake
92	Hejiawan			85.00	34.00		0.40	Quartz phyllite	Split cobble
93	Balamiao	264.00	112.00	90.00	30.00	1.24	0.33	Quartz phyllite	Flake
105	Beitaishanmiao	1228.00	213.00	110.00	62.00	1.94	0.56	Quartz phyllite	Cobble
116 *in situ*	Beitaishanmiao	1564.00	210.00	119.00	65.00	1.76	0.55	Quartz phyllite	Flake
117	Hongshikan	1092.00	226.00	103.00	48.00	2.19	0.47	Indeterminate	Flake
119 *in situ*	Beitaishanmiao	1700.00	220.00	126.00	56.00	1.75	0.44	Quartz phyllite	Cobble
120 *in situ*	Beitaishanmiao	966.00	171.00	102.00	54.00	1.68	0.53	Quartz phyllite	Cobble (naturally split)
121	Beitaishanmiao	1050.00	181.00	98.00	57.00	1.85	0.58	Quartz phyllite	Bipolar flake
122	Dudian	1060.00	170.00	115.00	50.00	1.48	0.43	Quartz phyllite	Bipolar flake
123 *in situ*	Dudian	812.00	187.00	98.00	38.00	1.91	0.39	Quartz phyllite	Split cobble
125 *in situ*	Hongshikan	312.00	106.00	67.00	39.00	1.58	0.58	Quartz phyllite	Cobble
127	Hejiawan	284.00	121.00	69.00	32.00	1.75	0.46	Quartz phyllite	Cobble
128	Hejiawan	782.00	156.00	103.00	49.00	1.51	0.48	Quartz phyllite	Split cobble
135 *in situ*	Beitaishanmiao	1228.00	192.00	102.00	46.00	1.88	0.45	Indeterminate	Cobble
138 *in situ*	Beitaishanmiao	826.00	140.00	91.00	51.00	1.54	0.56	Quartz phyllite	Cobble
139	Hongshikan	1638.00	200.00	118.00	57.00	1.69	0.48	Igneous rock	Cobble
140	Caojiayuan			108.00	48.00		0.44	Quartz phyllite	Split cobble
150 *in situ*	Caojiayuan	120.00	95.73	59.32	24.63	1.61	0.42	Quartz phyllite	Flake
Recent investigations									
1	Majiazui	912.00	185.42	96.46	59.94	1.92	0.62	Igneous rock	Flake
2	Changjiayuan	428.00	160.55	96.10	34.85	1.67	0.36	Quartz phyllite	Flake
3	Balamiao	704.00	140.13	97.07	55.10	1.44	0.57	Quartz phyllite	Cobble
4	Balamiao	688.00	156.63	86.60	47.48	1.81	0.55	Igneous rock	Cobble
5	Balamiao	818.00	172.16	104.05	46.58	1.65	0.45	Trachyte	Bipolar flake
6	Hongshikan	1182.00	206.92	120.91	45.41	1.71	0.38	Trachyte	Cobble
8 *in situ*	Niuchangmatou	464.00	159.95	103.66	34.33	1.54	0.33	Quartz phyllite	Flake
9	Fengjiawa	1168.00	216.62	122.07	48.21	1.77	0.39	Trachyte	Flake
10	Shuangshu	494.00	135.99	81.27	47.54	1.67	0.58	Quartz phyllite	Cobble

(*continued*)

(*Continued*).

Artefact number	*Site*	*Weight*	*Length*	*Width*	*Thickness*	*L/W (Elongation)*	*T/W (Refinement)*	*Raw Material*	*Blank*
11	Niuchangmatou	144.00	111.44	56.14	25.52	1.99	0.45	Quartz phyllite	Flake
12	Guanmenyan	340.00	134.24	72.56	45.27	1.85	0.62	Quartz phyllite	Flake
13	Majiazui	168.00	89.80	60.90	30.02	1.47	0.49	Trachyte	Flake
14	Niuchangmatou	510.00	150.00	79.83	45.81	1.88	0.57	Quartz phyllite	Bipolar flake
15	Guochachang	1182.00	200.31	114.15	56.25	1.75	0.49	Quartz phyllite	Bipolar flake
16	Caijiadu	786.00	151.73	92.36	60.88	1.64	0.66	Quartz phyllite	Split cobble
17	Balamiao	1184.00	188.79	91.24	71.16	2.07	0.78	Trachyte	Cobble
18 *in situ*	Majiazui	566.00	174.27	84.42	43.15	2.06	0.51	Quartz phyllite	Flake
19	Shuangshu	318.00	126.33	78.10	32.41	1.62	0.41	Quartz phyllite	Bipolar flake
20	Hongshikan	742.00	171.03	88.69	52.70	1.93	0.59	Quartz phyllite	Cobble
21	Guochachang	572.00	152.11	92.25	39.93	1.65	0.43	Trachyte	Cobble
22	Guochachang	324.00	125.94	82.27	31.61	1.53	0.38	Trachyte	Flake
23	Shuangshu	604.00	131.42	82.94	50.23	1.58	0.61	Quartz phyllite	Split cobble
24	Caijiadu	826.00	130.43	97.25	64.96	1.34	0.67	Quartz phyllite	Flake
25	Guochachang			92.62	52.34		0.57	Quartz phyllite	Flake
26	Shuangshu	572.00	134.61	77.22	57.07	1.74	0.74	Quartz phyllite	Cobble
27	Guanmenyan	1046.00	152.58	97.95	54.98	1.56	0.56	Quartz phyllite	Cobble
28	Shuangshu			100.33	49.88		0.50	Quartz phyllite	Bipolar flake
62	Guochachang	1554.00	203.00	109.00	68.00	1.86	0.62	Quartz phyllite	Cobble
63	Balamiao	1362.00	195.00	103.00	66.00	1.89	0.64	Quartz phyllite	Cobble
64	Waibiangou	836.00	173.00	113.00	39.00	1.53	0.35	Quartz phyllite	Bipolar flake
65	Guochachang	686.00	170.00	85.00	51.00	2.00	0.60	Trachyte	Indeterminate
66	Dudian	1278.00	185.97	130.21	62.70	1.43	0.48	Igneous rock	Flake
67	Dudian	592.00	156.50	105.62	41.78	1.48	0.40	Quartz phyllite	Bipolar flake
68	Dudian	958.00	171.72	109.25	59.64	1.57	0.55	Quartz phyllite	Cobble
69	Pengjiahe	428.00	140.96	75.10	37.92	1.88	0.50	Quartz phyllite	Bipolar flake
70	Zhuangzigou	450.00	142.77	89.58	45.95	1.59	0.51	Quartz phyllite	Bipolar flake
Excavations									
SS-244	Shuangshu	1724.00	203.00	108.00	85.00	1.88	0.79	Quartz	Cobble
SS-495	Shuangshu	828.00	179.00	101.00	60.00	1.77	0.59	Trachyte	Flake
SS-545	Shuangshu	310.00	141.00	76.00	25.00	1.86	0.33	Quartz phyllite	Bipolar flake
SS-546	Shuangshu	424.00	151.00	82.00	37.00	1.84	0.45	Quartz phyllite	Cobble

(*continued*)

(*Continued*).

