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A Study of the Lithic Assemblage from Zhoukoudian Locality 15

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1 Introduction

Zhoukoudian Locality 15 was found in 1932 and excavated in 1935—1937. It is one of the richest localities in the Zhoukoudian complex and a very important late Middle Pleistocene archeological site in North China and greater East Asia. However, the rich unearthed materials, including more than 10 000 stone artifacts and bones of at least 33 mammalian species, have remained inaccessible to researchers since the 1940s, and two partial reports[1—2] published in the 1930s have been the only original studies of the site for a long time.

In 1997, the author carried out a systematic analysis of the Loc. 15 lithic collection as part of his Ph.D. dissertation research[3]. Chronological studies, employing uranium-series and electron spin resonance methods, have yielded an estimated occupation span of 140 000—110 000 years BP for the excavated horizons of the site. A total of 6 870 lithic artifacts were analyzed for this study (their classes and frequencies are summarized in Table 1), and the results of this study have been published in several papers by the author[4—6].

Table 1 Artifact classes and frequencies

Class	N	%
cores	130	1.9
flakes	439	6.4
flake fragments	91	1.3
bipolar fragments	87	1.3
tools	1 281	18.5
spheroids	2	0.0
Hammer stones	7	0.1
burned pebbles	4	0.1
chunks	4 829	70.3
Total	6 870	100

2 Core reduction

2.1 Core forms and variability

Only direct hard hammer percussion cores are present at Locality 15. A total of 130 such cores are identified. Among these cores, 126 were on quartz. Based on the combination of reduction directions, platform number(s) and geometric relations among platforms, these cores are classified into three subclasses:

Simple cores

A total of 23 pieces were identified as *simple* or *test cores*. They were only minimally consumed with one or two platforms. There is great size variability within this group, with a maximum length of 140 mm, a minimum length of 34 mm and a standard deviation of 24 mm.

Discoid cores

Thirty-three cores have been classified as discoids (Fig. 1). This category is defined as cores that were flaked from the perimeter towards the center of the body; flake scars are found on two opposite sides of the core, making the piece more or less circular in plan view. The cores in this group are less variable in size and shape than simple cores. Most of the pieces are relatively small, with a mean length of 58 mm, a mean width of 47 mm and a mean thickness of 33 mm. Platform angles for most of the cores are open, with a mean of 79°.

An *alternate flaking strategy* is recognized from the discoid cores. That is, an initial flake was removed from one side of the core; the core was then turned over and a second flake was detached on the other side of the core, using the previous flake scar as its striking platform. The flaking direction alternated from one face to the other until the core was too small to produce usable tool blanks. The benefit of *alternate flaking* is that previous flake scars can serve as striking platforms for the removal of subsequent flakes, and a relatively consistent flaking angle can be maintained in the process. Therefore, it can serve as an alternative to platform preparation. However, because most cores in this category were reduced fairly extensively and most flake scars left by the late stage core reduction are very small, it is difficult to determine whether or not some such scars are actually the result of platform preparation.

Polyhedral cores

Seventy-four specimens are identified as polyhedral cores, constituting nearly 57% of the core class. These cores were flaked multi-directionally from several platforms, exhibiting an *opportunistic flaking strategy*. The size of cores in this group varies greatly, with a maximum length of 128 mm and a minimum length of 34 mm. Most of the cores are small (with a median of 53 mm and a mean of 56 mm), and most of them have open platform angles (with a mean of 82°).

Variability in cores

Statistical analyses found that the discoid group is lighter on average than the simple and polyhedral cores. Disc cores are also flatter and thinner than other core forms. The smaller size and weight of discoid cores indicate that they were more extensively reduced and consumed than other core forms. Polyhedral cores possess the least cortical surface, followed by discoid cores and finally simple cores.

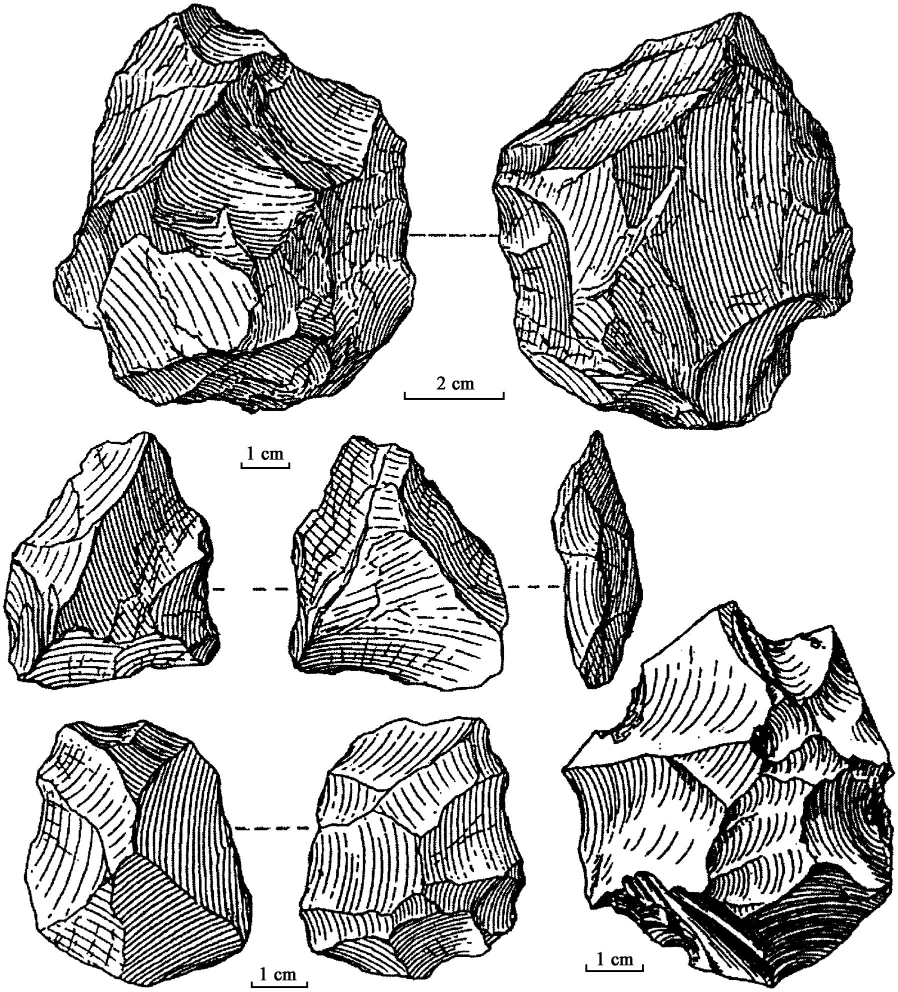

Figure 1 Discoid cores

Less cortex on polyhedral cores is closely related to flaking tactics: flakes were removed from all over the pebble surface and thus less cortex does not necessarily indicate more extensive flaking.

2.2 Flakes

A total of 439 whole flakes and 91 flake fragments produced by simple hammer percussion were collected from the site (Fig. 2). Among them, 393 pieces are quartz flakes.

Size and morphology

Most of the flakes are small, with both length and width measurements falling in the interval of 20—50 mm and thickness clustering between 5—20 mm. There are two specimens that are much larger than the other flakes. One measured 160×130×45 mm, and the other 103×175×36 mm, indicating that hominids at the site were capable of producing huge flakes when necessity arose and raw materials permitted.

