Chin. Sci. Bull. (2014) 59(7):651–661
DOI 10.1007/s11434-013-0105-5

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Geology

Newly discovered Palaeolithic artefacts from loess deposits and their ages in Lantian, central China

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Received: 24 June 2013 / Accepted: 6 November 2013 / Published online: 15 January 2014

Abstract Eight new Palaeolithic open-air sites were identified and 770 stone artefacts were collected from 2009 to 2011 in the Lantian area of the Bahe River valley, central China. Because the famous *Homo erectus* fossils were unearthed at the Gongwangling and Chenjiawo localities, and more than 30 Palaeolithic open-air sites were investigated in the 1960s in this region, the catchment of Bahe River is regarded as one of the most important hominin sites from the late early Pleistocene to the middle Pleistocene. These eight newly discovered open-air sites are located at the second ($n = 6$), third ($n = 1$) or higher terraces ($n = 1$) of the Bahe River. The Diaozhai section on the second terrace was sampled in detail. Two samples were collected for optically stimulated luminescence dating (OSL). The OSL results suggest that a buried lithic artefact layer at the Diaozhai site spans approximately 70–30 ka. The lithic assemblage analysis suggests that the stone artefacts were made of local pebbles/cobbles such as greywacke, quartz, sandstone and igneous rocks. The main percussion techniques that were used were direct hard hammer percussion and bi-polar techniques. The lithic artefacts comprise hammer stones, cores, flakes, retouched tools and flaking debris. Acheulian-type large cutting tools (LCTs) such as hand-axes, picks and cleavers were indentified in the Lantian region as well. This is the first time Acheulian-type LCTs from the late Pleistocene have been identified in this region. This study distinguishes age gaps between Western world and East Asian Acheulian-type tools.

Keywords Lantian area · Palaeolithic open-air sites · Loess deposit and chronology · Late Pleistocene · Acheulian-type lithic artefacts

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1 Introduction

The discovery of *Homo erectus* and their affiliated stone tools at the Gongwangling and Chenjiawo sites in the 1960s in Lantian, central China, is a great advancement in understanding human evolution in Eastern Asia. These findings have significantly expanded the dataset of *H. erectus* activity in China; in addition, the findings extended the time span when *H. erectus* lived in Eastern Asia back to 1.15 Ma ago [1–12]. Certainly, these findings are important in understanding our ancestors and the stone tool techniques that were dispersed globally during the Pleistocene epoch. Compared with the human remains and the wealth of mammalian fossils unearthed in this region [13, 14], there were only 26 lithic artefacts found at the

Gongwangling site. Twenty-four open-air sites with red silt deposit around the Gongwangling site were investigated, only approximately 20 lithic artefacts were collected [1–3, 8–10, 15–17], and only 10 lithic artefacts were found around the Chenjiawo site. A total of 27 sites with lithic artefacts from the early or middle Pleistocene were found in the Lantian region, and approximately 200 lithic artefacts were collected [10]. The Xishuidong site, reported in the 1980s, was the only cave site with fossils and lithic artefacts in the Lantian region [18]; however, whether these reported lithic artefacts were man-made has been strongly debated [16]. In addition to these Palaeolithic sites from the early and middle Pleistocene, 400 lithic artefacts from the late Pleistocene were found at the Laochihe and Yehu [8, 10] localities but without detailed description. These previous investigations clearly show that the Lantian region is a place worthy of further investigation.

Previous examination of the lithic artefacts collected from the Lantian region has revealed that the features of these lithic assemblages, their ages, the stratigraphy and even the excavation works were not well recorded. In addition, the lithic artefacts collected from the Gongwangling and Chenjiawo sites were not properly dated, and their ages are not known; therefore, the conclusions from previous reports regarding these stone tools are controversial [3, 8, 10, 16, 17]; the age, features and the assemblages of stone tools collected from the Lantian region were not well understood, and more work was required. Between June 2009 and March 2011, we undertook several field reconnaissance and sampling expeditions in the catchment of the Bahe River, Lantian Region (Fig. 1) and found eight open-air sites with lithic artefacts in the river terraces on the right bank of the Bahe River, a total of 770 lithic artefacts were collected. In this paper, we will report on the newly found lithic artefacts and the loess stratigraphy in which they were buried, and we discuss the implication of these newly discovered lithic artefacts.

2 Landform, stratigraphy and age of the newly discovered Palaeolithic sites

The Bahe River originates from the northern slope of the Qinling Mountains, it is one of the tributaries of the Weihe River and has a length of 92.6 km. The Bahe River flows through Lantian County, and there are well-preserved river terrace sequences along the river [19–21]. The river terraces are composed of the fluvial sediment and the upperlying aeolian loess deposit. The fluvial sediment is silt to cobble in particle size, and the loess–palaeosol sequences have a thickness of approximately 100 m. Our newly discovered open-air sites at Jijiawan, Diaoza, Ganyu and Xiazhaijiacun have thick loess deposits, providing excellent age constraints for these stone tools. The Jijiawan site is located on the boundary between two catchments on the highest river terrace; three pieces of core, flake and debris were found in situ in the palaeosol stratigraphy. The Xiazhaijiacun site is located on the third river terrace; four lithic artefacts were found in the loess–palaeosol deposit of the middle Pleistocene. The Diaozhai and Ganyu sites are located on the second river terrace, the lithic artefacts were