Artefact number	*Site*	*Weight*	*Length*	*Width*	*Thickness*	*L/W (Elongation)*	*T/W (Refinement)*	*Raw Material*	*Blank*
SS-562	Shuangshu	1186.00	195.00	97.00	70.00	2.01	0.72	Quartz phyllite	Cooble
SS-576	Shuangshu	456.00	147.00	83.00	35.00	1.77	0.42	Quartz phyllite	Flake
SS-T1	Shuangshu	356.00	128.00	97.00	25.00	1.32	0.26	Trachyte	Flake
SS-T3	Shuangshu	566.00	173.00	108.00	30.00	1.60	0.28	Quartz phyllite	Flake
SS-T10	Shuangshu			92.00	26.00		0.28	Trachyte	Indeterminate
SS-T21	Shuangshu	1220.00	183.00	121.00	47.00	1.51	0.39	Trachyte	Cooble
GCC-15	Guochachang			97.00	49.00		0.51	Quartz phyllite	Flake
GCC-46+47	Guochachang	664.00	146.00	80.00	63.00	1.83	0.79	Trachyte	Flake
GCC-77	Guochachang	296.00	108.00	85.00	29.00	1.27	0.34	Trachyte	Flake
BTSM-A-T1-01	Beitaishanmiao			93.00	46.00		0.49	Trachyte	Cobble
BTSM-A-T4-04	Beitaishanmiao	886.00	186.19	98.08	47.75	1.90	0.49	Trachyte	Cobble
BTSM-A-T6-01	Beitaishanmiao	662.00	163.78	85.10	47.96	1.92	0.56	Quartz phyllite	Split cobble
PJH-014	Pengjiahe	554.00	113.73	113.03	51.02	1.01	0.45	Trachyte	Split cobble
DTBA-2	Datubaozi	492.00	146.32	90.84	40.70	1.61	0.45	Quartz phyllite	Flake
WBG-1	Waibiangou	790.00	165.40	91.06	49.79	1.82	0.55	Quartz phyllite	Bipolar flake

CHAPTER SIX: SUBMITTED PAPER #5

Thesis pages: 104-126

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Quantifying the reduction intensity of handaxes with 3D technology: A pilot study of handaxes in the Danjiangkou Reservoir Region, central China

Quantifying the reduction intensity of handaxes with 3D technology: A pilot study of handaxes in the Danjiangkou Reservoir Region, central China

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Abstract

This paper presents an approach to analyzing the reduction intensity of handaxes with the aid 3D scanning technology. Two quantitative reduction indices, the Scar Density Index (SDI) and the Scar Area Index (SAI), are applied to handaxes from the third terrace of the Danjiangkou Reservoir Region (DRR), central China, dated to the Middle Pleistocene. The results show that most of the DRR handaxes in this sample show moderate reduction, which also reflects a least-effort reduction strategy and a generally short use-life for these tools. Detailed examination of the DRR handaxes by sector reveals that the tips generally show the most reduction, while the bases show the least shaping, with cortex often preserved on the base to facilitate handling. While western Acheulean assemblages in this regard are variable, there are many examples of handaxes of varying age with trimming of the bases. We also found no significant differences in the levels of reduction between the two main raw materials, quartz phyllite and trachyte. However, the type of blank used–large flakes versus cobbles–does play a significant role in the reduction intensity of the DRR handaxes. Finally, a small number of handaxes from the younger (the early Late Pleistocene) second terrace of the DRR was compared with those from the third terrace. The results indicate that there is no technological change in the reduction intensity through time in these two DRR terraces.

Introduction

Since the 1980s, lithic researchers have worked to develop a series of methods to measure reduction intensity, particularly as a tool for interpreting curation or re-sharpening of tools and morphological variability, and they have applied them to both experimental and archaeological assemblages. Among them, the quantitative reduction indices proposed by Dibble [1] (the ratio of the remaining surface area to platform area), and Kuhn [2] (the ratio of flake thickness at the point where retouch scars terminate to maximum medial thickness, also well-known as a Geometric Index of Reduction) are the two most influential indices. These two indices and their modified versions are still frequently applied in current research, which confirms their usefulness [3-20]. Shott and Weedman [11] have summarized them as three specific methods, namely, a simple size measurements method, a geometric measurements method, and an allometric method that relates shape and other attributes to size.

Allometry has also influenced the reduction study of handaxes. Based on the reduction hypothesis, McPherron [21] reanalyzed 38 British handaxe assemblages classified by Roe into either pointed or ovate groups. He argued that these shapes actually reflect different reduction intensities, with pointed handaxes in an initial stage of reduction and ovate handaxes in a later stage. For quantitatively measuring the reduction of handaxes, McPherron employed linear measurements, namely the tip length, overall length and width in his study and assumed that pointed handaxes would have both a long tip length and a long overall length. As reduction continued, tip length and length decreased quickly, but width decreased at a lower rate, finally leading to the formation of ovate shaped handaxes with lower elongation values (Length/Width) [21-23]. Thus, through comparing the tip length, length and elongation ratio, McPherron argued that it is possible to estimate the reduction intensity of different handaxe assemblages. This allometric method provided a new perspective in interpretation of the morphological variability of handaxes, and more importantly, it shifted attention from the final form of handaxes to their reduction process and flaking strategies. Consistent with this allometric method, most current reduction intensity analyses of handaxes are now integrated into studies of morphological variability [24-32]. The different extents of reduction are used as an indicator of the morphological variability of handaxes.

In contrast to McPherron's analysis of the size and shape of handaxes in relation to re-sharpening, McNabb et al. [33] proposed a method for the technological study of 'shaping', without reference to re-sharpening. By recording the extent of secondary flaking (flake scars > 1.5cm in length) and the degree of edge trimming (flake scars < 1.5cm in length), the authors identified five subcategories of secondary flaking for each face of a handaxe and five ordinal scales of edge trimming for each section of a handaxe (see McNabb et al. [33], Figs. 4 and 7). The frequencies of these attributes are then classed by the extent of reduction as light, moderate or extensive. This is a detailed and useful approach to reduction analysis of handaxes involving technological attributes. However, a potential problem may lie in the subjective divisions of different types of secondary flaking and different scales of edge trimming, which can vary according to the observer.

Another easily applied approach used by some researchers is the direct counting of the number of scars on a handaxe. Scar numbers are relatively easier to quantify at different stages of reduction for Early Stone Age handaxes than for the generally small-sized tools in the Middle Stone Age (Middle Palaeolithic) and Later Stone Age (Upper Palaeolithic). The assumption here is that extensively retouched handaxes would have more flake scars than less reduced handaxes. Using this concept, Hou et al. [34] compared the number of flake scars on the Bose Large Cutting Tools (LCTs; ~0.803Ma) with the number of scars on LCTs in two western Acheulean assemblages of similar age (0.99Ma-0.7Ma; Olorgesailie Members 1 through 7 in Kenya and Bed IV of Olduvai in Tanzania). They concluded that the Bose LCTs have a similar number of scars as the western Acheulean, and therefore they support the proposal that there is no technological difference between handaxes in the East and West. In addition, in Sharon's [35] comparative study of handaxes from Africa, West Asia and India, the number of scars was also regarded as an important attribute for the analysis of reduction extent.

Although the counting of flake scars is a useful and easily applied approach, it also has one limitation. As mentioned by Sharon [35], the visible number of flake scars on discarded handaxes is likely lower than the flake scars generated during manufacture, as a portion of the piece is lost in the process. For example, a handaxe with 20 flake scars but of a smaller size is not definitely less retouched than a handaxe of larger size with 30 flake scars. Considering the number of scars in conjunction with the size of handaxes would make this attribute size-independent and improve its value. Coincidentally, in the analyses of core reduction intensity of some East African Oldowan sites, Braun et al. [36-38] also suggested that flake scar number divided by mass of the piece is a more appropriate measure of reduction intensity.

For exploring the use-life and implied human behaviors of handaxes (e.g., raw material transport), Shipton [39, 40] proposed a flake scar density index in his analysis of Indian and East African material. Specifically, the scar number on a handaxe is divided by the product of the handaxe length and width as an indication of the surface area. The principle here is that a handaxe will start off with a low flake scar density, and as the reduction progresses, the value of flake scar density will steadily increase [39-41]. This is a size-independent method which addresses the limitation of the scar number approach discussed above. Due to the imprecision in measuring surface area, Shipton et al. [42] then applied a 3D technique to capture the area more accurately, producing a 3D surface area. Simultaneously, Clarkson [43] used a similar method to measure the reduction intensity of different types of cores (with bifaces included as one core type), and he introduced the Scar Density Index (SDI, or the ratio of flake scar number to 3D surface area). Moreover, Clarkson [43], Clarkson et al. [44] and Shipton and Clarkson [41] have used both experimental and archaeological materials to reinforce the reliability of this index.

