The earliest Late Paleolithic in North China: Site formation processes at Shuidonggou Locality 7

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Abstract
Shuidonggou (SDG) has long been recognized as the type site complex for the Chinese Late Paleolithic, as defined by the presence of blade technology and by its chronology. Recent field and laboratory research conducted in the past decade has revealed the presence of Paleolithic ornaments and two different technological components of an industry equivalent to the early Upper Paleolithic — Levallois-like blades and simple core and flakes which appear at SDG localities. Although clearly important for Paleolithic research in China and broader Old World prehistoric studies, relatively little is known about the SDG site formation processes and the specifics of site context. Here, we explore the various formation processes and sedimentary context associated with the stone artifact assemblage from one key site — Shuidonggou Locality 7 (SDG7).

Contrary to earlier suggestions that the SDG7 lithic accumulations are the result of secondary deposition, our study indicates that SDG7 has been preserved in near-primary context. Features that were previously argued to reflect fluvial disturbance are in fact localized collapse features caused by saturated sediment load in loess deposits in a lakeshore context. Multiple lines of evidence support the argument that the site preserves the original foraging behavior of the SDG hunter-gatherers. This evidence consists of the sedimentary matrix and the distribution patterns of archaeological materials (particularly the artifact assemblage composition, debitage size distribution, artifact conditions, orientation analysis, inclination, and spatial patterning). The SDG7 archaeological deposits were buried rapidly in shallow lake margin deposits of fine sands, silts, and clays that were minimally disturbed and subjected only to relatively low energy hydraulic forces. This indicates that the SDG7 occurrences are suitable for early hominin behavioral studies in North China at the start of the Late Paleolithic.

1. Introduction

Scientists have long recognized that archaeological materials in a deposit can be altered by site formation processes (Visher, 1969; Bar-Yosef and Tchernov, 1972; Gladfelder, 1977; Isaac, 1977; Hassan, 1978; Schick, 1986, 1991; Schiffer, 1987; Goldberg and Petraglia, 1993; Kuman, 1994; Petraglia and Potts, 1994; Kluskens, 1995; Sahnouni and Heinzelin, 1998; Ward and Larcomb, 2003; Dibble et al., 2006; Bernatchez, 2010; Marder et al., 2011). This realization has made interpreting the archaeological record more complicated (Isaac, 1983, 1984; Schick, 1987a,b, 1992; Potts, 1988; Bertran and Texier, 1995; Kuman et al., 1999; Shea, 1999; Kuman, 2003; Lenoble and Bertran, 2004; Brantingham et al., 2007; Benito-Calvo and de la Torre, 2011).

Fortunately, the impact of site formation processes on archaeological sites found in floodplain and lake margin environments is particularly well studied (Potts, 1982; Schick, 1986, 1987a; Sahnouni, 1998; Sahnouni and Heinzelin, 1998; Sahnouni et al., 2002; Morton, 2004). This is primarily because these types of localities are usually subjected to low energy fluvial processes, where there is relatively little movement of the archaeological materials. In contrast, high energy settings (e.g., coarse alluvial sediments and...
riverbank deposits) are much more complicated for archaeologists to interpret (Petraglia and Potts, 1987; Schick, 1992, 2001; Shea, 1999). Many of the sites found in Shuidonggou are in lake margin depositional contexts and thus were subjected to low energy fluvial activities.

The Shuidonggou site complex (38°17′55.2″N, 106°30′6.7″E; 1198 m a.s.l.) is located on the southwestern edge of the Ordos Desert in Ningxia Hui Autonomous Region of China. Since 1923, the site has long been recognized as critical to understanding the North Chinese initial Upper Palaeolithic, now referred to in China as the initial Late Paleolithic (Licent and Teilhard de Chardin, 1925; Boule et al., 1928; Jia et al., 1964; Bordes, 1968; Li, 1993; Yamanaka, 1995; Norton and Jin, 2009; Bae and Bae, 2012), the “Late Paleolithic” as defined by Gao and Norton (2002) and Norton et al. (2009). Early researchers classified the lithic industry from Shuidonggou Locality 1 (SDG1) as evolved Mousterian or emergent Aurignacian (Licent and Teilhard de Chardin, 1925; Boule et al., 1928; Zhou and Hu, 1988) because of the presence of a Levallois-reduction strategy for blades. Since 2002, a series of multidisciplinary investigations has been conducted at the site by the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP of the Chinese Academy of Sciences) and the Institute of Archeology of Ningxia Hui Autonomous Region that focused on new excavations, the analysis of a new series of optically stimulated luminescence (OSL) dates, and developing a better understanding of the geomorphology of the Shuidonggou site complex, a region that covers an area of over 50 km² (Gao et al., 2004, 2013a,b; Chen et al., 2012; Pei et al., 2012, 2014; Li et al., 2013; Yi et al., 2013).