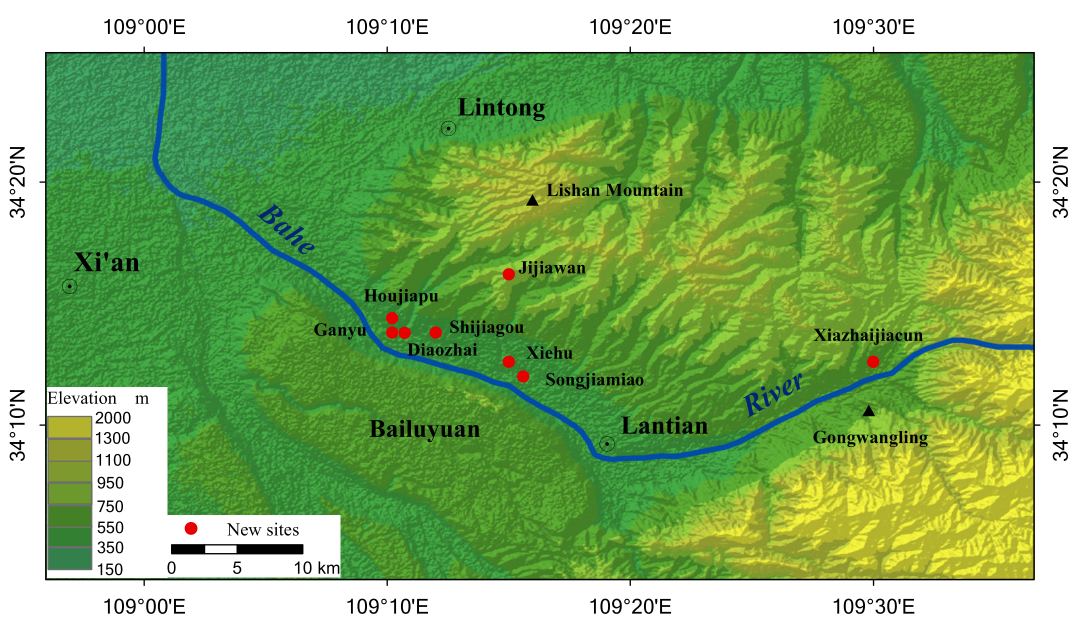

Fig. 1 The new Palaeolithic open-air sites in the Lantian region, central China

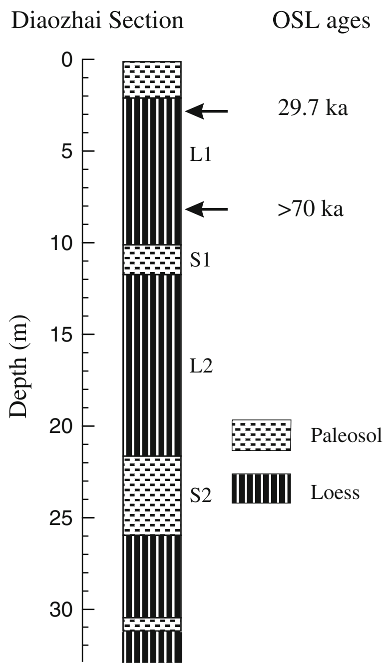

Fig. 2 Pedostratigraphy and TT-OSL ages of the Diaozhai loess–palaeosol sequence

collected in the in situ loess–palaeosol deposit, and the rejected materials sieved by farmers to make bricks.

The Diaozhai section comprises the buried soil of Holocene (S0), the Malan loess of the late Pleistocene (L1) and the buried soil of the last interglaciation (S1) (Fig. 2). The Holocene buried soil is dark reddish-brown (5YR 4/3), has an aggregated structure and contains white reticular carbonate film and plant roots. The Malan loess is dark orange (7.5YR 7/3). The silt particles are coarser than those found in the upper- and underlying palaeosols, and they contain worm holes and snail fossils, two flakes were found in this unit. The S1 palaeosol is light reddish-brown in colour (2.5YR 5/6), has a hard, aggregated structure, white reticular carbonate film and plant roots, the leached carbonate occurred in this unit. Below the S1, the L2 loess, S2 palaeosol, L3 loess, S3 palaeosol and L4 loess can clearly be identified in the field, and the lithic artefacts are mainly found in the L1. The Malan loess in the Ganyu loess–palaeosol section is well exposed, and the lithic artefacts are mainly found in the L2 loess; simultaneously, we found one core and two flakes in situ in the L2 loess. In addition, the loess materials used to make bricks were taken from the loess–palaeosol deposits above the S2 palaeosol, and the lithic artefacts collected from the rejected material sieved by farmers can be pinpointed in the loess–palaeosol section from which the farmers have taken the loess.

In order to test the age estimation of the loess deposit in the field, we took samples from the Diaozhai loess–palaeosol section at a depth of 1.0 and 8.2 m, respectively, for the optically stimulated luminescence dating (OSL). The samples were wrapped in light-tight black plastic bags immediately after extraction from the sections and were processed in the Nanjing University Luminescence Dating Laboratory under subdued red light. Sunlight-exposed ends of samples were excluded from equivalent dose (De) determinations but retained for radioisotope measurements (to determine dose rate). Quartz was isolated by immersion in 35 % H_2SiF_6 for up to 4 weeks with a subsequent 0.1 M HCl wash to remove fluorite precipitates. The coarse silt fraction (40–63 μm) was obtained by wet sieving. De values were measured using a modified SAR procedure [22] performed on a Risø TL-DA-15 TL/OSL reader. A blue LED ($\lambda = \sim 470$ nm) stimulation source was used (60 s, c. 400 mJ cm^{-1}) on samples, and the OSL signal was measured using a 9235QA photomultiplier tube filtered by 6 mm of Hoya U340. Equivalent doses were calculated using the blue stimulated OSL signal, integrated from the first 0.6 s of stimulation minus a background estimated from the last 6 s of stimulation. All growth curves were fitted using a saturating exponential plus linear function. Dose rates were calculated from uranium, thorium and potassium contents measured using neutron activation analysis (NAA), by equations and dataset [23]; thus, we obtained two ages of these two samples, 29.7 ka and >70 ka, respectively (Table 1), confirming the conclusion reached during the field observation. In addition, these newly investigated loess–palaeosol deposition sequences can be correlated with the well-dated typical loess–palaeosol sequence in the central Chinese Loess Plateau [24, 25], providing further age constraints for these loess deposits in the Lantian area.