Nearly 77% of the flakes are irregular. Most of the flakes are ordinary ones. Elongate flakes are very rare in this collection. Seven specimens may be classified as *blades*——pieces with a length /

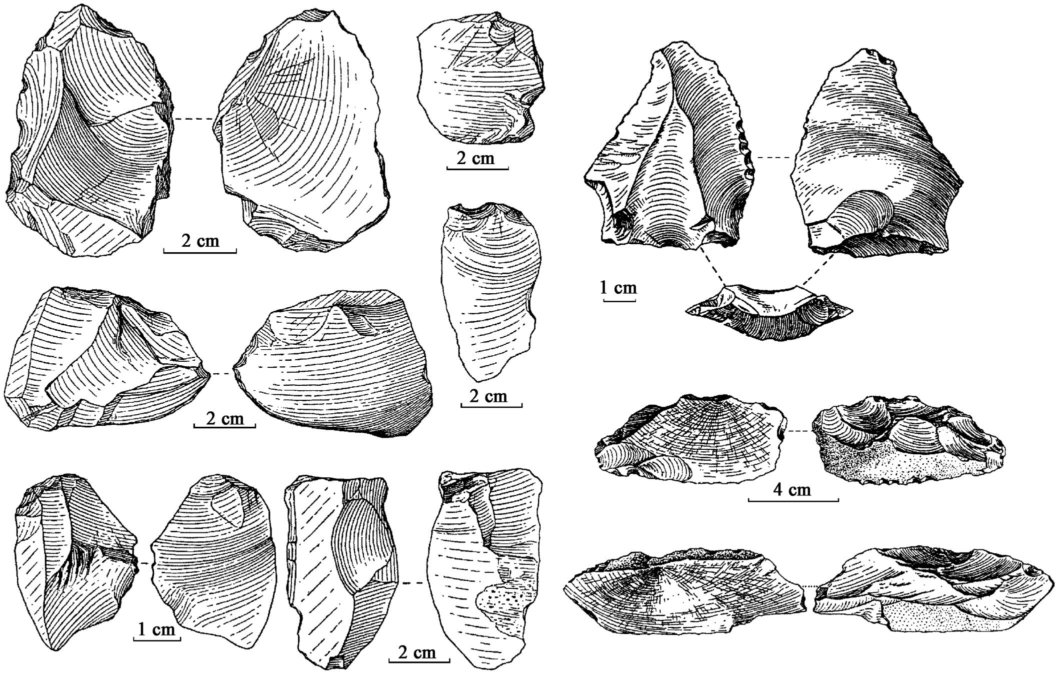

Figure 2 Flakes

width ratio > 2, a more-or-less regular shape and parallel lateral margins. However, these pieces constitute only a small proportion of the flake assemblage, and they are not really distinguishable from other flakes in morphology and technology, thus are not considered a separate class. A length/width ratio histogram for the whole flake assemblage is presented in Fig. 3. The figure shows that the length/width ratio is a continuous normal distribution. Thus, subdivision of flakes into different size groups will be arbitrary.

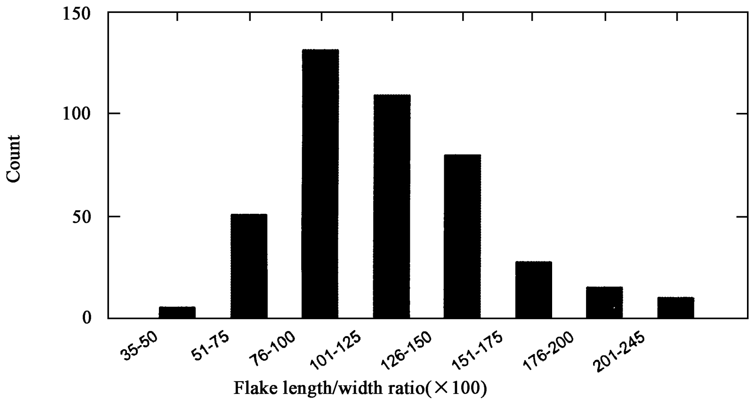

Figure 3 Flake length/width ratio

Striking platforms

Among these flakes, a large majority (63.8%) show plain platforms, 12.6% have cortical platforms, 9.2% possess scarred platforms, 6.9% exhibit dihedral platforms, 4.3% yield joint plane platforms, 2.5% of the flakes have linear platforms, 0.7% exhibit punctiform platforms.

Most of the flakes have small platform areas in relation to flake size. Platform angles were measured when possible. Most flakes have relatively small platform angles, with a mean of 108° for all flakes. Flakes with dihedral platforms have the smallest flaking angle mean (99°). Mean angles for other platform types are very similar (105°—109°). Figure 4 illustrates that the distribution of platform angles for all flakes is normal and unimodal.

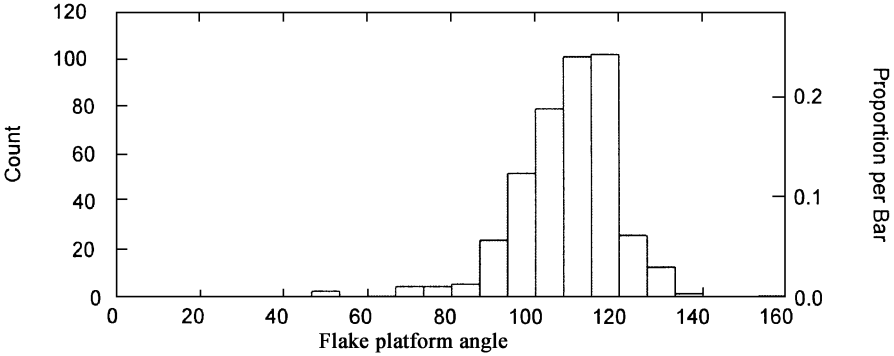

Figure 4 The distribution of flake platform angles

Attributes on ventral surfaces

Points of percussion on the Loc. 15 flakes are poorly preserved. Nearly 41% of the flakes exhibit no trace of striking points at all. Only 25% of the flakes exhibit obvious points of percussion. More than 77% of the flakes show no bulb of percussion. Only 3.2% of them exhibit salient bulbs of percussion. A few flakes are even concave at the position of the bulb of percussion. Impact damage scars are recorded simply as present or absent. Only 2.5% of the flakes exhibit impact damage scars. The rest have no trace of impact damage.

The lack of striking points, impact damage and salient bulbs of percussion has been attributed to soft hammer or billet flaking[7]. However, attributes on ventral surfaces are dependent largely on the flaking properties of the raw material. In the case of Loc. 15, flakes on different raw material types (quartz vs. non-quartz) show dramatic differences in these attributes: For quartz flakes, nearly 55% have no observable striking points, less than 5% exhibit deep striking points, more than 85% show no bulb of percussion, and less than 2% have salient bulbs of percussion. In contrast, for flakes on igneous material, sandstone and flint, less than 4% show no observable striking points, more than 10% exhibit deep striking points, 54% of them have no obvious bulb of percussion, and nearly 8% exhibit salient bulbs of percussion. This indicates that these technological attributes are not always related to flaking techniques.

Attributes on dorsal surfaces

One noticeable characteristic of the flake population is that most specimens do not present a dorsal cortex. Only 3% of the flakes are totally cortical, and 76% of the flakes have no cortex on their dorsal surfaces. Most flakes have 2—4 exterior flake scars.

Edge damage

Among the unretouched flakes, 69 pieces or 16% of the specimens exhibit post-reductional edge damage. The damage scars are usually small and not continuous. Such scars most commonly (68%) appear along one or both lateral sides of the flake. Some such edge damage may be interpreted as traces of utilization. However, it must be kept in mind that it is often impossible to distinguish utilization from natural edge damage, especially when such scars appear on quartz flakes.

2.3 Bipolar fragments

Only 87 bipolar fragments (Fig. 5) are identified from the assemblage, constituting 1.3% of the whole assemblage or 11.6% of the core/flake category. Thirty-five of these specimens exhibit wedge-shaped platforms or other kinds of impact damage at only one end. The remaining 52 pieces have impact traces on both ends. Most of the bipolar fragments are small, with a mean length of 34 mm, a mean width of 22 mm, a mean thickness of 14 mm and a mean weight of 13 grams.