The purpose of this paper is to present a 3D quantitative analysis of reduction intensity of a handaxe assemblage from the Danjiangkou Reservoir Region (DRR), central China [45-47]. Here, reduction of the DRR handaxes includes both shaping and the probable re-sharpening process, as these two aspects cannot be objectively distinguished, especially in cases where the reduction intensity is generally low, as in DRR. In addition to the 3D Scar Density Index (SDI), a Scar Area Index (SAI) which can quantify the reduction extent in different parts (i.e. tip, medial and base) of a handaxe, will also be used.

Materials and methods

Materials

The handaxes analysed in this paper are from both surface collections and excavations on the third terrace of the Danjiangkou Reservoir Region (DRR), central China (Fig. 1). Systematic investigations and excavations over the last two decades in this area have revealed it as another important handaxe-bearing region in China, along with the well-known regions of Dingcun, Bose and Luonan [45-59]. To ensure accurate measurements of surface area and volume for handaxes, only complete specimens are employed in our study, namely 92 handaxes in total. Of these, 76 are surface collected and 16 are excavated from the third terrace of the Han River, the longest tributary of the Yangtze River and the main feeder of the Danjiangkou Reservoir. The surface-collected material has been statistically confirmed to be consistent with excavated specimens in both morphology and technology [56]. The ESR, OSL and palaeomagnetic dating of the third terrace at the Shuangshu and Maling 2A sites indicate that these two handaxe-bearing sites formed in the Middle Pleistocene [51, 56].

In addition, 25 surface collected handaxes from the second terrace of the Han River were also used in a comparative study of differences in reduction intensity through time in the DRR. The Dishuiyan site, in which more than 20 comparable handaxes were excavated, is ca 100-50 ka by the TT-OSL method [60].

Ethics statement

The surface-collected handaxes (N = 101) were retrieved during field investigations carried out by one of the co-authors, Chaorong Li, and the permission to study these materials was issued by the Institute of Vertebrate Paleontology and Paleoanthropology (Beijing), Chinese Academy of Sciences, in which these specimens are stored. The excavated handaxes (N = 16) are stored in the Danjiangkou Museum in the Danjiangkou City, Hubei Province. The study of these materials was permitted by this museum. We ensure that the field work did not involve endangered or protected species.

3D scanning and measuring

For capturing the 3D image of each handaxe, we used two types of laser scanners. The NextEngine 3D Laser Scanner was used in the field, as it is light and portable. In the laboratory, the Range 7 3D Laser Scanner was used, as it gives excellent resolution but is difficult to carry in the field.

After attaining the 3D images, we then imported them into the Avizo Fire 3D Imaging Software (version 8.0) to accurately calculate the surface area and volume of the handaxes.

The segmentation function of this software was also applied to divide the handaxes into three portions with the piece aligned along the long axis, using the distal end as the guide. The scar coverage of each portion was then accurately extracted using this software. An example is given in Fig. 2, which shows the proportional division of the surface into distal, medial and proximal parts based on the length, for which the area of flake scar coverage is then calculated in each sector.

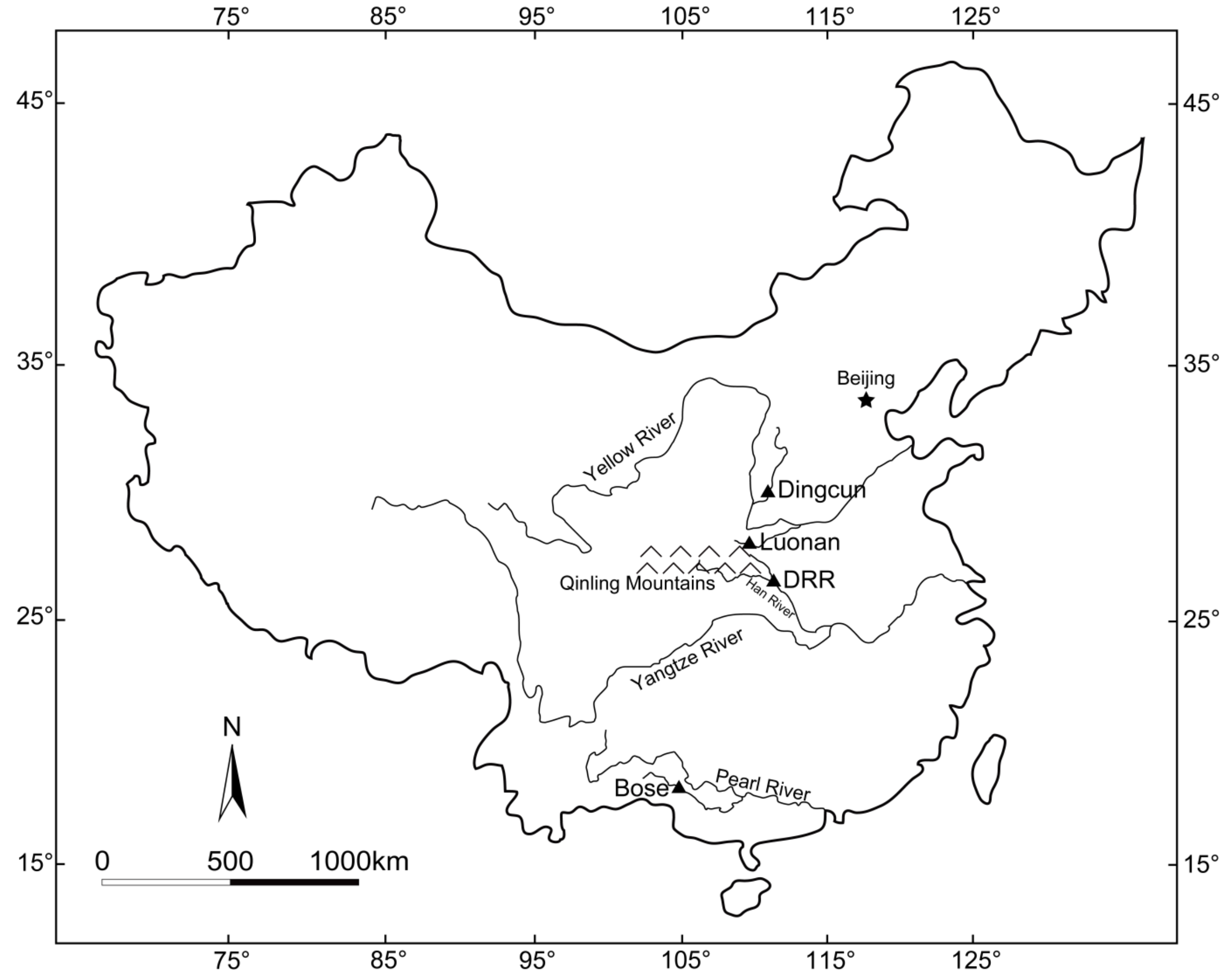

Fig. 1. The Danjiangkou Reservoir Region (DRR) and the other well-known handaxe regions in China.

Indices of SDI and SAI

The flake scar density (equal to the Scar Density Index, SDI) has been used as an effective indicator of reduction intensity of Indian and East African handaxes [39-42]. In an experimental test of the reliability of SDI, the regression analysis of transformed log SDI and