3 Stone artefacts collected from Jijiawan and other sites located above the third river terrace

The number of stone artefacts collected from the Jijiawan site, located on the highest Bahe River terrace, and the Xiazhaijiacun site, located on the third river terrace, is small (Tables 1, 2). The 13 stone artefacts collected from the Jijiawan site, including cores, broken flakes, chunks and retouched tools such as spheroids, picks (or hand-axes?) [Fig. 3(a), 1], and broken hand-axes (Tables 1, 2), show the obvious connection to the stone artefacts collected from the sites on the second river terrace with respect to raw material and typology. The hand-axe was made of a greywacke pebble, partly broken at the tip. It is 109.29 mm in length, 77.78 mm in width, 51.88 mm in thickness and weighs 474 g [Fig. 3(b), 7]. This specimen is bifacially retouched on one side, whereas the other side is retouched unifacially and only a little cortex remains on one face and at the butt.

Table 1 Raw material types of the stone artefacts

Site	Geographic coordinate	Quartz	Quartzite	Greywacke	Fine sandstone	Chert	Igneous rock	Siliceous limestone	*N* (%)
Diaozhai (LT01)	34°14′03″N,	49	48	9			6	2	114
	109°10′16″E	42.98	42.11	7.90			5.26	1.75	100
Ganyu (LT02)	34°14′37″N,	154	284	60	10	1	36	5	550
	109°10′14″E	28.00	51.64	10.91	1.82	0.18	6.55	0.91	100
Jijiawan (LT03)	34°16′28″N,	3	5	3	1		1		13
	109°15′05″E	23.08	38.46	23.08	7.69		7.69		100
Shijiagou (LT04)	34°13′58″N,	4	5	2					11
	109°11′48″E	36.36	45.46	18.18					100
Songjiamiao (LT05)	34°12′12″N,	18	6	12	1		3		40
	109°15′51″E	45.00	15.00	30.00	2.50		7.50		100
Xiehu (LT06)	34°12′43″N,	2	13				2		17
	109°14′59″E	11.77	76.47				11.77		100
Houjiapu (LTP07)	34°14′22″N,	9	6	2	1		2	1	21
	109°09′42″E	42.86	28.57	9.52	4.76		9.52	4.76	100
Xiazhaijiacun (LTP08)	34°12′50″N,	3	1						4
	109°30′2.8″E	75.00	25.00						100
Total (%)		242	368	88	13	1	50	8	770
		31.43	47.79	11.43	1.69	0.13	6.49	1.04	100

Table 2 Inventory of the lithic artefacts

Site	Types												*N* (%)
	Manuport	Hammer stone	Core	Flake	Retouched tools							Chip and chunk	
					Hand-axe	Cleaver	Pick	Chopper	Spheroid	Scraper	Point		
Diaozhai (LT01)			62	26			1	4	8	8	1	4	114
			54.39	22.81			0.88	3.51	7.02	7.02	0.88	3.51	100
Ganyu (LT02)	41	6	347	50	12	3	3	16	11	22	3	36	550
	7.46	1.09	63.09	9.09	2.18	0.55	0.55	2.91	2.00	4.00	0.55	6.55	100
Jijiawan (LT03)			4	1	1		1		3			3	13
			30.77	7.69	7.69		7.69		23.08			23.08	100
Shijiagou (LT04)			5	3								3	11
			45.46	27.27								27.27	100
Songjiamiao (LT05)		1	29	4	1		1	1				3	40
		2.50	72.50	10.00	2.50		2.50	2.50				7.50	100
Xiehu (LT06)			8	8				1					17
			47.06	47.06				5.88					100
Houjiapu (LTP07)			11					5	2	1		2	21
			52.38					23.81	9.52	4.76		9.52	100
Xiazhaijiacun (LTP08)			2	2									4
			50.00	50.00									100
Total (%)	41	7	468	94	14	3	6	27	24	31	4	51	770
	5.33	0.91	60.78	12.21	1.82	0.39	0.78	3.51	3.12	4.03	0.52	6.62	100