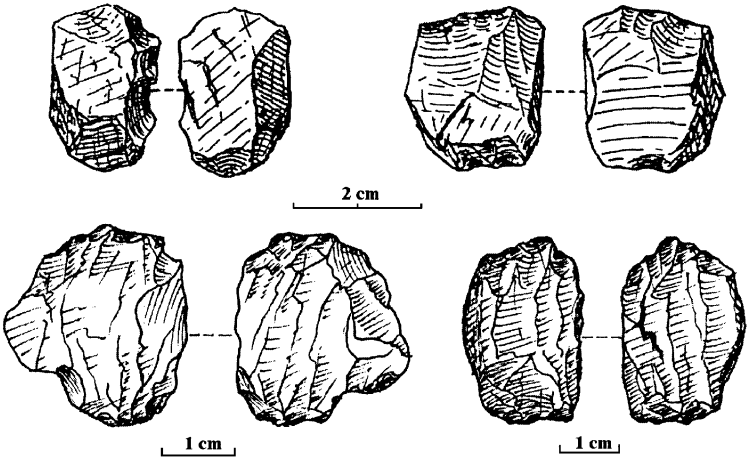

Figure 5 Bipolar fragments

2.4 Hammerstones

Only seven hammerstones were collected at the site (Fig. 6). Five of them are igneous pebbles and the other two are sandstone. They all exhibit impact scars at one or both ends. Two of them also have traces of battering at the center, an indication that they may also have been used as bipolar hammer stones.

The existence of hammerstones, cores, flakes, and chunk pieces is clear evidence that *in situ* stone tool making activities occurred at the site.

3 Retouched tools: typology, technology and variability

3.1 Tool types

A total of 1283 retouched tools were collected at the site. The classes and frequencies of those implements are presented in Table 2.

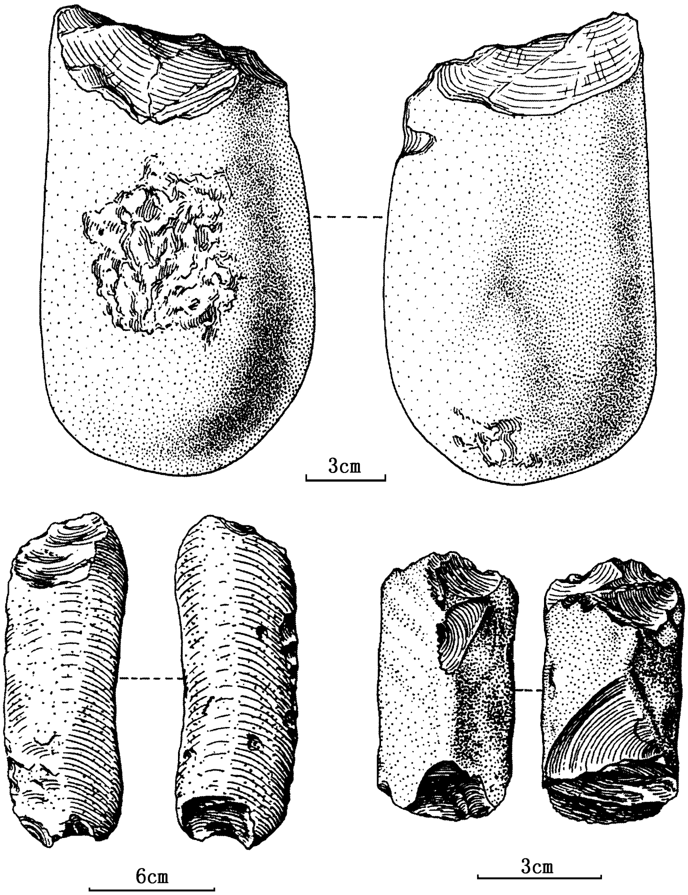

Figure 6 Hammerstones

Table 2 Retouched tool classes and frequencies

Class	Frequency	Percent
Scrapers	1 188	92.6
Single sidescrapers	1 043	
Double-edged scrapers	113	
Multiple-edged scrapers	12	
Thumbnail scrapers	12	
End scrapers	8	
Notches	24	1.9
Burins	17	1.3
Chopper-chopping tools	13	1.0
Points	10	0.8
Awls	5	0.4
Cleavers	3	0.2
Spheroids	2	0.2
Unclassifiable pieces	21	1.6
Total	1 283	100

A total of 1 188 scrapers were identified from the site (Fig. 7, 8), making up 17.3% of the whole assemblage or 92.6% of the retouched tools. The single sidescraper is the dominant type in the assemblage, with a total of 1 043 pieces constituting 87.8% of the scraper category. They include *Straight* ones (514 specimens), *Convex* ones (409 pieces) and *Concave* ones (120 pieces).

Other tools include points, burins, notches, chopper-chopping tools, cleavers, awls, spheroids and unclassifiable pieces (Fig. 9).

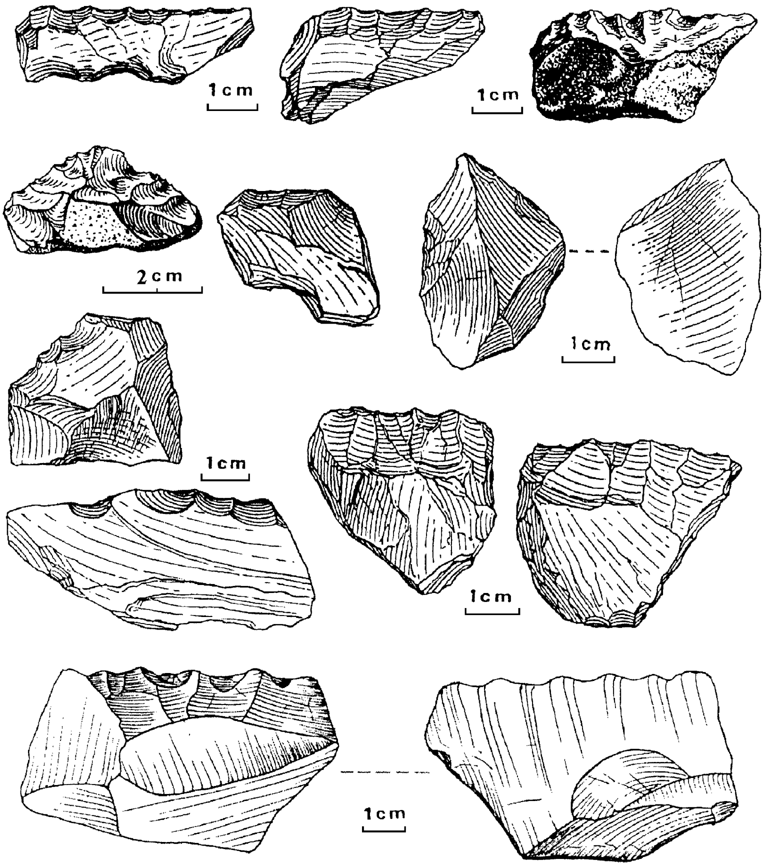

Figure 7　Single straight sidescrapers

3.2　Retouch technology

Burins, spheroids and pieces with irregular retouch are not included in the following analyses. Single sidescrapers, double-edged scrapers and multiple-edged scrapers are treated as separate entities.

3.2.1　Retouch method

Most of the modified tools appeared to be retouched by direct hard hammer percussion. Most modi-fication scars are deep, irregular and variable in size and shape, indicating that modification on those pieces was not well controlled. Nearly 96% of the retouched pieces exhibit scalar retouch, 2% exhibit fine marginal retouch, and another 2% show narrow and parallel modification scars.