Six new Paleolithic sites (designated SDG7–12) were discovered and large scale excavations were conducted at five [SDG2 (previously discovered), SDG7, SDG8, SDG9, and SDG12]. As a result of these excavations, new archaeological horizons have been identified and more than 50,000 Paleolithic stone artifacts were recovered (Pei et al., 2012; Gao et al., 2013a,b). The SDG assemblages include Levallois-like blade and traditional core and flake industries, microblades, large numbers of vertebrate fossils, some ostrich eggshell beads, hearths, pigments and bone tools. This diversity of artifactual evidence ranging from 38,000–20,000 years has made SDG one of the most important site complexes for study of early modern humans in northeast Asia (Norton and Jin, 2009; Pei et al., 2012; Boëda et al., 2013; Gao et al., 2013b; Li et al., 2013). The SDG lithic collections were primarily excavated in situ and are often found in high densities, ranging in size from several hundred to more than ten thousand artifacts from different localities.

Nevertheless, relatively little is known of the site formation processes that may have influenced the SDG archaeological assemblages. In other words, were the SDG artifacts found in their originally deposited context or are the accumulations the result of secondary deposition, perhaps the outcome of fluvial activities? We attempt to answer this question by evaluating the site formation processes that may have impacted the archaeological materials from SDG7, one of the primary Shuidonggou localities.
2. Site background

2.1. Geology and stratigraphy

Shuidonggou is located in the southwestern margin of the Ordos Desert, 28 km southeast of Yinchuan and approximately 10 km east of the modern channel of the Yellow River in Ningxia Hui Autonomous Region (Fig. 1). The Border River, a tributary of the Yellow River, originates in Qingshuiying about 40 km to the southeast and runs northwest along the southern edge of the Great Wall of China. After crossing under the Great Wall, it becomes the Shuidonggou River, which eventually feeds into the Yellow River (Bureau of Geology and Mineral Resources of Ningxia, 1983; Institute of Archeology of Ningxia Hui Autonomous Region, 2003). There is one low lying hill called Dongshan (1500–1400 m a.s.l.) which runs north to south in the eastern part of Lingwu county. The hill stretches to the north and the elevation is reduced to 1305 m a.s.l. The hill has also been referenced as “Heishan”, which lies 3 km west of Shuidonggou (Gao et al., 2008).

Five terraces, labeled T5 to T1 from oldest to youngest, are present between the east slope of Dongshan and SDG. The elevations of T5–T3 are 130 m–150 m, 130 m, and 110 m above the Yellow River water level. These terraces are mainly distributed in the piedmont belt south and west of SDG (Gao et al., 2008; Liu et al., 2009). Two grade terraces named T1 and T2 are present along the banks of the Border River; most of the SDG archaeological sites are located on these terraces.

The SDG site complex is located on a tributary drainage system dominated by the Border River. The site complex is situated in an ecotone, forming a semi-arid desert steppe separating the more arid Ordos Desert to the East and the Loess Plateau to the South, which is characterized by an open-steppe grassland environment. The region is dominated by a thick (10–40 m) sandy loess-like platform that is increasingly intercalated with alluvial sediments as one approaches the floodplain of the Yellow River. The loess-like deposits in the direct vicinity of SDG appear to correspond to the Late Pleistocene early Malan Loess (Barton et al., 2007). The Quaternary sequence is set in thick Neogene red clay that is found extensively throughout the region. At SDG, the Border River has cut through the sandy loess-like platform and underlying Neogene red clay producing steep exposure faces 10–20 m deep (Brantingham et al., 2004).