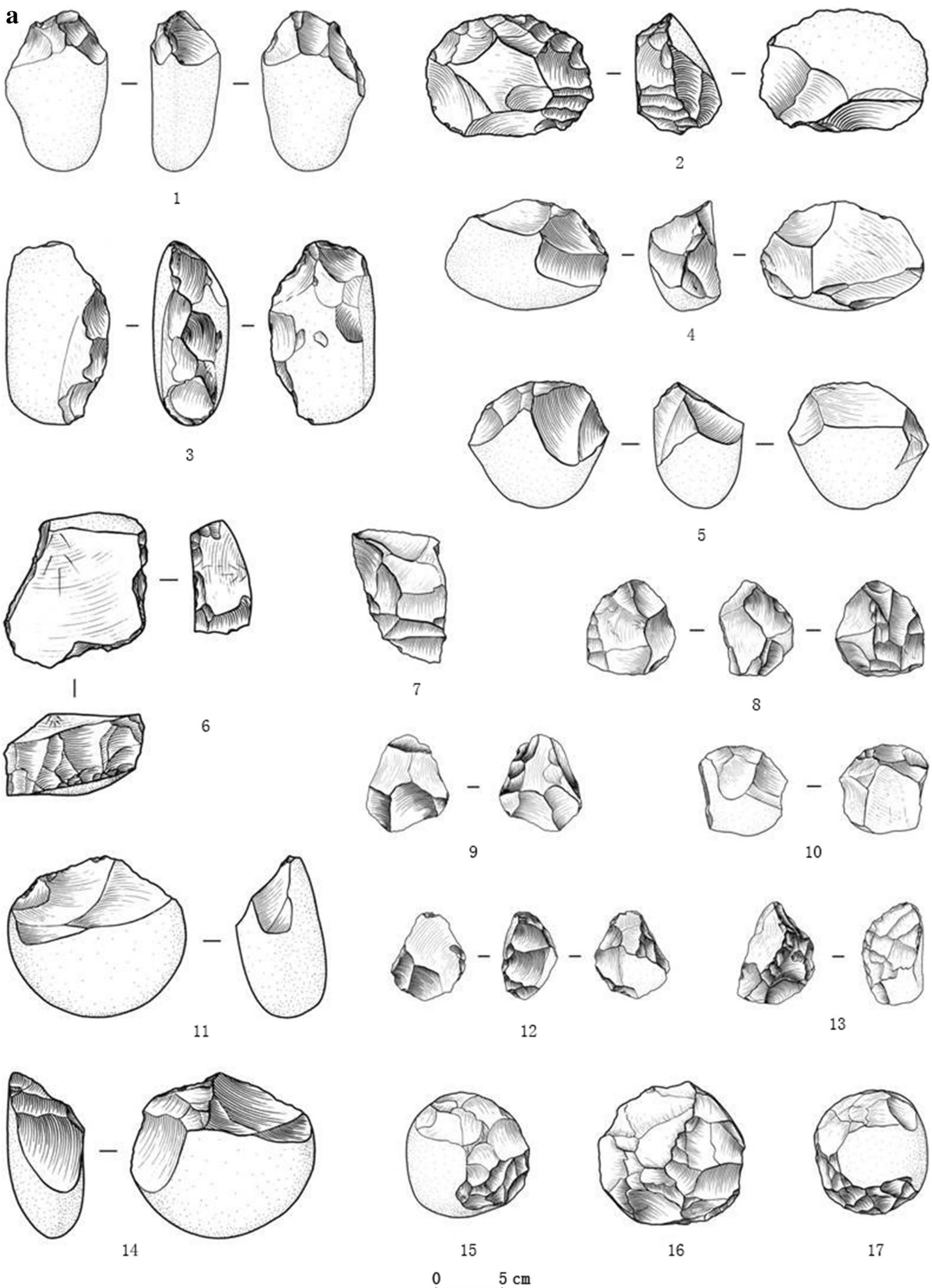

Fig. 3 Newly collected lithic artefacts from the Lantian area. **a**: **1** Pick (or Hand-axe?, LTP03:06); **2–4**, **7**, **10** Scrapers (LTP02:537, LTP01:108, LTP02:534, LTP02:544, LTP02:543); **5**, **11**, **14** Choppers (LTP02:526, LTP05:20, LTP02:488); **6** Core (LTP01:037); **8**, **9** Hand-axes (LTP02:549, LTP02:518); **12**, **13** Points (LTP02:504, LTP02:510); **15–17** Spheroids (LTP02:524, LTP02:489, LTP01:103). **b**: **1**, **3** Picks (LTP02:483, LTP01:100); **2**, **10** Cleavers (LTP02:533, LTP02:527); **4–9** Hand-axes (LTP02:540, LTP02:541, LTP02:528, LTP03:12, LTP02:532, LTP02:536); **11** Scraper (LTP02:538)