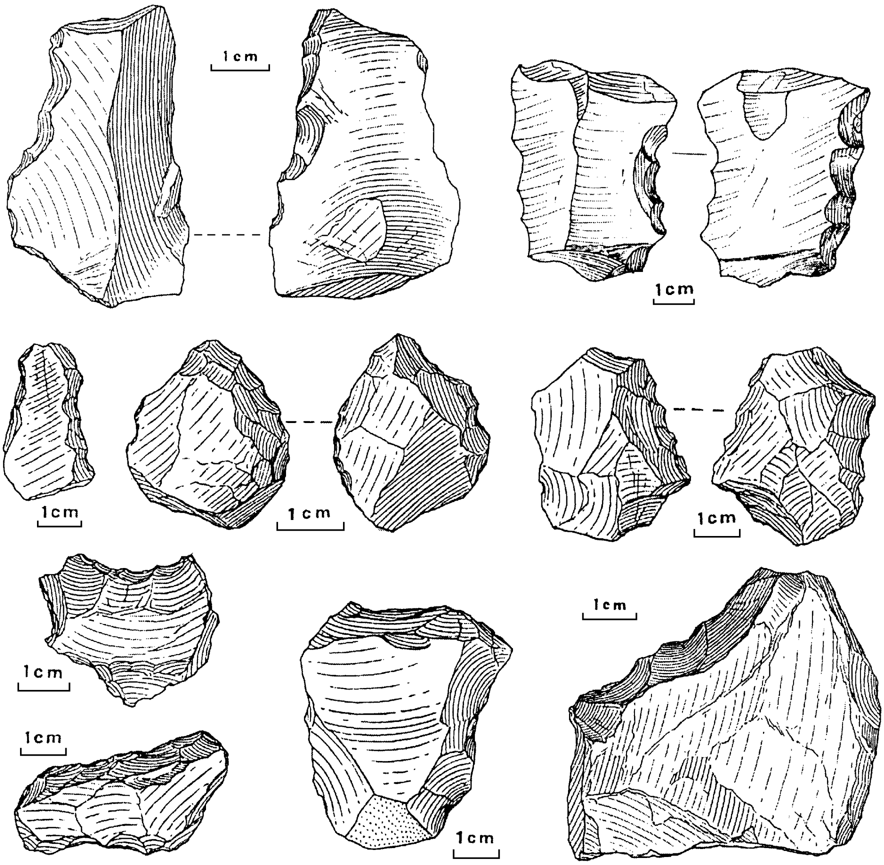

Figure 8 Double-edged scrapers

Modification was simple and minimal for most pieces in this assemblage. Only 81 out of 1 243 pieces' retouch scars evidence a second phase of retouch overlapping an earlier phase. Only three pieces show more than two layers of retouch. All of the pieces with more than one layer of retouch belong to the scraper class.

3.2.2 Retouch location

Retouch location is sorted into six categories: the left lateral side (L), the right lateral side (R), the proximal end (P) and the distal end (D) for tools on flakes, and the long side (LS) and the short side (SS) for tools on non-flake blanks. Documentation of retouch location is aimed at determining retouch preferences and the ways in which pieces of raw material were consumed. Only scrapers on which retouch locations can be clearly described are included in this analysis. For pieces with more than one modified edge, each edge is treated as an individual entity.

Table 3 shows that the majority of the tools (58.9%) were retouched on the longer sides of non-flake blanks. Only 15.4% of the pieces were modified on the short sides of the blanks. This contrast offers a clear indication of a tendency for maximizing the utility of raw materials. Among tools made on flakes, the number of pieces modified on the right lateral side (87) is slightly larger than that re-

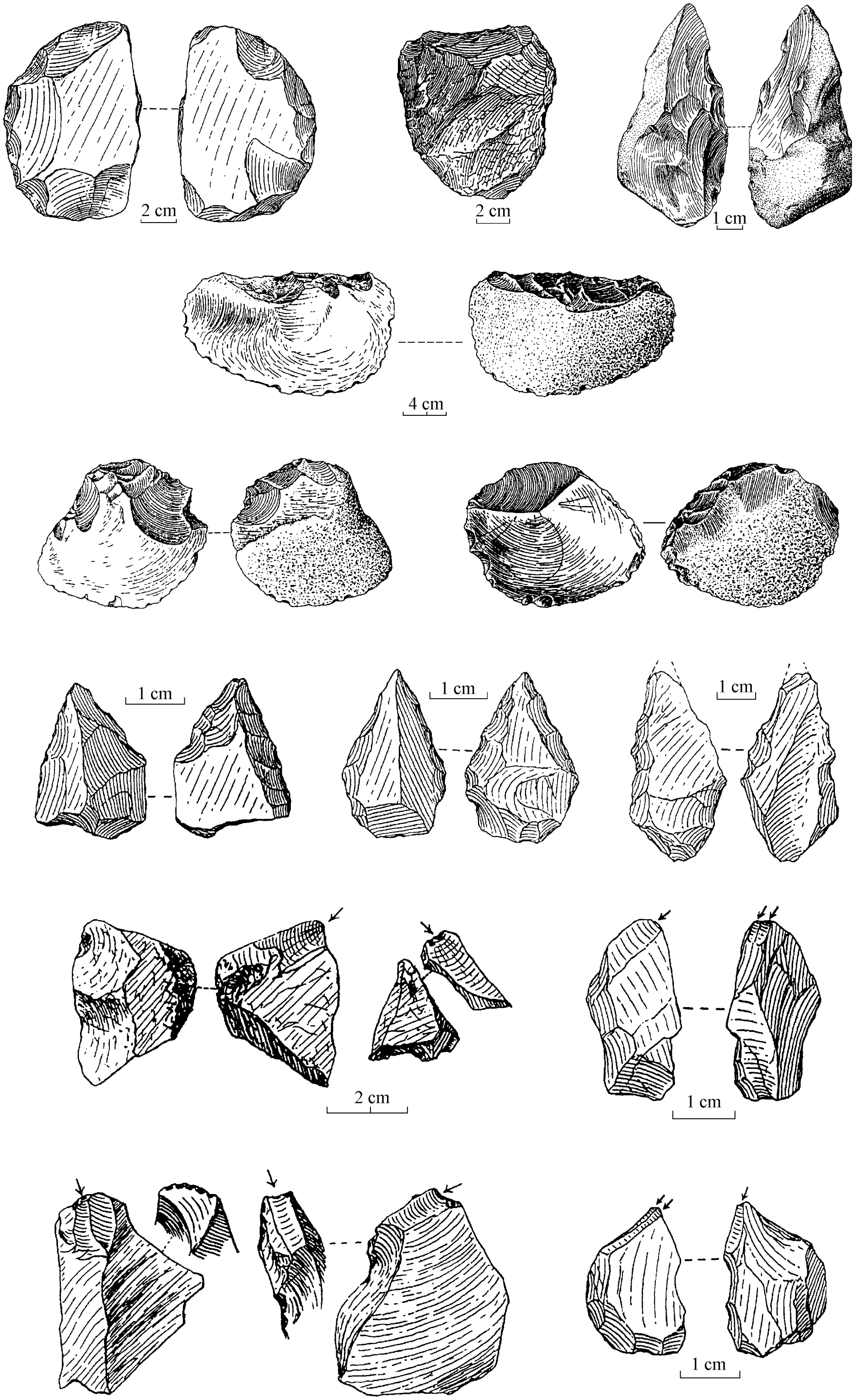

Figure 9　Choppors, cleavers, points and burins

touched on the left side (75). Only 4.6% of the tools were retouched on the distal ends, while 0.7% of the pieces were modified on the proximal ends. Only a small proportion of the implements (1%) display retouch continuously on more than one side/end of the flake.

Table 3 Frequencies for tool retouch locations

Location	IS	SS	R	L	D	P	RD	LD	LRD	Total
Number	490	128	87	75	38	6	4	3	1	832
Percent	58.9	15.4	10.5	9.0	4.6	0.7	0.5	0.4	0.1	100

RD: right side and distal end; LD: left side and distal end; LRD: left side, right side and distal end

3.2.3 Retouch direction

Retouch directions for modified pieces were first assigned to two general categories: unifacial and bifacial. In total, 1248 edges or 89.4% of the edges were modified unifacially: that is, modification scars exist on only one face of the blank, mostly on the dorsal surface when flakes were used as tool blanks, or on the more convex surface when pebbles or chunks were used. The remaining 148 edges (10.6%) were retouched bifacially. Among these bifacially modified edges, 30 exhibit the pattern of *alternating retouch*. Another 33 edges were modified using *reversed retouch*: one section was modified in one direction, while another was retouched in the opposite direction.

Special treatment was given to single-edged scrapers (single sidescrapers, endscrapers and thumbnail scrapers) fabricated on flakes. Sixty-five percent of these pieces were retouched on the dorsal surface, 25% on the ventral surface, and the remaining 10% was modified bifacially. No major differences in retouch directions can be detected among different morphological edge groups.

3.3 Variability

3.3.1 Quantitative variability

A variety of metric measurements were recorded for retouched tools, including length, width, thickness and weight. Other attributes of modified edges, such as angle, shape, length and invasiveness, were also recorded. These latter attributes highlight the basic functional characteristics of retouched tools.