SDG7 is located about 300 m southeast of SDG1, the locality first described by researchers. The site is buried within the left bank of the second terrace of the Border River at N 38°17’51.4”, E 106°30’20.7”, 1205 m a.s.l. (Fig. 1). The Border River and its small tributary have isolated stacks of alluvial and aeolian sediments 10–15 m high in a long peninsula bounded by sheer to steeply sloping bluffs (Brantingham et al., 2004). Late Pleistocene sediments at SDG 7 occur within a fluvial cut-and-fill sequence. There are three primary sedimentological units visible in the sections exposed in excavated profiles at SDG 7 (Fig. 2): a basal unit of coarse-grained fluvial sediments (or a fluvial cobble layer), a middle fluvio-lacustrine unit consisting of grey and grey–green bedded medium sands and silts, and an overlying unit of loess-like fine sands and silts with localized horizontal and bedding. Excavations from 2003 to 2005 revealed 11 stratigraphic layers with a total thickness
more than 12 m. Although Neogene red clay is absent at SDG7, this clay is found in contact with SDG7 below the fluvial cobbles layer 300–500 m upstream from the primary archaeological locality. The archaeological remains are restricted to the four lowest layers (Fig. 3), comprising the lower part of the middle fluvio-lacustrine unit above the basal gravel layer and with a total thickness of more than 3.5 m.

During the Quaternary several terraces were formed by the intermittent uplift of crust and the erosion of the Yellow River and its branches in the SDG area. During the early Late Pleistocene, the alluvial floodplain was broadly developed, probably due to increased precipitation (Gao et al., 2008). Just before the advent of Marine Isotope Stage (MIS) 3 the crust uplifted, resulting in the undercutting of the river and transforming the alluvial floodplain to the basal fluvial cobbles layer of terrace T2 (Herzschuh and Liu, 2007). During MIS 3, due to a moister and milder climate with increased precipitation, several small basins developed in different parts of the old Border River system in the SDG area, resulting in the formation of the fluvio-lacustrine gray–green loam stratigraphy that contains the archaeological deposits. After MIS 3, the precipitation decreased and the climate became relatively dry (Barton et al., 2007); this resulted in the disappearance of the small lakes and the formation of the upper unit of loess-like fine sand and silt layers.

2.2. Dating

Due to the importance of the initial Late Paleolithic and technological comparisons between the eastern and western parts of the Old World, the dating of T1 and T2 has received considerable attention (Madsen et al., 2001; Gao et al., 2002). Re-examination of the $^{14}$C and Optically Stimulated Luminescence (OSL) dates in T2 yielded an age of 38–20 ka for the occupation layers (Li et al., 2013). Because the archaeological remains from SDG 7 are from the same horizon as those from SDG2 which was successfully dated by $^{14}$C, a total of 9 sediment samples were collected from the archaeological layers of SDG7 for OSL dating. Medium-grained (45–63 μm) fractions of quartz were extracted from the samples using the procedures described by Nian et al. (2009). Equivalent dose measurements ($D_e$) were determined using the single-aliquot regeneration dose method (Murray and Wintle, 2000). All luminescence measurements, beta irradiation and preheat treatments were carried out in an automated Risø-TL/OSL DA-20 reader equipped with a 90Sr/90Y beta source (Bøtter-Jensen et al., 2003) and an EMI 9235 QA photomultiplier tube. Blue light LED stimulation (470 ± 30 nm) set at 90% of 50 mW cm$^{-2}$ full power and a 7.5 mm Hoya U-340 filters (290–370 nm) were used for the quartz OSL measurements.

The sample quartz was dominated by the fast component for the samples from SDG7. The quartz OSL signals for repeated measurements of the same dose showed good recycling within the ±10% range (Murray and Wintle, 2000), and the recuperation ratio remained low at <5% for the samples. Three natural aliquots of sample L2373 were bleached with a solar simulator (SOL2) of 6 h, and the dose recovery ratio (recovered/given dose) (Murray and Wintle, 2003) was 1 ± 0.06 for a given laboratory dose of 90 Gy with a 6.75 Gy test dose. A SAR protocol was used to measure the equivalent dose of the samples, the aliquots were stimulated at 125°C, and the preheat and cut-heat temperatures were at 260°C for 10 s and 220°C for 0 s respectively. The dates for the SDG 7 samples ranged from 22 ± 2 ka to 30 ± 3 ka with the medium-grained quartz SAR protocol, with ages increasing with depth.

Fig. 3. Profile of the archaeological layers at SDG7 site, showing the dating results, the sedimentary bedding structures, and localized collapse features within the archaeological layers.
within experimental error, except for samples L2440 and L2441 (22 ± 2 ka and 23 ± 2 ka) (Table 1). The strata of these two samples may have been disturbed by human activity or other factors.

sedimentary context of the archaeological layers, along with the vertical dispersion and composition of the stone tool accumulations.