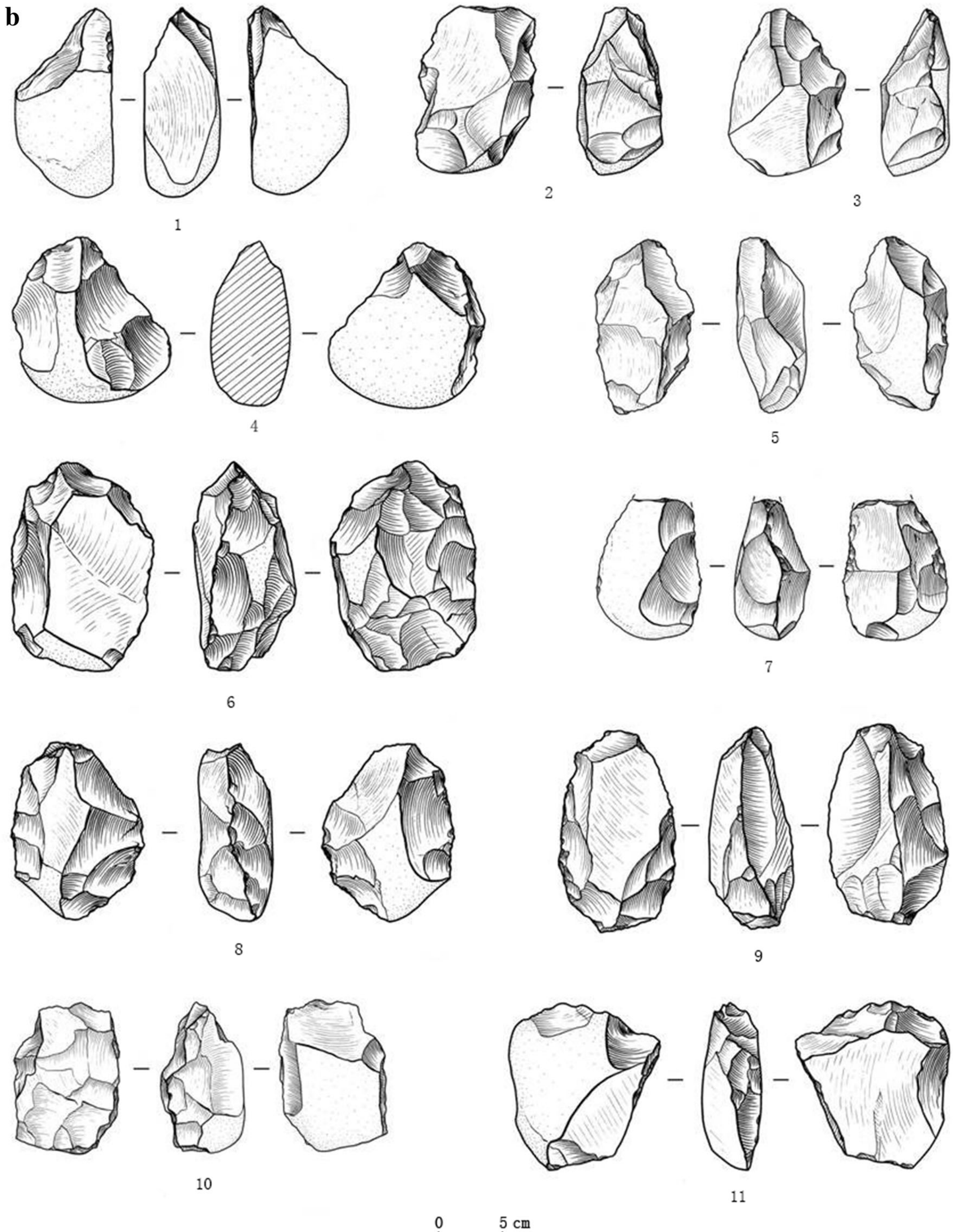

Fig. 3 continued

4 Stone artefacts collected from the sites on the second river terrace

Of the six newly identified Palaeolithic sites located on the second river terrace, the quantity of the stone artefacts collected from the Diaozhai and Ganyu sites is much greater than from the other four sites (Tables 1, 2). The retouched tools are mainly heavy-duty tools and LCTs such as choppers [Fig. 3(a), 5, 11, 14], heavy-duty scrapers, hand-axes, picks, cleavers and spheroids; light-duty tools or small tools such as scrapers and points are rare. The analysis of the stone artefacts collected from the two major sites—Diaozhai and Ganyu—is as follows.

4.1 Stone artefacts collected from the Diaozhai site

The stone artefacts collected from the Diaozhai site can be classified into four types: cores ($n = 62$, 54.39 %), flakes ($n = 26$, 22.81 %), retouched tools ($n = 22$, 19.3 %) and chunks ($n = 4$, 3.51 %). There are 15 complete flakes (57.69 %) and 11 broken flakes (42.31 %). Among the retouched tools are choppers ($n = 4$, 18.18 %), picks ($n = 1$, 4.55 %), scrapers ($n = 8$, 36.36 %), spheroids ($n = 8$, 36.36 %) and points ($n = 1$, 4.55 %). The raw materials of all of these artefacts include quartz ($n = 49$, 42.98 %), quartzite ($n = 48$, 42.11 %), greywacke ($n = 9$, 7.90 %), igneous rock ($n = 6$, 5.26 %) and siliceous limestone ($n = 2$, 1.75 %) (Tables 1, 2).

Cores make up a large proportion of the artefacts. Of the 62 cores, 15 have a maximal diameter of over 100 mm, maximal diameter of 44 cores is between 50 and 100 mm, and maximal diameter of three cores is less than 50 mm. The average length of the cores is 67.51 mm (SD = 20.39), the average width is 76.57 mm (SD = 20.03), the average thickness is 62.66 mm (SD = 18.64), and the average weight is 516.2 g (SD = 379.49). The core platforms are dominated by a cortical surface ($n = 45$) with mixed platforms ($n = 15$) and fixed platform types ($n = 2$) making up the remainder [Fig. 3(a), 6]. Nine cores (14.52 %) can be identified as bi-polar cores for the obvious characteristics, whereas the other 53 cores (85.48 %) are hard hammer-knapping cores.

Of the 15 complete flakes, only one flake has a maximal diameter of over 100 mm, 10 have a maximal diameter of between 50 and 100 mm, and the other four diameters are less than 50 mm.

In the domain of retouched tools, only one of the four choppers is bifacially retouched on the edge, the rest are retouched unifacially. Half of the eight scrapers are heavy-duty scrapers [Fig. 3(a), 3]. The raw material of the spheroids includes granite ($n = 3$), quartzite ($n = 3$) and greywacke ($n = 2$). All of the spheroids are perfectly round, their weight ranging from 714.6 to 1,135 g [Fig. 3(a), 17]. The pick was made of a quartzite flake, retouched on the interior surface, 129.6 mm in length, 88.84 mm in width, 51.21 mm in thickness and weighing 656.6 g [Fig. 3(b), 3]. The point, which is small and made of quartz, is 27.36 mm in length, 16.15 mm in width, 7.94 mm in thickness and weighs 3.4 g (Fig. 4).