The Loc. 15 stone tool assemblage is dominated by small pieces (Table 4). Considerable variation exists in the size of these tools. Chopper-chopping tools and cleavers are the largest tools in this assemblage, with mean lengths of 110 mm and 172 mm and mean weights of 453 grams and 1011 grams, respectively. Scrapers, burins, awls and points are mostly small pieces and are all relatively uniform in size.

The mean lengths, widths, thicknesses and weights for single-sided scrapers, double-sided scrapers and multiple-sided scrapers are very similar. No consistent or significant size difference can be detected among these three subgroups. Therefore, the argument that scrapers with more edges are produced as a result of more extensive consumption of raw material or resharpening[8] does not seem to apply.

Table 4 Length for tools by class (mm)

Class	N	Minimum	Maximum	Median	Mean	SD
Awl	5	22	38	32	30	6
Burin	17	18	52	33	35	8
Chopper	13	54	190	104	110	40
Cleaver	3	130	213	173	172	42
Notch	24	21	92	33	36	13
Point	10	19	52	33	35	11
Endscraper	8	15	33	20	21	7
Thumbnail scraper	12	18	29	21	21	3
Single sidescraper	1043	18	125	35	37	11
Double sidescraper	113	19	95	37	40	13
Multiple sidescraper	12	28	68	35	39	12
Irregular pieces	21	26	70	42	42	11

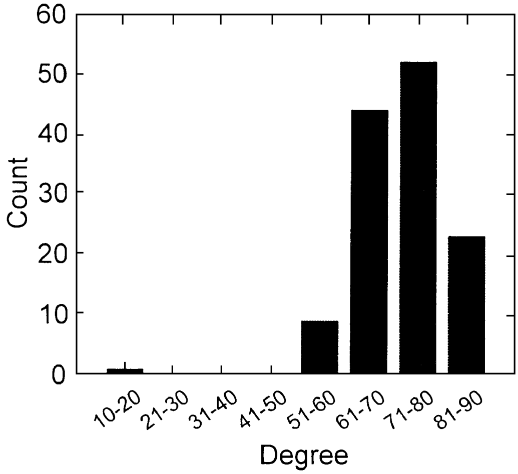

Figure 10 Edge angle distribution for tools

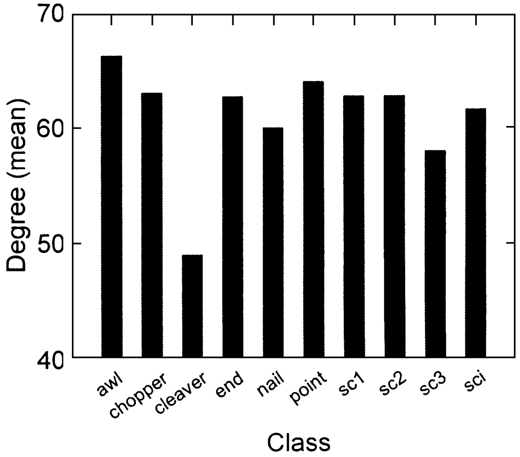

Figure 11 Edge angle means for tools by class

3.3.2 Variability in edges

Angle

Edge angle was measured for each individual edge. A total of 1377 retouched edges were measured. Fig. 10 shows the distribution of edge angles for scrapers, chopper-chopping tools, cleavers, awls and points. The distribution is continuous and unimodal, with the majority falling in the interval of 60°—80°. Fig. 11 presents edge angle means by individual tool types. It is obvious that the edge angle mean for cleavers is distinctly smaller than that for other groups. This is because cleaver edge angle was measured on the unretouched edge, which is thought to be the working end. The lack of discrete multimodality in the distribution of edge angles may suggest that the different tool types were not selected or prepared for tasks that required different edge angles[9].

Length

According to Table 5, awls and notches exhibit minimal retouch length on the side edges. Next shortest are edges on points. Chopper-chopping tools exhibit the maximum retouch length as a group and the largest variation in edge length within the group. Within the scraper group, the general trend is that the more edges a tool possesses, the shorter the length of each edge. Pieces with convex edges display longer retouched edges and show greater variation in edge lengths than the other two groups. Pieces with concave edges display the shortest edges in this class.

Table 5 Edge length (mm) for tools by class

Class	N	Minimum	Maximum	Median	Mean	SD
Awl	5	7	20	14	14	5
Point	10	10	37	22	21	8
Chopper	13	55	254	110	118	63
Notch	24	8	32	15	15	5
Thumbnail scraper	11	18	32	24	25	4
Endscraper	8	13	51	20	25	13
Single sidescraper	1 043	11	161	29	32	13
Double sidescraper	113	14	66	26	28	9
Multi sidescraper	12	12	35	22	23	6

Invasiveness

The measurements for invasiveness of retouch are very similar among the scrapers, except that the straight-edged sidescrapers possess slightly more invasive retouch than other groups. In general, the scrapers are only marginally modified in their working edges, with a retouch invasiveness mean of less than 10 mm. In contrast, the chopper-chopping tools are more invasively modified, with an invasiveness mean of 29 mm.

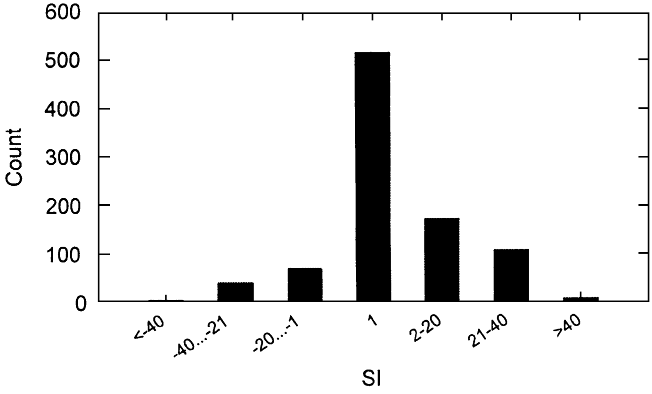

Figure 12 The Distribution of shape index for single sidescrapers

Edge shape

In order to conceive and present edge shape variation accurately, the Shape Index (SI) created by Barton[9] was adopted in this study. As defined by Barton, SI was created from the reciprocal of the radius of curvature of edges. The reciprocal was used in order to represent edge shapes as the amount of positive (for convex) or negative (for concave) deviation from a straight edge.

Figure 12 shows the distribution of Shape Index for single sidescrapers. The distribution of SI is continuous and unimodal, indicating that such edge shape variations might occur naturally, probably as a function of the morphology of the original blank. Thus the different edge shape groups do not necessarily represent discrete functional tool types.

4 Raw material exploitation

4.1 Raw materials utilized

Table 6 provides a summary of stone raw material utilization at Loc. 15. Six lithic raw material types were recognized, namely vein quartz, various igneous materials, rock crystal, flint, sandstone and quartzite. The overwhelming majority of the artifacts were fashioned on quartz; other materials altogether make up less than 5% of the assemblage.

Table 6 Raw material frequencies for artifacts by class

Material	quartz		igneous		crystal		flint		sandstone		quartzite
Class	N	%	N	%	N	%	N	%	N	%	N
core	126	1.8					2		1		1
flake	393	5.7	113	1.6			15	0.2	9	0.1	
bipolar	86	1.3			1						
hammer			5	0.1					2		
chunk	4730	68.9	32	0.5	66	1.0	1				
tool	1198	17.4	54	0.8	14	0.2	12	0.2	4	0.1	1
Total	6533	95.2	204	3.0	81	1.2	30	0.4	16	0.2	2

4.2 Raw material variability and exploitation strategy

An examination of raw material distribution in various artifact classes reveals that quartz is dominant in all categories, and both direct hammer percussion and bipolar flaking were applied to this material. No cores or flakes produced by direct hammer percussion on crystal were collected. Only one bipolar fragment on crystal was recognized, which makes crystal and quartz the only two material types on which bipolar flaking is known to have been applied. Only two nuclei (both flint) were collected in the category of non-quartz materials; a much smaller proportion of debris of these materials was found in comparison to quartz, and flakes on these non-quartz materials are larger and more regular. This may indicate that while most, if not all, quartz materials were processed at the site, flint, igneous and sandstone materials were not; instead, they were apparently flaked at other locations before potential tool blanks were selected and then brought to the site.