Table 1
<table>
<thead>
<tr>
<th>Lab no.</th>
<th>Depth (m)</th>
<th>U (ppm)</th>
<th>Th (ppm)</th>
<th>K (%)</th>
<th>Disc no.</th>
<th>Dce (Gy)</th>
<th>Age (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2375</td>
<td>5.9</td>
<td>4.27 ± 0.14</td>
<td>10.7 ± 0.3</td>
<td>1.76 ± 0.06</td>
<td>6</td>
<td>3.26 ± 0.21</td>
<td>71 ± 2</td>
</tr>
<tr>
<td>L2374</td>
<td>6.3</td>
<td>4.43 ± 0.14</td>
<td>9.41 ± 0.27</td>
<td>1.72 ± 0.06</td>
<td>4</td>
<td>3.17 ± 0.2</td>
<td>69 ± 4</td>
</tr>
<tr>
<td>L2373</td>
<td>6.7</td>
<td>4.13 ± 0.13</td>
<td>8.88 ± 0.27</td>
<td>1.66 ± 0.06</td>
<td>7</td>
<td>3.01 ± 0.19</td>
<td>68 ± 2</td>
</tr>
<tr>
<td>L2372</td>
<td>7.1</td>
<td>4.2 ± 0.13</td>
<td>9.86 ± 0.29</td>
<td>1.7 ± 0.06</td>
<td>6</td>
<td>3.12 ± 0.2</td>
<td>73 ± 3</td>
</tr>
<tr>
<td>L2438</td>
<td>7.6</td>
<td>2.89 ± 0.11</td>
<td>7.79 ± 0.25</td>
<td>1.92 ± 0.06</td>
<td>6</td>
<td>2.85 ± 0.17</td>
<td>67 ± 4</td>
</tr>
<tr>
<td>L2439</td>
<td>8.7</td>
<td>3.6 ± 0.13</td>
<td>11 ± 0.32</td>
<td>1.57 ± 0.05</td>
<td>8</td>
<td>2.94 ± 0.19</td>
<td>71 ± 4</td>
</tr>
<tr>
<td>L2440</td>
<td>9.2</td>
<td>4.93 ± 0.16</td>
<td>10.3 ± 0.32</td>
<td>1.65 ± 0.06</td>
<td>6</td>
<td>3.23 ± 0.22</td>
<td>70 ± 5</td>
</tr>
<tr>
<td>L2441</td>
<td>9.7</td>
<td>4.3 ± 0.14</td>
<td>10.3 ± 0.31</td>
<td>1.7 ± 0.06</td>
<td>6</td>
<td>3.16 ± 0.2</td>
<td>73 ± 3</td>
</tr>
<tr>
<td>L2442</td>
<td>10.2</td>
<td>2.98 ± 0.11</td>
<td>9.62 ± 0.29</td>
<td>1.52 ± 0.05</td>
<td>6</td>
<td>2.65 ± 0.17</td>
<td>78 ± 5</td>
</tr>
</tbody>
</table>

Estimated water content: 20 ± 5%.

2.3. Excavation and materials

After undertaking systematic mapping of the research area and studying the geomorphology and stratigraphy of the Border River terraces and the SDG7 deposits yielding in situ archaeological materials, we identified an area of 25 m² for excavation. The archaeological layers were excavated in 2–5 cm increments for a total of 35 spits, with larger spits used for sterile layers. Sediments were dry sieved with 4 mm mesh. Materials were three dimensionally point-plotted using a total station EDM. Specimens were entered into an electronic database after each spit was excavated, and systematic sampling for sedimentary analysis (particle size, magnetic susceptibility, etc.) was done. Orientation and inclination (dip) of the stone artifacts were measured by a compass used to record such data for site formation studies. A total of 9901 stone artifacts were recovered. In addition, two ostrich eggshell beads and 486 vertebrate faunal specimens were recovered during excavations. The identified species include Lepus sp., Vulpes sp., Canis sp., Felis microtus, Cervidae, Bubalus sp., Gazella przewalskii, Equus sp., Equus hemionus, and Struthio sp. (Pei et al., 2012; 2014; Gao et al., 2013a).