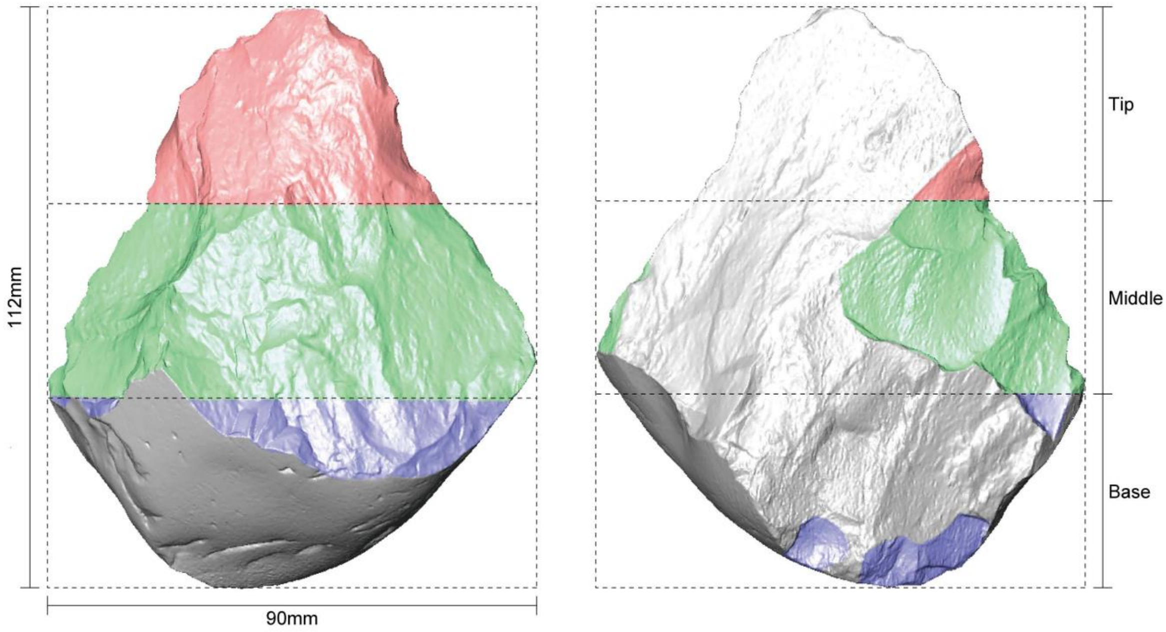

Fig. 2. Segmentation of a 3D scanned handaxe into three proportional sectors.

log % Mass Remaining of bifaces produced a very strong relationship (R^2 = 0.916) [43]. In addition, a recent study of the experimentally reduced handaxes also indicates a strong relationship (R^2 = 0.803) between increasing SDI and decreasing % original mass [41]. For this reason, the 3D SDI was adopted in our analysis of reduction extent of the DRR handaxes. All visible flake scars on a handaxe were counted in this study, regardless of their interpretation as shaping vs. resharpening scars.

As a result of the use of 3D technology, a new index, Scar Area Index (SAI, scars area divided by the total surface area), is now possible. A reasonable assumption for this index is that the flake scars area on handaxes increases with reduction. The unretouched blank for a handaxe would have a SAI value of 0, while a completely retouched handaxe would reach a SAI value of 1. Through the accurate measuring of the scars area in different sectors of the handaxes, we can estimate not only the overall reduction intensity, but also the reduction intensity of the different parts. We need to bear in mind that the flake scars area does not necessarily relate to the number of flake scars. This is particularly applicable to hard hammer percussed handaxes, in which a small number of large scars can produce a large area of scar coverage, and conversely, a large number of small scars can produce a small area of scar coverage. Despite this, the SAI index can reflect the general pattern of the reduction extent of handaxes.

In addition, it should be noted that both the SDI and SAI indices will reveal the relative extent of reduction, but not the actual mass lost during the reduction. In order to investigate quantitatively how much mass has been lost in the reduction process, it is necessary to conduct knapping experiments in future research.

Results

The application of SDI to reduction intensity

A test of the validity of SDI is presented first. Considered to provide a good fit to the data, a cubic regression is conducted for weight and SDI (see also Shipton [39, 40]). The result shows that the relationship between weight and SDI is significant ($R^2 = 0.46$, $r = 0.50$, $p < 0.001$), although there is considerable variation (Fig. 3). Therefore, we suggest that the SDI used in this study is appropriate for measuring the reduction intensity of handaxes. Fig. 4 shows three handaxes (left side of the figure) that are low in weight but high in SDI, and three handaxes (right side of the figure) that are high in weight but low in SDI. Detailed information for each specimen is provided in Table 1.

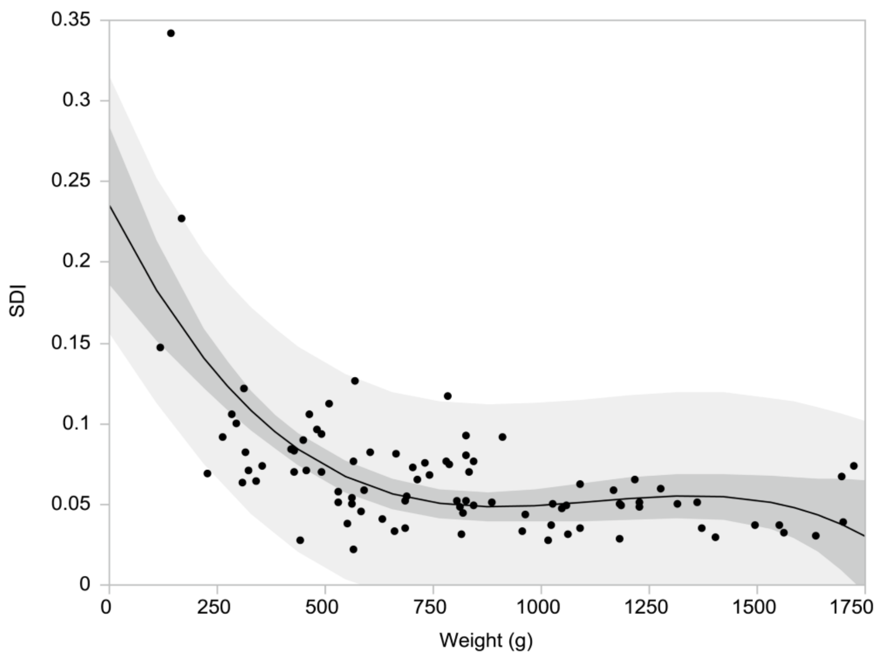

Fig. 3. Cubic regression between weight and SDI.

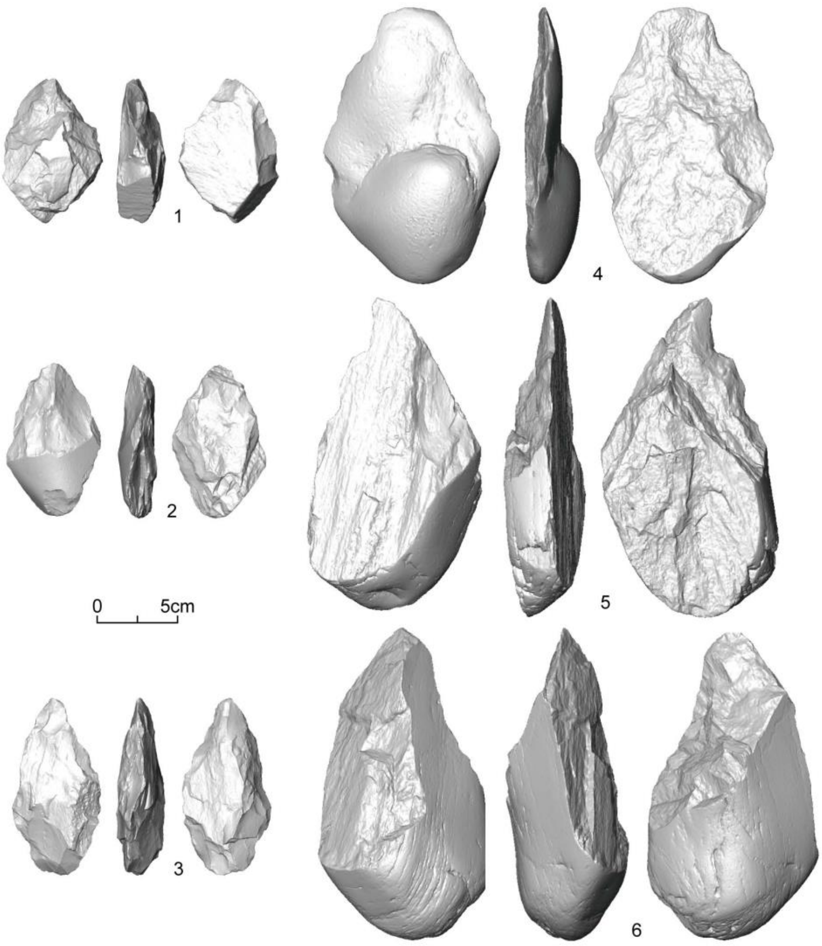

Fig. 4. 3D scans of the DRR handaxes.

Table 1. Data for the DRR handaxes presented in Fig. 4.