Raw material frequencies were also examined by class of tool. More than 93.4% of the retouched pieces were produced on quartz. This material was used to make all categories of tools except cleavers. More than 4% of the tools were produced on igneous materials, including burins, chopper-chopping tools, cleavers, notches and sidescrapers. Fourteen pieces were made on crystal, including burins, thumb-nail scrapers, and sidescrapers; 12 tools were fabricated in flint, all sidescrapers. The four sandstone pieces are all chopper-chopping tools. Only one retouched piece (a cleaver) was fashioned on quartzite. These statistics indicate that hominids at Zhoukoudian had the ability to select different materials to produce a variety of implements, but tended overwhelmingly to selectively use quartz.

The *Minimal Nodule Analysis* approach[10] has been applied to examine the processing of minority raw materials. Non-quartz materials were sorted into minimal groups based on color and texture similarities in order to explore reduction technologies applied to different raw materials and the degree to which different materials were consumed. Refitting for these material groups was attempted. No conjoining elements were found, one indication that these materials may not have been originally processed on site. However, the application of such tests was impeded by the incompleteness of the collection, making this particular analysis inconclusive.

4.3 Raw material distribution, availability, and quality

Most of the lithic materials exploited at Zhoukoudian were available in the landscape near the site. "Dragon Bone Hill," where the key Zhoukoudian localities are found, and the larger "Eestern Hills" are composed of various rock types, including quartzite, limestone, sandstone and slate. The weathered outcrops on the hills and in the bed of the Zhoukou River provided a ready source for hominids to procure and select the stone materials they needed for making tools. A gravel layer on the Zhoukou River terrace, the so-called Lower Gravel" formed during the Middle Pleistocene, is rich in various kinds of rounded stones and is believed to be one of the principal raw material sources for the Zhoukoudian hominids[11]. Several surveys of the distribution of suitable stone materials have been conducted in the Zhoukoudian area. Nodules of vein quartz, quartzite and sandstone were readily encountered. Rock crystal was found in a granitic area about 5 km north of the site. A few exotic materials, such as flint and agate, could not be located easily near the site. It has been estimated that the area within a radius of 5 kilometers was sufficient for the Zhoukoudian hominids' exploitation of lithic raw material[11].

While quantity is one factor to be considered, quality is quite another. Numerous stones can be easily obtained close to the site, but materials exhibiting high quality and workability are relatively scarce in the region. Quality may be assessed both in terms of the nature of apparent conchoidal fracture and the range of size and shape in which the material is found. In general, the conchoidal fracturing properties of the dominant raw material types at the site—vein quartz and rock crystal—are very poor, thus limiting the number of usable flakes that can be detached from any one nucleus. Quartz tends to fracture along structural planes making it difficult for the toolmaker to control the size and shape of the flakes detached. Lithic analysts and modern flint-knappers have suggested that quartz and coarse-grained quartzite are intractable and undesirable lithic materials for stone tool manufacture[12].

In summary, lithic raw materials available to the Zhoukoudian hominids combine abundance and low quality. The cost of obtaining raw materials and using them to produce stone tools was balanced by these two conflicting factors, which in turn strongly affected the nature of lithic morphology, typological variability and technology at the site.

4.4 Consumption of raw material

An important aspect of raw material economy is the degree to which artifacts were consumed, that is, modified, reduced, reused, resharpened and exhausted. Several quantitative measures have been used to assess the extent to which a piece of raw material or raw materials as a whole were consumed.

4.4.1 Extent of core reduction

Core reduction intensity was examined by the ratio of simple, minimally worked or tested cores to extensively worked cores. In the case of the Loc. 15 assemblage, the ratio of simple cores (23 pieces) to the combination of discoid (33 pieces) and polyhedral (74 pieces) cores has been used. A ratio of 1∶4.7 indicates that there are far more extensively consumed cores than minimally worked or tested nuclei.

4.4.2 Raw material use intensity

A major measure of raw material use intensity is the ratio of unmodified flakes to retouched tools. Such a ratio provides a rough estimate of the number of flakes actually used out of the total flakes produced as tool blanks[13−14]. A total of 530 unretouched complete flakes and flake fragments were collected from the site, and 848 tools retouched on flakes and flake fragments were identified. The ratio of unmodified flakes/flake fragments to retouched flake/flake fragments is 1∶1.6. That is, about 38.5% of flakes and flake fragments were not retouched into tools.

4.4.3 The Index of Retouch Length (IRL)

In order to assess the extent of retouch on blanks, an *Index of Retouch Length* was created for the modified tools. The IRL is simply the ratio of retouch length or edge length to the total length of the margin on which retouch was located. The margin length was measured only for that portion which exhibits the characteristics and potential to be retouched into a working edge. The idea is that if a portion of the workable margin was not modified, this indicates that the toolmaker intended to leave it in its natural state, rather than that the physical condition of the blank prevented him or her from completing the task. The larger the retouch index, the more complete the retouch, thus the more intensively a piece of raw material was modified. An index of 1 would indicate the whole workable margin length was retouched, and retouch of that margin was thorough and complete. Only scrapers are included in this analysis. While some pieces were only minimally or partially retouched, an index mean of 0.89 indicates that in the case of most scrapers, a large proportion (almost 90%) of the workable margin was retouched into a workable edge (Fig. 13). The result suggests that most of the tools at the site were intensively modified transversely, at least on one workable margin. No significant difference was found on retouched margins among different raw material groups.

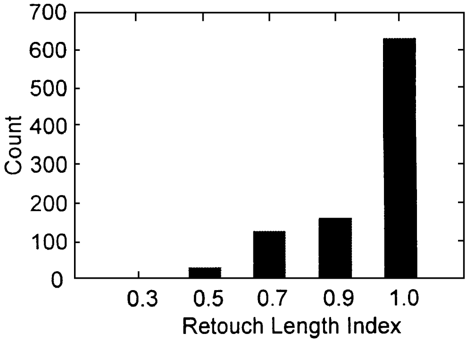

Figure 13 Retouch length index for scrapers

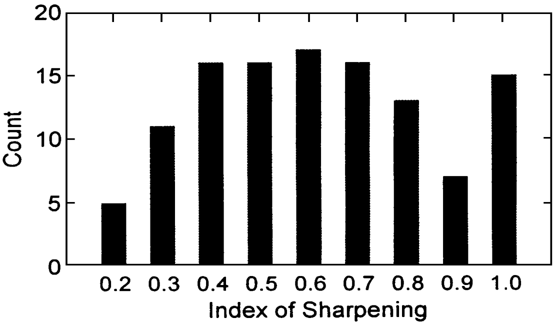

Figure 14 Index of sharpening for scrapers made on flakes

4.4.4 The Index of Sharpening (IS)

The *Index of Sharpening* or resharpening developed by Kuhn[15] was adopted in this study. The IS estimates the amount of material removed by primary retouch and resharpening from the original blank. A flake blank is idealized as triangular in cross-section and thickest in the center. Ideally, during the process of retouch and sharpening, the edge moves toward the central ridge of the blank. An index calculated as the ratio of edge thickness to piece thickness at the central ridge indicates how close the modification came to the central ridge: the larger the index, the closer the retouch scars encroached on the piece central ridge, and the more complete and extensive the modification carried out. Only scrapers made on flakes are included in this analysis. An index mean of 0.66 indicates that most flake tools were retouched to a moderate extent. Figure 14 is a visual representation of the result. It is clear that the majority of pieces have an index falling between 0.4 and 0.8.

A high IRL and a relatively low IS may indicate that while hominids at the locality intended to make use of the lateral margin of a blank as much as possible, they did not put much effort into reworking their tool edges, a conclusion that is also supported by the fact that the overwhelming majority of the tools at the site exhibit only one retouch layer. A possible explanation is that it is easier and more efficient to pick up a suitable piece of material, make use of its sharp edge or apply primary retouch to its lateral side to make a working edge, than to resharpen the worn edge on a used tool, provided that suitable raw materials are abundant at the site.