3. Site formation processes

SDG 7 site has been argued to be in secondary context because of disruptions in the horizontal bedding (Fig. 3). However, these are in fact collapse features that typically occur in loess deposits in lakeshore contexts. As water flows into the lake, deposits become saturated and heavier than the surrounding layers, resulting in a localized collapse in the strata. Contrary to indicating a secondary context, such features at SDG7 actually reflect a gentler, lake-shore sedimentation process. These collapse features, along with the elongate-shaped artifact concentrations in the uppermost of archaeological layers (Fig. 4), suggest that only low-velocity water currents have influenced the final deposition of the archaeological materials at SDG7. Studies in other regions of the world have found support for such an interpretation (e.g., Langbein and Leopold, 1968; Isaac, 1977; Schick, 1986, 1991, 1992, 2001; Petraglia and Potts, 1987, 1994; Sahinou, 1998; Sahinou and Heinzelin, 1998; Shea, 1999; Morton, 2004). Therefore, the question we need to address is: “Which agent(s), geological or behavioral, were primarily responsible for the accumulation of the archaeological materials?” We attempt to answer this question by analyzing the sedimentary context of the archaeological layers, along with the vertical dispersion and composition of the stone tool accumulations.

3.1. Sedimentary context of the archaeological strata

The sedimentary matrix of the archaeological layers is formed by fine grained particles, primarily silt loaded with a heterometric and heterogeneous phase. Table 2 displays the results of the different size classes in the sediments. It is generally accepted that silty sediments are most common in flood plain or lake margins, which are known to be deposited at lower flow speeds (Hassan, 1978). Our analysis indicates that the sedimentary matrix is primarily formed by fine grained sediments, mainly silt in shallow lake margins. Therefore, the uppermost spits of SDG7 archaeological layers appear to have been subjected to minimal hydraulic reworking.

Table 2

<table>
<thead>
<tr>
<th>Size classes</th>
<th>Size range</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granules and small pebbles</td>
<td>&gt;0.25 mm</td>
<td>71.71</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.25–0.125 mm</td>
<td>2.46</td>
</tr>
<tr>
<td>Very fine sand and coarse silt</td>
<td>0.125–0.0156 mm</td>
<td>79.38</td>
</tr>
<tr>
<td>Fine silt to clay</td>
<td>&lt;0.0156 mm</td>
<td>17.45</td>
</tr>
</tbody>
</table>

3.2. Vertical and lateral dispersion of archaeological remains

The excavations at SDG7 reveal that the archaeological occurrences are vertically distributed through 3.50 m thickness of silt and find sands, with <0.125 mm size classes dominate (96.83%) the grain size. The vertical distribution indicates a high density of artifacts, and sterile levels are absent (Fig. 5). The total stone artifact assemblage weighs 112.38 kg. Overall density of stone artifacts at SDG7 is approximately 396 artifacts/m², and a massive 4.50 kg of artifactual materials per square meter. It is remarkable that the stone artifacts show elongated patterns in the uppermost of archaeological layers which suggests they were disturbed by hydraulic agencies. Various other aspects of the artifact assemblage, however, indicate that hunter–gatherer behavior is mainly responsible for these prodigious concentrations of artifacts, with post-depositional factors such as gentle lamellar water flow affecting the original deposition of the material.

3.3. Stone artifacts concentration

We analyzed the variation in the SDG7 stone artifact concentrations to evaluate the degree of post-depositional disturbance of
artifact assemblages using criteria primarily developed by Schick (1986; see also Petraglia and Potts, 1987, 1994; Schick, 1991, 1992; Shea, 1999; Sahnouni, 1998; Sahnouni and Heinzelin, 1998). The specific analyses we conducted here for site formation are technological composition; debitage size distribution; condition of the artifacts; patterning in the artifacts orientations, inclinations, and spatial patterning.

3.3.1. Technological composition

The initial step to appraise formative processes is to inspect the technological coherency of the unearthed stone artifact assemblage. If artifact manufacture occurred at the site, the expected assemblage composition would incorporate artifactual elements that match technologically, especially in the core/debitage ratio. When the artifact assemblage is not coherent, alternative explanations should be considered including the possibility of hydraulic transport (Schick, 1986).