4.2 Stone artefacts collected from the Ganyu site

Seven categories of raw materials are utilised in the stone-artefact-knapping process (Table 3). Quartzite makes up the highest proportion, followed by quartz, greywacke and granite. Fine sandstone, siliceous limestone and chert are used occasionally.

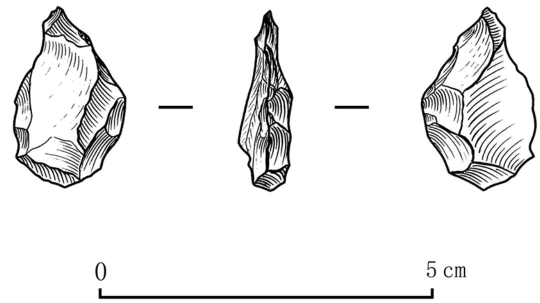

Fig. 4 Point collected from the Diaozhai site (LTP01:114)

Diverse types of stone artefacts were collected from this site, including manuports ($n = 41$, 7.46 %), hammers ($n = 6$, 1.09 %), cores ($n = 347$, 63.09 %), flakes ($n = 50$, 9.09 %), retouched tools ($n = 70$, 12.73 %) and chunks ($n = 36$, 6.55 %). Flakes comprised 31 complete flakes (62 %) and 19 broken flakes (38 %). Seventy retouched tools can be classified as choppers ($n = 16$, 22.86 %), spheroids ($n = 11$, 15.71 %), hand-axes ($n = 12$, 17.14 %), cleavers ($n = 3$, 4.29 %), picks ($n = 3$, 4.29 %), scrapers ($n = 22$, 31.43 %) and points ($n = 3$, 4.29 %).

4.2.1 Manuports

Forty-one manuports collected from the Ganyu site are all medium-sized pebbles/cobbles, four of which exceed 100 mm in maximal diameter. The weight of the manuports ranges from 16 to 1,296.7 g.

4.2.2 Hammer stones

Six hammer stones, which are covered by a cortical surface with clear puncture marks, are composed of three types of raw materials: quartzite ($n = 3$), igneous rock ($n = 2$) and greywacke ($n = 1$).

4.2.3 Cores

Cores compose the highest proportion of the lithic assemblage collected from the Ganyu site ($n = 347$, 63.09 %). The average length of all cores is 70.48 mm (SD = 20.30), the average width is 76.20 mm (SD = 20.79), the average thickness is 58.76 mm (SD = 18.08), and the average weight is 506.2 g (SD = 404.83). The largest core size is 151.9 mm in length, 151.22 mm in width, 145.72 mm in thickness and weighs 4,455.0 g.

Table 3 Raw materials corresponding to lithic types at the Ganyu site

Types	Quartz	Quartzite	Igneous rock	Siliceous limestone	Greywacke	Chert	Fine sandstone	Total
Manuport	8	15	5		12		1	41
Hammer stone	3	2		1				6
Cores	111	177	20	4	27	1	7	347
Flakes								
Complete flake	11	17	2		1			31
Broken flake	8	10			1			19
Retouched tools								
Chopper	2	12			2			16
Spheroid	2	5	2		2			11
Hand-axe	1	10			1			12
Cleaver		2		1				3
Pick	1	1	1					3
Scraper	6	14			1		1	22
Point	2	1						3
Chip and chunk	2	17	4		12		1	36
Total	154	284	36	5	60	1	10	550
Percentage (%)	28.00	51.64	6.55	0.91	10.91	0.18	1.82	100

The core platform types are dominated by cortical platforms ($n = 261$, 47.84 %), including 166 single cortical platform cores (24.21 %), 84 double-cortical platform cores (24.21 %) and 11 multi-cortical platform cores (3.17 %); in addition, 70 cores are mixed platforms cores (cortical and dihedral or other fixed platform types) with a few fixed platform cores such as plain platform cores ($n = 6$) and dihedral platform cores ($n = 6$) making up the remainder.

Forty-three cores have just one flaking scar (12.39 %), 58 cores have two flaking scars (16.72 %), and the other 246 cores have more than three flaking scars (70.89 %).

The majority of the cores collected from this site are hard hammer-knapping cores ($n = 343$, 98.85 %) compared with the four bi-polar cores (1.15 %).

4.2.4 *Flakes*

Thirty-one complete flakes account for 5.64 % of the total stone artefacts, including seven flakes that have a maximal diameter of over 100 mm, accounting for 22.58 % of the complete flakes. The largest flake, which was made of cream quartzite, is 133.45 mm in length, 202.76 mm in width, 99.2 mm in thickness and weighs 3,478.0 g. Twenty-two flakes have a maximal diameter of between 50 and 100 mm, accounting for 70.97 %; two flakes have a maximal diameter of less than 50 mm, accounting for 6.45 %.

Twenty-nine complete flakes have a cortical platform (93.55 %), one complete flake has a dihedral platform (3.23 %) and one has a crushed platform (3.23 %). There are two complete flakes that can be identified as bi-polar flakes (6.45 %), and the other 29 (93.55 %) were produced by the direct hard hammer percussion technique.

There are 19 broken flakes, including seven half flakes and 12 distal snaps. Four broken flakes have a maximal diameter of over 100 mm, 12 broken flakes have a maximal diameter of between 50 and 100 mm, and the other three have a diameter of less than 50 mm.