4.4.5 The number of retouched edges

The 1 188 scrapers preserve a total of 1 313 retouched edges. The vast majority of the pieces (1 063 pieces) are single-edged tools. The ratio of single-edged to multi-edged specimens is 8.5∶1. Such a high ratio indicates that in general, hominids at the site chose to replace worn tools with new ones rather than reworking used pieces. An analysis of the number of retouched edges on different materials reveals that all raw materials were not treated the same way. The ratio of single-edged to multi-edged pieces is 9.6∶1 for quartz, 3∶1 for crystal, 2.2∶1 for igneous material and 1.4∶1 for flint, indicating that the non-quartz materials were more extensively consumed than vein quartz, and hominids favored better-quality raw materials when they were available.

5 Discussion and conclusions

5.1 Variability of core reduction technology

At least two major core reduction technologies are present at Loc. 15. One is direct hard hammer percussion, and the other is bipolar flaking. A third flaking method, the so-called block-on-block, might have been used at the site as represented by a few large flakes with open platform angles and wide and thick platforms. Large and wide flakes with striking angles usually exceeding 120° and large and thick butts have traditionally been classified in China as being produced by the block-on-block method[16]. However, recent studies show that these characteristics are not necessarily the signature of the block-on-block method; such flakes can be produced by direct hammer percussion. In fact, it is almost impossible to differentiate flakes produced by hammer percussion and those by the block-on-block method[17—18].

Two hammer-percussion flaking strategies can be inferred from various core forms. One is *multi-directional flaking*, or may be called *opportunistic flaking*: Flakes were detached from a pebble wherever suitable striking platforms and angles were found, with no consideration or planning for later flaking. The results of this flaking strategy are the polyhedral cores. The other core reduction strategy is the *alternate flaking*, represented by discoid cores. That is, flakes were alternately detached from the two faces of flat cores; previous flake removals on one face served as striking platforms for new flake detachments on the opposite face. In this way, suitable striking platforms and angles could be maintained throughout much of the flaking process, even without platform prepa-ration. *Alternate flaking* thus appears more systematic and better planned.

Most flakes appear to be produced on unprepared cores. No evidence for systematic platform preparation can be recognized either on cores or on flakes. However, some flakes yield small dorsal flake scars paralleling the detachment axis of the flake, which could be an indication that some cores were actually shaped or prepared before reduction, probably on the detachment faces.

5.2 The Issue of Levallois Technology

A single flake in the Loc. 15 collection has become a virtual trademark for the site because of its resemblance to a Levallois point. This is typical of an old research tradition: Qualitative observations on a few special artifacts dominated the research agenda. Researchers have come to realize that an ideal Levallois technology is not easily recognizable from the end products in an archaeological collection[19]. Experimental replication and refitting reveal that some flake/blank forms that can be easily classified as Levallois products were actually produced by non-Levallois method; while some typologically non-Levallois” pieces were in fact produced by Levallois flaking[20]. One particularly problematic artifact form is the so-called “Levallois point,” defined as a triangular piece, with a pattern of flake scars on the dorsal face resembling an inverted “Y.” Boëa[20] has examined in depth the production of such artifacts. His studies demonstrate that such pieces can be produced by a large number of flaking techniques, such as flaking on pyramidal cores, discoid cores, etc. The observation that “Levallois points” can be produced from discoid cores is particularly relevant to the issue of “Levallois technology” at Loc. 15. The “Levallois point” from Loc. 15 is probably a product of discoidal technology, or *alternate flaking*, and is not a true Levallois product. No other evidence from the collection supports the scenario of a Levallois presence at the site. Similar situations are also identified at some Japanese Paleolithic sites, where “Levallois points” are found associating with discoidal cores and no true Levallois cores or other products are recovered[21]. Thus, Loc. 15 follows a scenario in which all lithic artifacts were produced by non-Levallois technology, but some (only 1 in 439 flakes at Loc. 15) are typologically or morphologically Levallois.

5.3 The status of bipolar flaking

Hominids frequently used the bipolar flaking technique in stone tool production when exploiting small-sized raw material packages or such intractable raw materials as quartz. The role of bipolar technology in defining Paleolithic cultural traditions is one of the most important issues in Paleolithic research in China. Occurrences of bipolar technology in North China share the following features: 1) At most of the sites yielding evidence for bipolar flaking, this method played only a supplementary role in tool blank production: bipolar fragments make up only a small proportion in the assemblages, compared to the majority of artifacts produced by direct hammer percussion. Zhoukoudian Loc. 1 is a notable exception; 2) The overwhelming majority, if not all, of the bipolar fragments were made on vein quartz, a material that could not be easily flaked by direct hammer percussion; 3) Most bipolar fragments are small, and are useful only in fabricating small implements; 4) Most bipolar flakes were not retouched into tools. At Zhoukoudian Loc. 1, a total of 3890 unretouched bipolar flakes and 768 retouched bipolar flakes were collected, that it to say that only **1 out of 6** such flakes were used as a tool blank. In contrast, in the group of direct hammer percussion flakes, 1 231 whole and unretouched pieces were collected, and 588 retouched tools on such flakes were identified. That is, **1 out of 3** direct percussion flakes were converted into a retouched tool. The conclusion is obvious: a much larger portion of flakes from bipolar percussion was wasted, and bipolar flaking is not an especially efficient technique to produce usable tool blanks.

Eighty-seven bipolar fragments were collected at Loc. 15, constituting only 11.6% of the core-flake category. Considering the large number (4 829) of unidentifiable chunks collected from the site, some of which could be bipolar, and that poor-quality quartz was the main raw material used, the actual number of bipolar products could be higher. Even so, it is still a huge departure from the pattern at Loc. 1. A possible explanation for the decline in the number of bipolar fragments at Loc. 15 is that hominids at the site had become much more sophisticated in producing flakes from vein quartz by direct hammer percussion, reducing their dependence on the wasteful bipolar method.

5.4 The role of raw material in lithic technology

The major characteristics of the Loc. 15 assemblage (e.g., being small, irregular, and waste-dominated) are direct results of procurement of low-quality raw materials at the site. The low quality of the principal raw material, quartz, is reflected not only in the existence of rich structural plans and the diminished presence of regular conchoidal fractures, but also in their small and irregular original sizes and morphologies. Essentially, these hominids could *only* produce waste-dominated artifact assemblages and small and irregular tools on such materials. Therefore, the Zhoukoudian Loc. 15 case is a compelling verification of Andrefsky's model of poor-quality raw material leading to informal stone tools[22]. One implication is that cultural/technological developmental stages or standards for human ancestors should not be judged solely on the typological and morphological features of stone tool assemblages. Instead, the ecological setting and natural conditions within which human adaptations took place, including, among others, raw materials available for tool manufacture, must be taken into consideration.

The study of raw material economy has placed a great deal of emphasis on the cost of *obtaining* raw material. Such costs are believed to vary as a function of three major factors: the distribution of lithic material sources, the movement of hominid groups relative to such sources, and the scheduling of labor investment in foraging[15]. This study indicates that the abundance of raw material sources in the Zhoukoudian area conveniently accessible to human groups had a profound impact on raw material exploitation and consumption. A direct result of abundant raw material availability is the lavish utilization of those materials, evidenced by the presence of a large quantity of chunks and unretouched tool-making potentials (flakes and flake fragments). Moreover, the vast majority of retouched tools were modified simply and minimally, as indicated by the low index of sharpening, the low frequency of scrapers with multiple edges and the presence of multiple retouch layers.