Fig. 6 presents the technological breakdown of the SDG 7 stone artifacts. As can be seen in the histograms, the debitage category [SFD (small flaking debris <20 mm) + debitage] depicts the highest frequency ($n = 9669, 97.66\%$), while cores and percussors (hammerstones) show the lowest frequency, respectively $1.07\%$ ($n = 106$) and $0.05\%$ ($n = 5$) (Table 3). Although the percentage of SFD (55.47%) is marginally lower than what is expected for a completely
preserved collection of artifacts knapped on-site, compared to the experimentally generated assemblage (Schick, 1986), the core/debitage ratio (0.01) and core frequency (1.07%) at SDG 7 indicate that the cores and debris components match technologically. Five battered stones appear to have been used as hammerstones, which indicates that stone artifact knapping occurred at the site. Therefore, the SDG 7 assemblage exhibits a coherent artifact composition. It is very unlikely that the artifact assemblage suffered from significant fluvial disturbance.

### 3.3.2. Debitage size distribution

If stone tool knapping occurred on-site and material was not subject to fluvial winnowing, the debitage size distribution would resemble the expected experimental data generated by Schick (1986), with a distinctive peak of small debris (<2 cm) and decreasing numbers of larger artifacts ≥2 cm. Fig. 7 compares the SDG7 debitage data against Schick’s (1986) experimental data. The SDG7 size distribution pattern shows a strong negative skew toward smaller sizes and resembles the one produced by experimental knapping made by Schick (1986), who also used a 4 mm sieve to sort her flaking debris. Thus, SDG7 site seem to represent an area where early hominins did manufacture their stone artifacts. The debitage was probably rapidly buried subsequently by low velocity floods, resulting in the elongated patterns of some materials.

3.3.3. Artifact condition

Artifact conditions were recorded for each lithic raw material (Table 4) as they are widely used indicators for the integrity of site context (Petraglia and Potts, 1987, 1994; Shea, 1999). Most of the raw materials were derived from local sources: silicified limestone (n = 5335, 33.22%) and chert (n = 2808, 28.36%) dominate, while quartzite (n = 966, 9.76%), quartz (n = 447, 4.51%), and sandstone (n = 345, 3.49%) are less common. Condition was recorded as fresh/unabraded, slightly abraded, or abraded (with edge damage also considered in the degree of abrasion).

3.3.4. Orientation patterns

Analysis of stone artifact orientations provides a valuable indicator of any disturbance by water at a site. Experimental studies

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**Table 3**

<table>
<thead>
<tr>
<th>Artifact categories</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFD (Small Flaking Debris &lt;20 mm)</td>
<td>5492</td>
<td>55.47</td>
</tr>
<tr>
<td>Core/core tools</td>
<td>106</td>
<td>1.07</td>
</tr>
<tr>
<td>Retouched pieces</td>
<td>121</td>
<td>1.22</td>
</tr>
<tr>
<td>Debitage</td>
<td>4177</td>
<td>42.19</td>
</tr>
<tr>
<td>Hammerstones</td>
<td>5</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9901</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

**Table 4**

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Silicified Limestone</th>
<th>Chert</th>
<th>Quartzite</th>
<th>Quartz</th>
<th>Sandstone</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>Fresh/unabraded</td>
<td>4327</td>
<td>43.70</td>
<td>2505</td>
<td>25.30</td>
<td>690</td>
<td>6.97</td>
</tr>
<tr>
<td>Slightly abraded</td>
<td>897</td>
<td>9.06</td>
<td>285</td>
<td>2.88</td>
<td>217</td>
<td>2.19</td>
</tr>
<tr>
<td>Heavily abraded</td>
<td>111</td>
<td>1.12</td>
<td>18</td>
<td>0.18</td>
<td>59</td>
<td>0.60</td>
</tr>
<tr>
<td><strong>Sub-total</strong></td>
<td><strong>5335</strong></td>
<td><strong>33.22</strong></td>
<td><strong>2808</strong></td>
<td><strong>28.36</strong></td>
<td><strong>966</strong></td>
<td><strong>9.76</strong></td>
</tr>
</tbody>
</table>

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have shown that when artifacts are subjected to fluvial processes, a preferred orientation occurs (particularly for elongated artifacts) in response to current strength and direction (Schick, 1986; Morton, 2004). In general, elongate materials tend to be oriented either parallel (debitage size < 4 cm) or perpendicular (debitage size ≥ 4 cm) to flow trajectory. Fig. 8 is a rose diagram that presents the pattern of the long axes of the stone artifacts from SDG7. The artifact orientations show a random pattern with no preferred orientation. It can be inferred from this orientation diagram that the stone artifact assemblage was not subjected to intense fluvial disturbance.