4.2.5 *Retouched tools*

Among the 16 choppers, 12 were made of quartz pebbles/cobbles, and the rest were made of quartzite and siliceous limestone. Ten choppers are unifacially retouched [Fig. 3(a), 14] on the edge, and the rest are retouched bifacially [Fig. 3(a), 5]. Fourteen choppers have convex edges, and the other two have rectilinear edges.

Among the 11 spheroids, five were made of quartzite pebbles/cobbles, and the other six were made of diverse raw materials such as quartz, greywacke and granite pebbles/cobbles. Of the blanks, one spheroid is retouched from a pebble/cobble that is nearly round [Fig. 3(a), 15], and the other 10 were made of multi-knapped cores [Fig. 3(a), 16].

Twelve hand-axes were collected from this site, made of diverse raw materials such as quartzite ($n = 10$), quartz ($n = 1$) and greywacke ($n = 1$). Six hand-axes were damaged at the tip. Measurement data show that seven hand-axes are over 125 mm in length, and the other five (including the damaged one) are between 66 and 84 mm

[Fig. 3(a), 4–6, 8, 9]. The 12 hand-axes weigh between 131.5 and 1,590.3 g.

Because the hand-axe is considered the symbol of Acheulian assemblage, we describe five typical specimens as below:

LTP02:528, an oval hand-axe that is retouched by a large quartzite flake, is 161.6 mm is length, 112.76 mm in width, 73.22 mm in thickness and weighs 1,590.3 g [Fig. 3(b), 6]. It is relatively thick, bifacially retouched around the edges and still maintains a small portion of the cortical platform at the butt.

LTP02:532, a teardrop-shaped hand-axe, retouched by a quartzite flake and partly damaged at the tip, is 137.43 mm is length, 99.95 mm in width, 57.68 mm in thickness and weighs 858.3 g [Fig. 3(b), 8]. It is bifacially retouched on both sides up to the middle of the handle. A bit of cortex remains at the butt.

LTP02:536, a teardrop-shaped hand-axe, retouched by a quartzite flake, is 155.39 mm in length, 88.07 mm in width, 63.48 mm in thickness and weighs 855.7 g [Fig. 3(b), 9]. It is bifacially retouched on one side up to the middle of the handle and partially retouched on the other side, with no cortex remaining.

LTP02:541, a hand-axe retouched by a quartzite flake, is 135.29 mm is length, 73.99 mm in width, 49.33 mm in thickness and weighs 528.6 g [Fig. 3(b), 5]. It is bifacially retouched around the edges and maintains a small portion of cortex on one face.

LTP02:518, a teardrop-shaped hand-axe, retouched by a quartzite flake and partly damaged at the tip, is 66.69 mm in length, 59.8 mm in width, 38.28 mm in thickness and weighs 180.6 g [Fig. 3(a), 9]. The portion that remains appears quite regular in shape and symmetrical and is bifacially retouched around the edges with no cortex remaining.

Two of the three cleavers were retouched by a quartzite flake, whereas the third was retouched by a siliceous limestone. Two are described below:

LTP02:533, retouched by a quartzite flake and partially damaged at the distal end by a brick press, is in the shape of a “U” shape. It is 131.76 mm is length, 93.15 mm in width, 65.06 mm in thickness and weighs 958.7 g [Fig. 3(b), 2]. Entirely retouched on both sides, it still retains a bit of cortex at the butt.

LTP02:527, made of a siliceous limestone flake, was reshaped to a “U” shape. It is 111.12 mm in length, 82.19 mm in width, 61.25 mm in thickness and weighs 783.7 g [Fig. 3(b), 10]. Entirely retouched on both sides, it nevertheless retains a bit of cortex at the butt and on one surface.

Three picks were retouched by quartz, quartzite and granite pebbles/cobbles, respectively. LTP02:483, retouched by a quartzite pebble, is 146.18 mm is length, 74.44 mm in width, 56.36 mm in thickness and weighs 854.9 g [Fig. 3(b), 1]. This specimen is the largest pick in terms of size, alternately retouched on both sides and retaining the entire cortex on the surface of the handle.

Among the 22 scrapers, 13 are heavy-duty scrapers that are over 100 mm in length [Fig. 3(a), 2, 4, 7; (b), 11], whereas the other nine scrapers are shorter but nevertheless over 65 mm [Fig. 3(a), 10]. Various raw materials were used for retouching the scrapers such as quartzite ($n = 4$), quartz ($n = 4$), greywacke ($n = 1$) and fine sandstone ($n = 1$). Eight scrapers were retouched on the exterior surface, six were retouched on the interior surface and the rest were bifacially retouched.

Of three points [Fig. 3(a), 12, 13], two were made of quartz, and the other was made of quartzite.

4.2.6 Chunks

Most chunks collected from the Ganyu site range from 45 to 106 mm in length and 101–512 g in weight. The existence of chunks at this site indicates that the early hominins hunted or gathered at this location and used it for stone knapping when they required stone tools quickly. Nevertheless, the absence of small chips could indicate that large machines such as bulldozers have been used here. Consequently, the small chips cannot be differentiated.