However, the low rate of raw material consumption, especially the lack of extensive reworking of modified pieces, is not simply the result of careless waste of raw material, but represents instead a wise exploitation strategy adopted by the Loc. 15 hominids. When a tool's edge wore out, the user had several options to solve the problem. They could resharpen or rework the worn edge, create another edge or more edges on the piece, or they could simply abandon it and make a new tool. It is generally accepted that large, fresh tools are more desirable or usable, whereas small extensively consumed specimens would present functional disadvantages[15]. One factor underlying specific choices is the cost of raw material procurement. If raw material was abundant, making new tools would be the first logical choice. If suitable raw material was scarce or costly to obtain, conditions would favor reworking used tools, either by resharpening worn edges, or by creating new edges, or both. Obviously, the human groups at this site primarily chose to make new tools to replace used ones. This strategy should be considered a special kind of optimization of raw material utilization, provided that raw materials at Zhoukoudian were abundant and available, but poor in quality and workability.

5.5 Strategies for exploiting different raw materials

This study found that the human groups at Zhoukoudian Loc. 15 had the intelligence and ability to exploit raw materials differently according to their different properties of workability and their relative accessibility. Quartz, a material found in abundance near the site, was included in nearly all artifact categories, mostly as "primary products" (e.g., cores, flakes/flake fragments, debris and chunks). Flint and igneous materials, on the other hand, are represented in only a limited number of artifact categories, mainly as tool-making potentials-flakes and modified tools. Some "primary products" such as cores and debris are virtually absent from these non-quartz material groups. Flint and igneous flakes are more regular and larger than flakes detached from quartz. Furthermore, non-quartz materials were far more extensively consumed than quartz, as is evidenced in the much lower proportions of waste, higher flake-to-tool conversion rates, and higher frequencies of multi-edged tools for the former than for the latter.

Two conclusions can be drawn from these observations. First, most, if not all, quartz materials were processed mainly on-site, leading to the presence of waste materials or by-products in the assemblage. Igneous rocks and flint, as exotic materials in this case, were flaked primarily at their original outcrops or other find-spots with only selected tool-making potentials subsequently transported to the site for further modification and utilization, so that nuclei, flake fragments, debris and chunks are underrepresented at the site. Second, although hominids at Zhoukoudian Loc. 15 relied overwhelmingly on vein quartz to make stone tools, they favored better-quality raw materials, such as flint and igneous rocks. When such materials were encountered, they were collected, brought to the site and exploited optimally.

5.6 Adaptation strategies

This study focuses on the relationship between raw material and lithic variability. However, it is clear that raw material constraints cannot solely dictate characteristic features of a particular lithic assemblage. Three important factors operating at a regional scale have been identified as contributing significantly to the structure of observed assemblage variability: the availability of raw material and the strategies by which it was procured; particular activities through which the tools were made and used; and the role of sites within a settlement or mobility system[23].

It has been suggested that settlement organization places fundamental constraints on lithic technology[24]. The geological setting of Loc. 15, its large and varied lithic assemblage, and the presence of numerous broken animal bones all suggest the site was used as a human base camp, for longer or shorter periods. In such more-or-less stable environments, people tend to produce and use informal and simple *expedient tools* and exercise wasteful raw material exploitation strategies[25]. Under such circumstances, human groups at Zhoukoudian may have adopted a *provisioning of place* strategy[15]—that is, supplying living or foraging places where tools are likely to be needed with manufacturing materials. As a result of *in situ* raw material accumulation and reduction, such spots are often filled with waste materials, unretouched pieces, and tools exhibiting minimal modification. The Loc. 15 assemblage clearly fits the description of such an adaptive strategy.

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References:

[1] Jia L. Preliminary report on the excavation of Choukoutien Locality 15[N]. Shijie Ribao, 1936-01-19, 1936-02-09.

[2] Pei WC. A preliminary study on a new Paleolithic locality known as Locality 15 at Choukoutien[J]. Bull Geol Soc China, 1939, 19 (2): 147—187.

[3] Gao X. Interpretations of Typological Variability within Paleolithic Remains from Zhoukoudian Locality 15, China[D]. Ph. D. Dissertation, University of Arizona. 2000.

[4] Gao X. Core Reduction at Zhoukoudian Locality 15[J]. Archaeology, Ethnology &Anthropology of Eurasia, 2000, 3 (3): 2—12 (in English).

[5] Gao X. A study of stone tool typology and retouch technology at Zhoukoudian Locality 15[J]. Acta Anthropol Sin, 2001, 20 (1): 1—18 (in Chinese with English abstract).

[6] Gao X. A study of raw material exploitation and economy at Zhoukoudian Locality 15[J]. Acta Anthropol Sin, 2001, 20 (3): 186—200 (in Chinese with English abstract).

[7] Crabtree D. Comments on lithic technology and experimental archaeology[A]. In: Swanson E ed. Lithic Technology: Making and Using Stone Tools. The Hague: Mouton Publishers. 1973, 105—114.

[8] Dibble H. Interpreting typological variation of Middle Paleolithic scrapers: function, style, of sequence of reduction[J] ? J Field Archaeol, 1984, 11: 431—436.

[9] Barton CM. Lithic variability and Middle Paleolithic behavior: new evidence from the Iberian Peninsula[M]. Oxford: BAR International Series, 1988, 408.

[10] Kelly RL. Hunter-Gatherer Mobility and Sedentism: A Great Basin Study[D]. Ph. D. dissertation, University of Michigan, 1985.

[11] Pei W, Zhang S. A Study on the Lithic Artifacts of Sinanthropus[M]. Beijing: Science Press, 1985.

[12] Maloney N, Bergman C, Newcomer M *et al*. Experimental replication of bifacial implements using Bunter quartzite pebbles[A]. In: MacRae RJ, Maloney N eds. Non-flint stone tools and the Paleolithic occupation of Britain. Oxford: British Archaeological Reports, British Series, 1988, 189: 25—48.

[13] Gamble C. The Paleolithic settlement of Europe[M] . Cambridge: Cambridge University Press, 1986.

[14] Rolland N, Dibble H. A new synthesis of Mousterian variability[J] . American Antiquity, 1990, 55: 480—499.

[15] Kuhn SL. Mousterian Lithic Technology: An Ecological Perspective[M] . Princeton: Princeton University Press, 1995.

[16] Pei W, Wu R, Jia L, *et al.* Report on the Excavation of Palaeolithic sites at Dingcun, Xiangfen County, Shanxi Province[M] . Memoirs of the Institute of Vertebrate Paleontology and Paleoanthropology, Series A (2). Beijing: Science Press, 1958.

[17] Aigner JS. Important archaeological remains from North China[A] . In: Ikawa-Smith F ed. Early Palaeolithic in South and East Asia. The Hague: Mouton Publishers, 1978, 163—233.

[18] Liu Y. A restudy on the Dingcun artifacts[J] . Acta Anthropol Sin, 1988, 7(4): 306—313.

[19] Copeland L. Levallois or non-Levallois? Reflections on some technological features of Hummal Leve IA (El-Kowm, Syria)[M] . Comison V, X Congresso, Union Internacional de Ciencias Prehistoricas, 1981, 1—25.

[20] Boëda É. Levallois: a volumetric construction, methods, a technique[A] . In: Dibble HL, Bar-Yosef O eds. The Definition and Interpretation of Levallois Technology, Monographs in World Archaeology No. 23, 41—68. Madison: Prehistory press, 1995.

[21] Sato H, Nishihaki Y, Suzuki M. Lithic technology of the Japanese Paleolithic: Levallois in Japan[A] ? In: Dibble HL, Bar-Yosef O eds. The Definition and Interpretation of Levallois Technology, Monographs in World Archaeology No. 23, 485—500. Wisconsin: Prehistory Press, 1995.

[22] Andrefsky W. Raw material availability and the organization of technology[J] . American Antiquity 1994, 59 (1): 21—34.

[23] Milliken S. The role of raw material availability in technological organization: a case study from the south-east Italian Late Palaeolithic[A] . In: Milliken S ed. The Organization of Lithic Technology in Late Glacial and Early Postglacial Europe, 63—82. Oxford: BAR International Series, 700, 1998.

[24] Binford LR. Organization and formation processes: looking at curated technologies. J Anthropol Res, 1979, 35: 255—273.

[25] Parry W, Kelly R. Expedient core technology and sedentism[A] . In: Johnson J, Morrow C eds. The Organization of Core Technology, 285—309. Boulder, CO: Westview Press, 1987.