Number	Weight (g)	Scars Number	Surface Area (mm^2)	SDI	Total scar area (mm^2)	SAI
1	168	24	10587.9	0.227	7070.4	0.668
2	120	14	9540.3	0.147	7920.3	0.830
3	144	37	10831.8	0.342	10831.8	1.000
4	566	7	31231.4	0.022	14357.7	0.460
5	1018	11	41174.8	0.027	32134.8	0.780
6	1404	12	41413.8	0.029	17220.1	0.416

Although the indices of SDI used here cannot show how much mass is lost during reduction, they do provide us with information about the relative intensity of handaxe reduction. Adapting statistical models used in demography, Shott and colleagues suggest that different distributional patterns of reduction could correspond to different cumulative-survivorship curves [11, 61-63]. In other words, the fit between the length of handaxe use and SDI has the ability to reveal the underlying use-life of tools and the related human behaviours. In Fig. 5, we can see that most of the DRR handaxes possess lower SDI values and locate on the left side of the histogram, with 83.5% (N = 76) of them lower than 0.09 on the SDI value. Only a small number of handaxes has relatively higher SDI values and locate on the right side of this diagram. Therefore, it is reasonable to infer from Fig. 5 that most of the DRR handaxes were less extensively reduced and generally had short use-life before discard. This situation may relate to the use of locally available raw materials close to the site and brief occupation periods. For visualizing the reduction intensity of the DRR handaxes, six handaxes with the values of SDI from 0.08 to 0.09 are presented in Fig. 6 (see Table 2 for information on individual specimens).

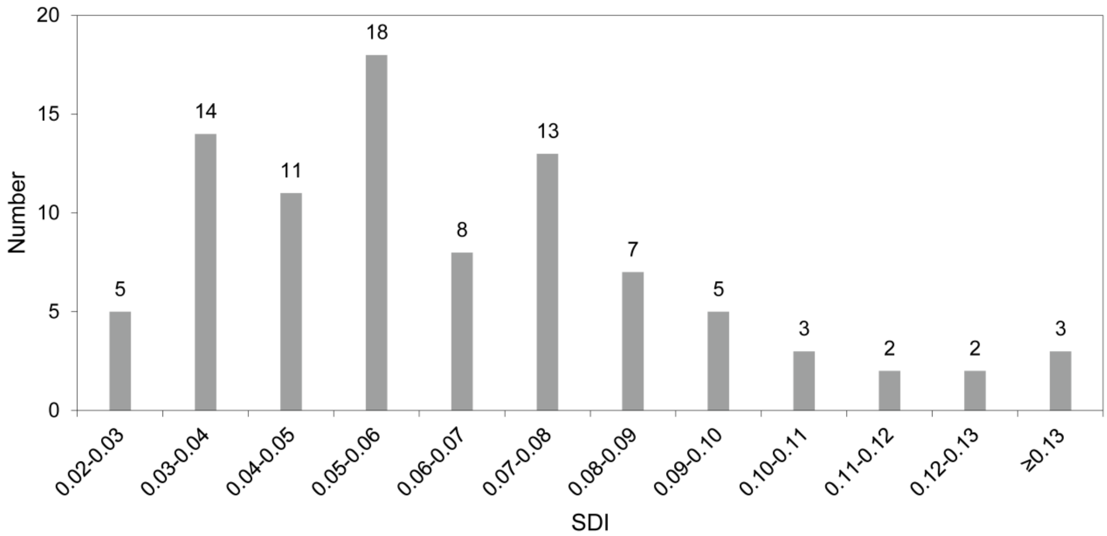

Fig. 5. The number of handaxes within the different ranges of the SDI values.

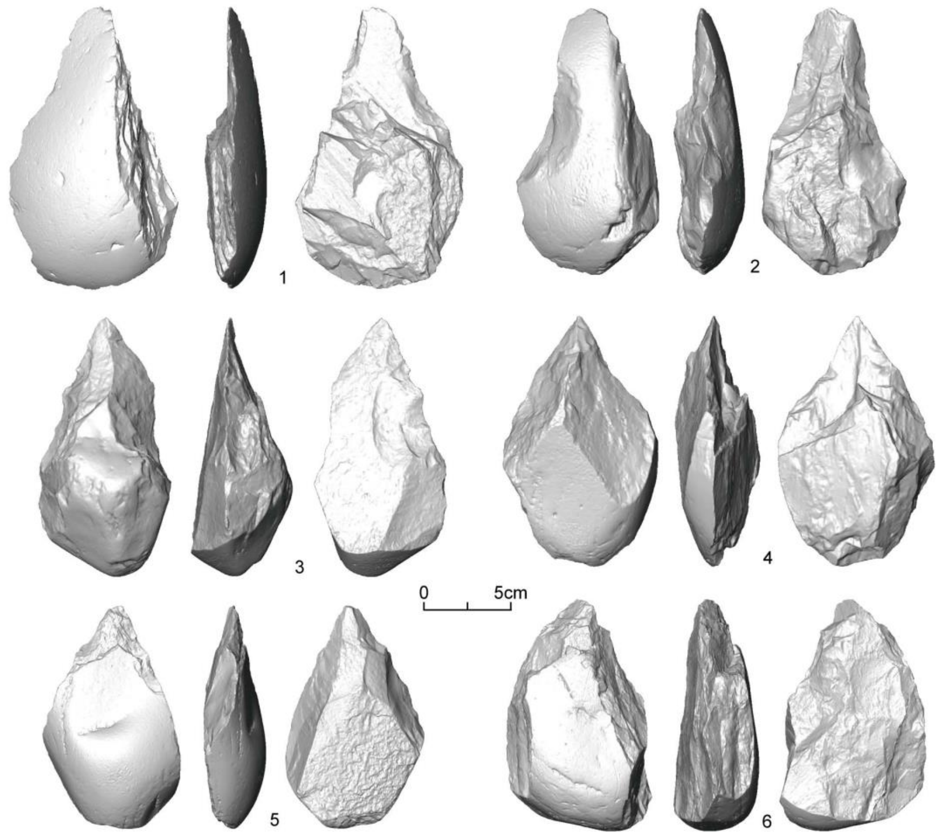

Fig. 6. 3D scans of the DRR handaxes with relatively high SDI values (0.08-0.09).

Table 2. Data for the DRR handaxes presented in Fig. 6.

Number	Scars number	Surface area (mm^2)	SDI	Total scar area (mm^2)	SAI
1	20	24087.9	0.083	15320.1	0.636
2	18	21382.7	0.084	8487.6	0.397
3	21	25775.1	0.081	12122.6	0.470
4	19	21317.4	0.089	14276.5	0.670
5	14	17005.5	0.082	5594.3	0.329
6	20	24453.6	0.082	17229.3	0.705

The application of SAI to reduction intensity

Based on the 3D segmentation of handaxes into three proportional parts, namely, tip, middle and base, we can examine the pattern of reduction intensity in each sector. Fig. 7 and Table 3 show that the values of SAI for tips are high, with 34.8% of them scoring in the range 0.75-0.99 and 41.3% of them fully covered by flake scars. For the middle sections, 59.7% are concentrated in the range 0.26-0.75 and 30.4% in the range 0.76-0.99. The SAI values for the bases are generally low, with 32.6% scoring in the range 0.01-0.25, 34.8% in the range 0.26-0.50 and 23.9% in the range 0.51-0.75. Therefore, we can conclude that most of the shaping was invested in the tips of the DRR handaxes, while the bases usually have the least reduction, with an intermediate degree of reduction in the middle sectors. The reason for this pattern is undoubtedly related to the functional differences for each part: the tip is the most utilised part, while the middle may be related either to use or to shaping of the tip; and the smooth cobble surface is often left on the base for holding comfort.