### 3.3.5. Artifact inclination

The combination of artifact inclination or dip is a sensitive indicator of water flow direction (Schick, 1986). Schick found that minor inclinations (5°–10°) of stationary artifacts are produced by weaker flow velocities, while higher velocities tend to produce steeper inclinations, ranging between 10 and 30° or more (Schick, 1984, 1991).

Fig. 9 provides insight into the strength of the flow velocity. It shows that the majority of the SDG7 stone artifacts is characterized by only a slight inclination. Nearly 50% of the specimens have an inclination ranging between 0 and 10°, and slightly more than 25% shows a dip from 20 to 30°; less than 20% of the total assemblage has a dip greater than 30°. Overall, these inclination patterns suggest a lower velocity current.

### 3.3.6. Spatial patterns

As with distribution in vertical space, spatial variation on the horizontal plane is important for determining the degree of post-depositional movement of artifacts (Schick, 1986). The stone artifact assemblage at SDG7 is fairly concentrated horizontally, as indicated by the average number of artifacts (396) and weight (4.50 kg) per square meter. Fig. 10 shows the spatial distribution for the density of artifacts within the meter square units. Overall, artifact spatial configurations do not exhibit any major spatial trends produced by fluvial modification as observed in simulations of hydraulic site disturbance, such as linear patterns for artifacts with a long axis (Schick, 1986). Rather, the minor spatial trends are indicative of only minimal disturbance. Fig. 10 shows that most of the artifacts are concentrated in the southeast area regardless of type, composition, and size. As proposed by Schick (1986), if a site has undergone hydraulic disturbance, the small debitage component of the artifact assemblage most likely concentrates in a downstream position. As more than 90% of the assemblage is < 4 cm in size but a full range of sizes is also present, it can be inferred that the total assemblage was disturbed by gentle water movement from northwest to southeast, and the SDG 7 artifact spatial trends overall indicate minimal disturbance.

In summary, multiple lines of evidence suggest the SDG7 archaeological materials were minimally disturbed. The archaeological remains were concentrated in 350 cm of the 1 m vertical distribution and in high density, suggestive of long term and/or successive occupations. Furthermore, the SDG 7 materials were deposited in a fine sedimentary matrix buried in a shallow lake margin, with little-to-no evidence of high energy fluvial activity impacting the lithic accumulation.
4. Conclusions

The following conclusions may be drawn from our detailed study of site formation processes at the SDG7 site:

1) SDG7 is one of the newly discovered and excavated sites in the SDG site complex. The OSL dates indicate that human foragers occupied the site sometime at intervals between 30,000 and 22,000 years. The archaeological materials are densely concentrated within the full sequence of artifact-bearing deposits. Sedimentary matrix analysis shows that the site was buried in shallow lake margin deposits of fine sands, silts, and clays, which was influenced by relatively low energy hydraulic forces. Sedimentary bedding structures and localized collapse features typical for lakeshore loess deposits, as well as the distribution of the archaeological remains, suggest minimal re-working, though some re-arrangement of the smaller artifacts may have occurred.

2) The SDG7 stone artifacts are generally fresh and unabraded, displaying a coherent assemblage composition, including cores, retouched pieces, debitage, and percussors. Debitage dominates the assemblage. In addition, small flaking debris (SFD < 20 mm) exhibits a similar size profile to that produced by Schick (1986) in her experimental tool making studies, suggestive that knapping occurred on the site. The lithic artifacts do not show high inclinations or preferred orientation patterns. Analysis of both vertical and spatial positioning of the artifacts also suggests dense concentrations. Multiple lines of evidence presented here suggest it is unlikely the SDG7 archaeological remains were subjected to high energy fluvial disturbance.

3) The study presented in this paper emphasizes the relevance of inspection of Paleolithic occurrences for hydraulic winnowing prior to any behavioral interpretation of the excavated stone assemblage at the SDG site complex, even though these sites are in low energy lake margin and floodplain contexts. We conclude that the SDG7 stone artifacts are suitable for early human behavioral studies within the SDG site complex and the earliest Late Paleolithic of northern China. We hope that future studies in China analyze the potential effects of various site formation processes in order to better understand the formation of these archaeological collections.

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