5 Discussion

Previous studies on the Lantian region showed that the stone artefacts from the early/middle Pleistocene or earlier stratum came from the loess–palaeosol deposit. Lithic artefacts from the Gongwangling and Chenjiawo sites were partially collected around the sites and partly excavated from the deposits, the layers in which in situ stone artefacts are buried can range from several metres to a dozen metres in height [1, 3]. These findings indicate that the early hominins lived in the Lantian region for a long period of time. This conclusion was again demonstrated when new discoveries of stone artefacts at the Jijiawan site, located on the highest Bahe River terrace, and the Xiazhaijiacun site, located on the third terrace, actually came from different layers of the deposits. Fewer stone artefacts were collected from Jijiawan and Xiazhaijiacun than from the Diaozhai and Ganyu sites, which are located on the second terrace. Based on our long-term study of the Palaeolithic sites that are buried in the loess–palaeosol deposits in the Qinling Mountains area [26, 27], we maintain that all of these open-air sites were temporary activity stations. Most of these stone artefacts were not in situ specimens, but collected specimens. Although we have only reached preliminary conclusions regarding the chronology, our calculations are sufficient to reveal the cultural development and the transformation of *H. erectus* in the Lantian area. The discovery of the stone artefacts buried in the upper Pleistocene deposit on the second terrace of the Bahe River indicates for the first time that the Palaeolithic assemblage in the Lantian region lasted from approximately 70 to 30 ka with respect to stratigraphy and chronology. We considered this a breakthrough in our understanding of the Palaeolithic sequence and chronology of *H. erectus* in the Lantian region and accordingly extend the date range of early hominins' activity from the early and middle Pleistocene to the later period of the late Pleistocene.

With respect to raw materials, the analysis of stone artefacts collected from the Jijiawan site, located on the highest Bahe River terrace, and the Xiazhaijiacun site shows that the early hominins chose quartzite, quartz, greywacke and igneous rock pebbles/cobbles on the riverbank for stone knapping, whereas the fine sandstone, siliceous limestone and chert were only used occasionally. This conclusion is reinforced by the analysis of the stone artefacts collected from the second terrace.

Direct hard hammer percussion was the principal stone-knapping technique. Because the flake-knapping method can scarcely be distinguished in the research [28] and since the large proportion of bi-polar cores and flakes among the artefacts, we maintain that the bi-polar method was also frequently used in the lithic assemblage of the Lantian region, which actually is consistent with previous studies [8, 16]. Nevertheless, artefacts demonstrating the anvil-chipping method were only recently discovered at a few sites (e.g. Songjiamiao), which demonstrates that this method was only used occasionally in this area [28, 29].

With respect to lithic assemblage composition, there is an obvious similarity between the stone artefacts from the lower Palaeolithic formation and the stone artefacts from the upper Pleistocene deposit. With the exception of hammers, cores, flakes, chunks and small debris produced during the knapping process, heavy-duty tools such as choppers, heavy-duty scrapers, hand-axes, picks, cleavers and spheroids were more abundant than small tools such as scrapers and points. A considerable number of heavy-duty tools were made by large flakes and retouched bifacially on the edges. This study also showed that there were more cleavers, hand-axes and spheroids in the Lantian region than previous research has indicated.

Coincidentally, a series of Palaeolithic sites from the same period were identified recently in nearby areas such as the Luonan Basin in the South Luohe River valley in the Qinling Mountains and the Hanzhong Basin [26, 27, 30–36]. The Luonan Basin located near the upper South Luohe River, the South Luohe River and Bahe River both originated in the Caolianling Mountain, which is located in eastern Lantian county. The Palaeolithic sites of these two regions produced similar chronological data and lithic assemblages. In the Lantian region, on the north side of the Qinling Mountains, numerous granite pebbles/cobbles were found that came from the granitoid intrusions formed from the Indosinian–Yanshanian to the Himalayan. These findings are quite different from the abundance of quartz or quartzite pebbles/cobbles along the riverbanks and on the river terraces in the Luonan Basin. However, attribute analysis shows that quartzite and quartz are still the dominant raw materials in the Lantian region. This phenomenon, along with the identical knapping technique and lithic assemblage composition [26, 27, 30], reinforces the similarity of the Palaeolithic assemblages in the entire Qinling Mountains area.

Hand-axes, cleavers and picks are generally considered the representations of the Acheulian complex and were widespread in Africa and on the west side of the Eurasian continent during the *H. erectus* period. According to current archaeological recordings, the Acheulian complex originated in Africa approximately 1.7 Ma ago [37, 38] and spread to Europe and Asia with the dispersal of *H. erectus*, lasting until approximately 0.2 Ma, when *Homo sapiens* appeared and the Acheulian complex faded and was finally replaced by the Mousterian complex. In previous studies on the Lantian region, hand-axes were occasionally reported; however, this suggestion was not widely accepted [4, 17, 39–44]. Our new discoveries of hand-axes, picks and cleavers (which were discovered for the first time in this area) indicate that the Acheulian LCTs in the Lantian region lasted until the late Pleistocene, which suggests that the Palaeolithic industry in East Asia had its own distinctive development pattern that perhaps differed from western Palaeolithic industry in terms of chronology: when the transition from the Acheulian complex to the Middle Stone Age (MSA) was accomplished and blade technology finally appeared with the emergence of modern humans in Africa and Europe, the Acheulian complex, including hand-axes, cleavers and picks, nevertheless prevailed in the Qinling Mountains area and, of course, in East Asia. Therefore, this new discovery in the Lantian region may be considered valuable for identifying Palaeolithic industry characteristics in East Asia, the comparison between west and east world in terms of Palaeolithic culture and human behaviour concerning modern human origins in East Asia.

Acknowledgments The authors thank Jian Zhao for drawing the lithic charts and Fangying Zhu for drawing the map, thank the three anonymous reviewers and the invited review editor for their comments on the earlier draft of this paper. This work was supported by the One Hundred Talent Person Project of the Chinese Academy of Sciences (KZCX2-YW-BR-24), the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA05130201 and XDA05120704) and the National Natural Science Foundation of China (41072122 and 41202127).

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