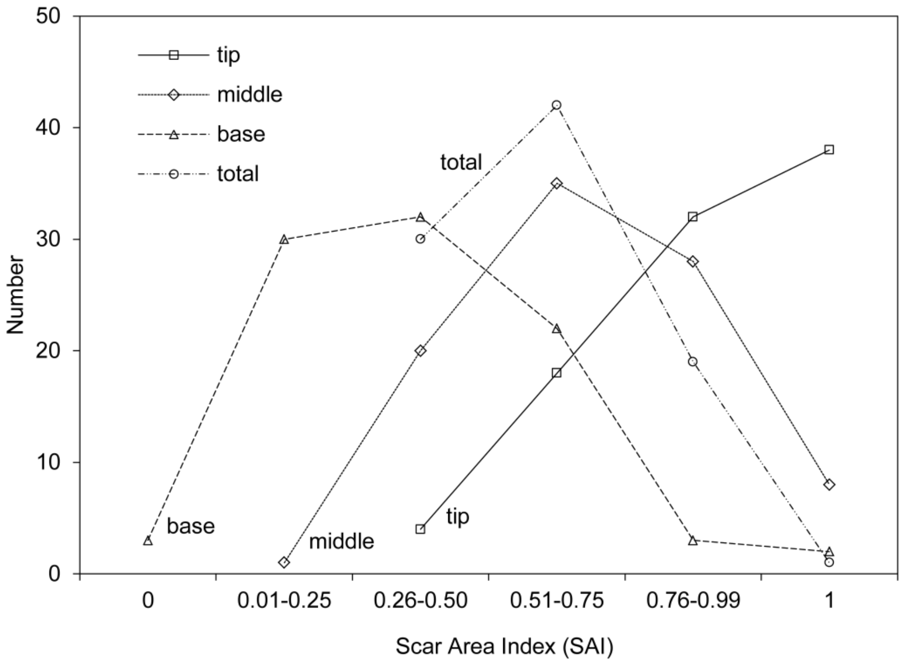

Fig. 7. The distribution of the SAI values in relation to handaxe sectors.

Table 3. DRR handaxe analysis by sectors in relation to the SAI values.

SAI	Tip		Middle		Base		Total	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*
0	0	0	0	0	3	3.3	0	0
0.01-0.25	0	0	1	1.1	30	32.6	0	0
0.26-0.50	4	4.3	20	21.7	32	34.8	30	32.6
0.51-0.75	18	19.6	35	38.0	22	23.9	42	45.7
0.76-0.99	32	34.8	28	30.4	3	3.3	19	20.7
1	38	41.3	8	8.7	2	2.2	1	1.1

The overall extent of reduction for the whole body of handaxes ranges from 0.26-0.99, with over 45.7% in the range of 0.51-0.75 (Table 3). If a cut-off point of 0.75 is used to represent the boundary between extensive (> 0.75) and moderate reduction (≤ 0.75), we can see that more than three quarters (78.3%) of handaxes in DRR were only moderately reduced. This result is consistent with our analyses of the SDI, where results show that the DRR handaxes generally show a low extent of reduction.

Comparing reduction intensity for different types of raw materials and blanks

Quartz phyllite (N = 67) and trachyte (N = 15) were the most frequently used raw materials for DRR handaxes, although the number of trachyte pieces is much lower than the number of quartz phyllite in the current study sample. Both raw materials are abundant and locally available in the nearby gravel layers of the Han River [50, 55, 56]. The comparisons of SDI and SAI by raw material show substantial overlap (left halves of Figs. 8 and 9). This observation is supported by the *t*-test (t = -0.305, p = 0.761 for SDI; t = 0.478, p = 0.634 for SAI), which shows there is no statistically significant difference in the levels of reduction between the two raw materials. We can, therefore, further infer that a consistent reduction strategy was employed despite raw material differences.

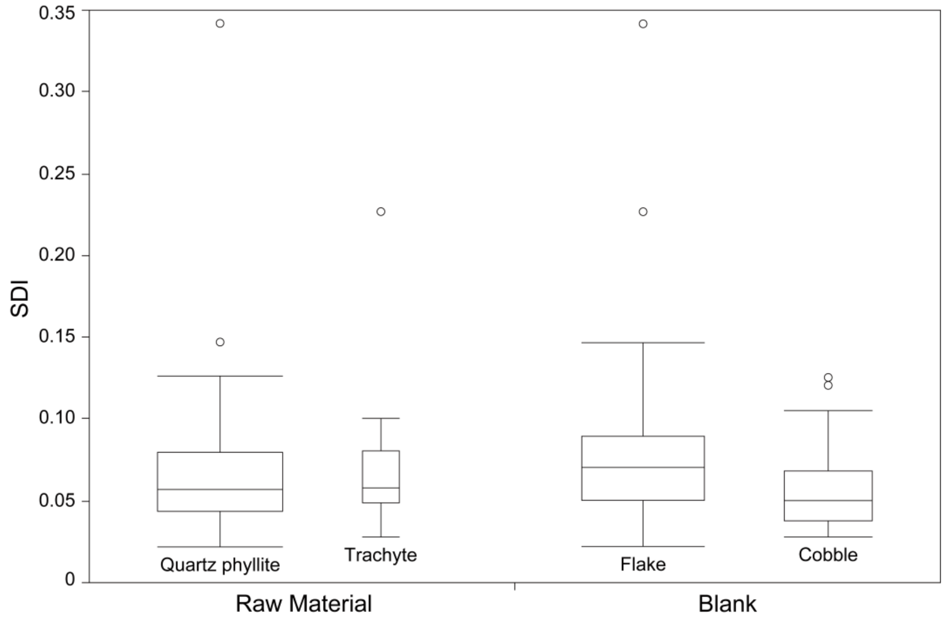

Fig. 8. Box plots of SDI values for the different types of raw materials and blanks.

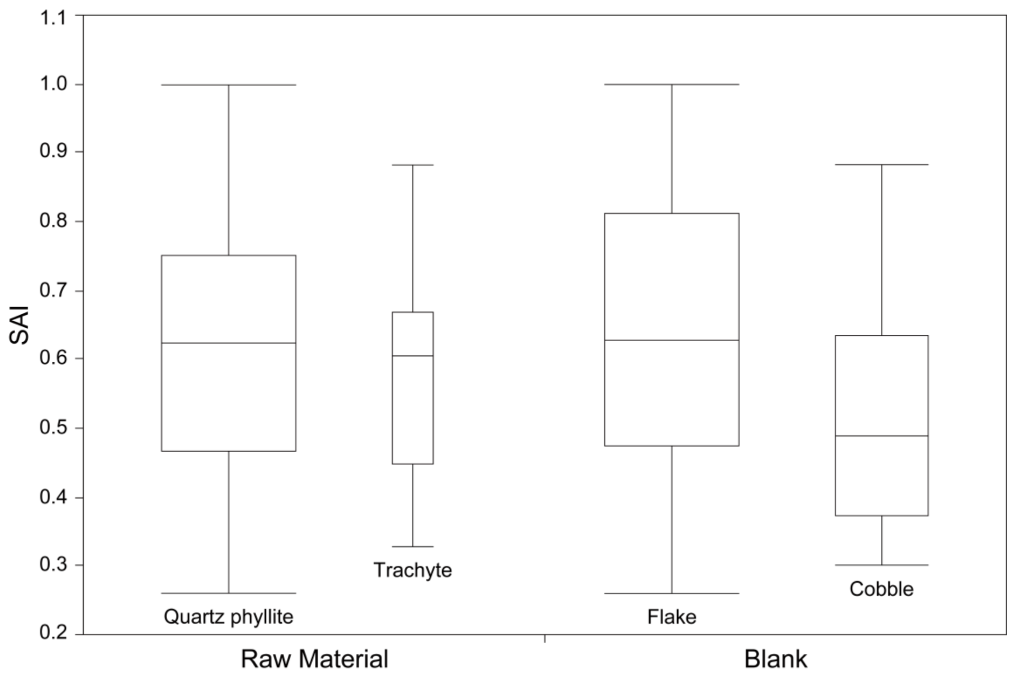

Fig. 9. Box plots of SAI values for the different types of raw materials and blanks.

In contrast, there is a clear trend of lower SDI and SAI with cobble blanks (N = 45) compared with flake blanks (N = 32). This is visible on the right halves of Figs. 8 and 9. The *t*-test also shows significant differences in the levels of reduction between the two blank groups (t = 2.438, p < 0.05 for SDI; t = 2.708, p < 0.01 for SAI). This difference probably relates to the large flat ventral surface provided by flake blanks and their relative thinness compared to cobbles, both of which facilitate reduction.

Comparing the reduction intensity of handaxes from T2 and T3 of the DRR

The 3D quantitative method provides an objective way to compare reduction intensity through time. Here, the 25 handaxes from the second terrace of the DRR are compared with the 92 handaxes from the third terrace analysed in the foregoing sections. The preliminary age of handaxes from the second terrace is the early Late Pleistocene (100-50 ka) [60], while the handaxes on the third terrace are dated to the Middle Pleistocene [51, 56]. Therefore, handaxes in the DRR provide an opportunity to examine the regional change in reduction intensity from the Middle to the early Late Pleistocene. Attributes used in this analysis include the number of scars, surface area, volume, total scar area, and the indices of SDI and

SAI. The *t*-test shows that there are no statistically significant differences ($p > 0.05$) between handaxes from T2 (the second terrace) and T3 (the third terrace) in any of these attributes (Table 4) and thus no technological change in reduction intensity through time in the DRR.

Table 4. Comparison of mean values between handaxes from T2 and T3 in DRR.

	T2 (N = 25)	T3 (N = 91)[a]	*t*-statistic	*p*-value*
Scars number	16.76	18.12	-0.955	0.342
Surface area (cm^2)	318.03	305.21	0.604	0.547
SDI	0.058	0.067	-0.969	0.335
Total scar area (cm^2)	196.85	181.69	0.882	0.380
SAI	0.620	0.605	0.384	0.702

[a] Because of the highly weathered surface of one handaxe, its scar number is indeterminable. Thus, 91 handaxes were used for comparison.

* p (two-tail) < 0.05 is a statistically significant difference.

Summary and Conclusion

The extensive application of reduction intensity indices in the past three decades has remarkably improved the ability of lithic analysts to interpret human behaviour. With the aid of 3D scanning technology, in this paper we applied two quantitative reduction indices, the Scar Density Index (SDI) [41, 43, 44] and the Scar Area Index (SAI), to the analysis of reduction intensity of the T3 DRR handaxes. The SDI in this study shows that most of the handaxes in DRR have a relatively low intensity of reduction, which also indicates a generally short use-life as argued by Shott and Sillitoe's reduction distribution model [11, 61-63]. In addition, the short-use lives of these handaxes may suggest that open-air sites along the river terrace were not occupied by hominids for a long time. The analysis of SAI also shows that the overall reduction intensity of the DRR handaxes represents a least-effort reduction strategy, with 78.3% of handaxes only moderately reduced (SAI ≤ 0.75). The detailed SAI analysis of the different parts of the DRR handaxes shows that tips generally show the most reduction, while the bases show the least, a pattern which is relatively common in some Chinese handaxe assemblages. It is not surprising that the handaxe tip would receive most attention in shaping. The middle section could be functional if the edge were used, but it relates also to shaping of the piece overall. The base of a handaxe was the holding unit, with only limited or no shaping present.

The two raw materials used in DRR, both locally available, did not have an influence on the reduction intensity, suggesting that the behavioural interpretation of short-term use is correct. In addition and because of the abundance of raw materials, the DRR handaxe knappers seem to have employed an expedient exploitation strategy. However, the type of blanks did play a role in the reduction extent of the DRR handaxes. Those made on flake blanks generally show a higher level of reduction than those made on cobble blanks, presumably because flake blanks were thinner than cobbles, and they provided a large flat surface which made reduction easier. The preliminary comparison of handaxes from T2 and T3 of the DRR suggests that there is no technological change in the reduction intensity from the Middle Pleistocene to the early Late Pleistocene in this region, although more specimens from terrace two need to be analysed.

The results presented here demonstrate that the application of quantitative technological indices is necessary and useful in estimating the reduction intensity of handaxes. According to this estimation, we can further investigate the behaviour of handaxe makers in the DRR, such as their adaptation to the local raw materials, their energy investment in making handaxes, and the use-life of handaxes. The potential of the indices used in this paper has been confirmed; however, as we have mentioned already, these indices can only indicate the relative extent of handaxe reduction and they still need to be further tested. In future research, experiments will be conducted to further evaluate the mass lost at different levels of the index values, and to support the validity of the current indices. Additionally, owing to the long lasting and widespread use of handaxe technology in the Pleistocene, the reduction intensity of handaxes at different developmental stages and in different regions will be further examined to address the technological evolution and adaptive behaviour of Acheulean hominids. Finally, this study has provided detailed information on the nature of handaxes in the DRR, which will serve as a comparative sample for a better overall understanding of these industries in China, in comparison with the western Acheulean.

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CHAPTER SEVEN: CONCLUSIONS

7.1 Answers to the research questions in this thesis

The research questions of this thesis were proposed in chapter one. Here, I list all the questions again, with the relevant answer to each and its significance for understanding the Chinese Acheulean.

Papers 1 and 2 (chapters two and three):

1. How do we define the different types of LCTs (e.g., handaxe, pick) found in DRR?

An appropriate classification system is the basis of research work. However, this basic question seriously restricts the development of the Chinese Early Palaeolithic. In particular, with regard to study of the Acheulean in China, there have been long-term and prominent debates on the definition of a handaxe. One main reason for this, in my opinion, is that the criteria used to define Chinese handaxes are borrowed from the Later Acheulean in western Europe, in which handaxe technology is in an advanced stage. Extensively bifacial shaping, thinner body and more symmetrical shapes are regarded as features of the later Acheulean handaxe. Therefore, most unifacially flaked specimens and handaxes with thick bodies in China were not considered handaxes, and the former have been called picks and the latter proto-handaxes. As a result, the Acheulean affinity of these tools was rejected.

In the study of DRR LCTs, I employed a classification system based on African Acheulean materials, considering two factors. First, the popular European-based Lower Palaeolithic typological system used by Chinese archaeologists has proved inadequate for discussing the Acheulean technocomplex in other parts of the Old World (Sharon 2007). In contrast, African typological classification, which includes an intact developmental sequence for the Acheulean Industrial Complex, provides more comprehensive information. Secondly, African typological classification has been developed over many years through the study of a series of Acheulean sites, such as Olduvai Gorge (Leakey 1971, 1994; de la Torre 2005), Koobi Fora (Isaac 1997), Kalambo Falls (Clark 1974, 2001a), Olorgesailie (Kleindienst 1961; Isaac 1977) and Cave of Hearths (Mason 1988; McNabb & Sinclair 2009).

One contribution of African typological classification is the identification of variability in the Acheulean Industrial Complex during its long developmental sequence. This also influences our definitions of LCTs in the DRR, where there are significant differences in environment and raw material with the African and western European Acheulean sites. Thus, a slight modification to the African typological classification was made due to regional variability. For instance, the unifacial cobble pick is regarded as a unique LCT type in the assemblages in DRR, whereas there are no western assemblages showing the consistent occurrence of this type. The definition of each type of LCT in DRR, namely handaxe, cleaver, pick, pick-like handaxe and unifacial cobble pick, can be found in the methods sections of papers 1 and 2 (i.e. chapters 2 and 3). My co-authors and I believe that this classification system of LCTs will play an important role in resolving the debate on classification, thus promoting research in other LCT regions, and also facilitating communication between East and West.

2. What are the typological and technological characteristics of the DRR LCTs and are these characteristics consistent with the Acheulean tradition or not?

The detailed analysis of the typology and technology of the DRR LCTs is one of the main purposes of papers 1 and 2. It also contributes to our understanding of the variability of the Chinese Acheulean. From the perspective of typology, the DRR LCTs contain not only the typical western Acheulean tool types (handaxe, picks and cleavers), but also a special type, unifacial cobble picks, which do not commonly occur in western Acheulean assemblages. The appearance of this special type in the DRR is likely an ecological adaptation to the local environment, as discussed in these two papers. In addition, although cleavers do occur in the DRR, they are currently low in number compared with handaxes. This is closely related to the original size and homogeneous texture of raw materials, as in the neighbouring region of the Luonan Basin, in which giant quartzite cobbles of good quality were available, and cleavers form a high proportion of LCTs (Wang 2006). A similar paucity of cleavers has also been observed in many sites in western European where suitable raw materials are absent (Villa 1983; Santonja & Villa 2006).

From a technological perspective, the DRR LCTs show commonalities with the western Acheulean. The detaching of large flakes and the intentional shaping of flakes or cobble blanks into LCTs are two main aspects that demonstrate the technological commonality and also the existence of stable technological tradition in the DRR. The lower number of LCTs on side-struck flakes (a common blank type in the western Acheulean) is due to the specific flaking properties of the main raw materials, quartz phyllite and trachyte. Bipolar flaking was also one of the methods used to detach large flakes, as this flaking strategy worked well in producing LCT blanks. These features are influenced by the locally available, but poorer quality raw materials and clearly suggest a good regional adaptation.

In addition to the above points, the analysis of DRR LCTs from the Middle Pleistocene third terrace and the early Late Pleistocene second terrace shows that there are no significant typological and technological changes over time in DRR. This observation is worthy of further examination.

Paper 3 (chapter four):

3. What are the complete technological strategies contained in the in situ *assemblage of Shuangshu?*

The *in situ* assemblage at the Shuangshu site provides a good opportunity to reconstruct the technological strategies in a complete assemblage. As discussed in the paper, two reduction sequences are revealed from this assemblage. One is the predominant use of quartz in the production of small-to-medium sized artifacts. This is a simple and expedient technology that dominates the whole assemblage. The other is the use of quartz phyllite and trachyte in the production of LCTs, which displays the technical criteria characteristic of the Acheulean techno-complex.

In addition, a series of findings from the *in situ* assemblage indicates that the production, use and discard of small-medium sized artifacts were conducted on site, and therefore they represent the complete reduction strategies of these hominids. However, current evidence also shows that there was an incomplete reduction sequence for these LCTs, in that the detaching of large flakes did not happen on site. A systematic study of cores and flakes from other excavated sites will help to test this conclusion and also provide information about the carrying behaviour of hominids and the regional usage strategy for these sites.

4. What is the real proportion of LCTs in the in situ *context in DRR and how do we interpret this phenomenon?*

The excavated sites in DRR were summarized in this paper (see Table 8 in paper 3). It shows a clear pattern that the number of LCTs in all *in situ* assemblages is small and their proportion is low. On the other hand, the total number of artifacts is also small for the size of the excavation areas.

Norton and colleagues (Norton *et al.* 2006; Norton & Bae 2008) have argued that the low proportion of LCTs would not support the label Acheulean to describe the handaxe-bearing sites in East Asia. However, in my opinion, the number of LCTs in a site is not the key criterion for judging the attributes of a site. Various factors can influence the proportions of LCTs as the context of a site changes. In the case of the DRR, the relatively small population size is regarded as an important factor that resulted in the low number of LCTs, as well as the low number of total artifacts in the sites. In addition, the less intensive use of these sites could indicate the high mobility of the hominids, and this is another likely factor influencing the low number of both LCTs and total numbers of artifacts.

Paper 4 (chapter five):

5. What are the morphological characteristics of East Asian (including DRR) handaxes?

One of the most debated questions for East Asian handaxes is their morphology. Norton and colleagues (Norton *et al.* 2006; Norton & Bae 2008) argue that the morphology of East Asian handaxes is different from handaxes in the typical western Old World Acheulean. Nevertheless, Petraglia and Shipton (2008) consider that there is some degree of overlap in the measurements of handaxes from either side of the “Movius Line”. To further examine the morphological characteristics of East Asian handaxes, I conducted a quantitative inter-continental comparison. In addition to the generally used materials from IHRB, Bose and Luonan, the DRR handaxe assemblage was included in the analysis.

The results show that morphological variability is a common phenomenon, not only in East Asian handaxes, but also in western Acheulean handaxes. And moreover, the variability of East Asian handaxes is not significantly different from that of the western Acheulean.

Therefore, I suggest that the morphological difference, especially handaxe thickness, is likely not a reliable indicator of handaxe variation between the East and the West.

6. How do we interpret the morphological variability of East Asian (including DRR) handaxes?

In this paper a stepwise approach was used to interpret the morphological variability. A detailed description of this approach can be found in the methods section of this paper. The results indicate that the morphological variability of East Asian handaxes is influenced by multiple factors, which include raw materials, selection of blanks, reduction intensity, subsistence ecology, technical tradition and others. Each factor likely plays an unequal role in determining the morphological variability of handaxes. Thus, conducting the specific analysis for each assemblage is necessary for a better understanding of this subject. The same applies to Acheulean sites in the western part of the Old World, in which a detailed examination of the context of each site is also very necessary. For example, the thicker bodies of handaxes from Doornlaagte in South Africa are unusual and need explanation – for example, perhaps as a quarry site.

Paper 5 (chapter six):

7. How do we quantify the reduction intensity of the DRR handaxes with the aid of 3D scanning technology?

As an advanced method, 3D scanning technology is increasingly used in the technological and morphological analyses of stone artifacts. With the aid of 3D scanning, the proportional segmentation of handaxes and the accurate calculation of surface area were determined and presented in this paper, which further inspired the application of quantitative indices to estimate the reduction intensity of the DRR handaxes. Here, two reduction indices, the Scar Density Index (SDI) and the Scar Area Index (SAI), were used.

8. What levels of reduction do the DRR handaxes show and what are the reasons for this?

Both SDI and SAI show that most of the handaxes in DRR have relatively low levels of reduction, and it can be further inferred that the use-lives of these handaxes were generally short. With regard to the interpretation, I suggest that the abundance of locally available raw materials and the relatively short-term usage of these open-air sites are two possible reasons that led to the low reduction intensity of the DRR handaxes.

7.2 Future research

As a result of the current studies, some significant but still unanswered questions about the DRR Acheulean are raised.

First, when did LCTs first appear in DRR? This is an important question for understanding the origins of the DRR Acheulean. Currently, the earliest LCTs in DRR have been reported from the fourth terrace Yunxian Man site (~0.8Ma; see Li & Feng 2001; de Lumley & Li 2008). However, the original excavation report states that all bifacially shaped tools were actually collected from the nearby surface (Li *et al.* 1998), while the one LCT excavated *in situ* is unifacial (de Lumley & Li 2008; Feng 2008). Therefore, further excavation work on terrace four is needed to reveal the earliest origin of the Acheulean technology in DRR. Alongside the exploration of the earliest Acheulean technology in DRR, more dating work for the DRR handaxe-bearing sites on different terraces of the Han and Dan Rivers need to de conducted to build a robust chronological framework.

Second, how do we interpret the co-existence of open-air LCT sites and the cave sites with only Mode 1 core and flake technology? In addition to the abundant open-air sites found along the river terraces, the cave sites are also important findings in DRR, e.g., the Middle Pleistocene Bailongdong cave and the Late Pleistocene Huanglongdong cave. Preliminary studies of the stone artifacts from these cave sites show that unlike the LCT technology displayed in the open-air sites, only simple core and flake technology was used (Pei *et al.* 2008b; Li, Y.H. *et al.* 2014). A detailed comparative study of the two different types of sites in the future should provide answers for this co-existence phenomenon.

Third, why is there no technological change of LCTs through time in these two DRR terraces, namely, from the Middle Pleistocene terrace three to the early Late Pleistocene terrace two? Is this related to the relatively small samples used for this study, or is it because of an absence of the diffusion of new ideas, or because of the small population size that did not undergo innovation? Regardless of the reason, the exploration of this question will reveal more information about the nature of the Chinese Acheulean.

Fourth, why was the Acheulean techno-complex in DRR not replaced by Levallois technology or other forms of advanced technology during the Late Pleistocene? What does this tell us about the origins of modern humans in China? Current dating evidence shows that the LCT sites in DRR persisted until the early stage of the Late Pleistocene (Liu & Feng 2014). Nevertheless, in the western part of the Old World, this is a time period characterised by the use of innovative Levallois technology. We are not expecting to answer these questions in the short term, but it is now the time to carefully consider them and intentionally collect the data to address such questions.

Overall, all the questions proposed here are crucial for understanding the evolutionary history of the Chinese Acheulean techno-complex and the people who possessed this technology. Future research should focus on answering these questions satisfactorily.

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