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# Chronological studies of Shuidonggou (SDG) Locality 1 and their significance for archaeology

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A B S T R A C T

Shuidonggou Locality 1 (SDG 1), discovered in 1923, is one of the most important Upper Paleolithic sites in China, and excavations since its discovery have produced abundant cultural remains and other materials. However, only limited ranges of dating methods have been applied to the site. This study discusses the results of dating samples by optically stimulated luminescence (OSL) from two sections at SDG 1. Medium grained (45–63 μm) quartz was extracted and used for age determination by the single aliquot regeneration (SAR) protocol. The OSL ages of five samples from the cultural layer in the section excavated in 1963 were between 32 ± 3 ka and 39 ± 4 ka, and four samples from the cultural layer excavated in 1980 were dated from 42 ± 3 ka to 46 ± 3 ka. The OSL data were consistent with newly acquired AMS $^{14}C$ dates. The dating results show that ages varied from ca. 22 ka to 46 ka for the cultural layer at SDG 1. The onset of Levalloisian blade technology in China is dated to ca. 43 ka at SDG 1, perhaps reflecting a fast dispersal of modern humans, and earlier than previously thought. Systematic excavation at SDG 1 is needed to establish the exact stratigraphic position of Paleolithic assemblages in order to discuss their relationships with initial Upper Paleolithic industries in Eurasia.



## 1. Introduction

Shuidonggou Locality 1 (38°17′55.2″N, 106°30′6.7″E) (Fig. 1), was discovered by Licent and Teihard de Chardin in 1923 and was the first Paleolithic site to be excavated in China. The Shuidonggou area is located 33 km southeast of Yinchuan in the Ningxia Hui Autonomous Region and contains 12 localities, numbered SDG 1–12. In this study, we concentrate on SDG 1, located on the right side of the Biangou River. Excavations in 1923, 1960, 1963 and 1980 produced numerous stone artifacts, some animal fossils, ornaments and traces of fire (see e.g. Licent and Teilhard de Chardin, 1925; Jia et al., 1964; Ningxia, 2003). Due to the complicated pattern of the sediment and limitations on the choice of dating techniques or laboratory protocols, the age of SDG 1 is still under dispute. Optically stimulated luminescence (OSL) dating is an invaluable technique for dating archaeological sites (see e.g. Roberts, 1997; Zhou et al., 2000; Bowler et al., 2003; Grine et al., 2007; Jacobs et al., 2008; Nian et al., 2009; Zhang et al., 2010; Gliganic et al., 2012), and has shown great improvement in the measuring precision and range over the last 20 y. In the present study, we attempt to employ OSL dating to constrain the chronology of SDG 1, and their significance for archaeology will be discussed.

## 2. Research history of SDG 1

More than 6700 artifacts were found in SDG 1 from the excavation of 1980, 5500 of which were from the lower culture layer, along with 63 mammalian fossils representing 15 species (Niangxia, 2003). The stone items include complete and skillfully flaked cores, points, scrapers and blades. An engraved stone artifact was also recovered, and provides a rare indication of cognitive capacities in the early Late Paleolithic of East Asia (Peng et al., 2012). The SDG 1 lithic industry is characterized by Levallois cores and blades and may be related to early Late Paleolithic industries in

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Siberia and Mongolia (Brantingham et al., 2001; Derevianko, 2009; Gladyshev et al., 2010).

The profile of SDG 1 has been described in different ways by several researchers (Fig. 2) (see e.g. Ningxia Museum, 1987; Liu et al., 2009). Stratigraphically, the sequence at SDG 1 is divided into two parts, one Late Pleistocene, and the other, Holocene. Since its discovery, several dating methods have been used to establish a chronological framework for the site (Table 1). According to the conventional (Conv.) $^{14}$C and accelerator mass spectrometry (AMS) methods, U-series and OSL dating, we can easily identify the Holocene layer containing Neolithic remains, but disputes continue about the age of the Late Pleistocene deposits. In this study, we focus on the Late Pleistocene sediments relevant to the deposits in which Paleolithic remains were found. The two dating results published by Li et al. (1987) (PV-331, PV-317) and Ningxia Museum (1987) were derived from the same data, but were slightly different because of different correction methods. Moreover, the bone sample (PV-331) was probably contaminated by young carbon (Madsen et al., 2001; Gao et al., 2008). U-series dating results on two teeth from the lower cultural layer of SDG 1 were 34 ± 2 ka and 38 ± 2 ka respectively (Chen et al., 1984), which were older than the Conv. $^{14}$C age of carbonate (PV-317, 25450 ± 800 BP). OSL dating methods were also applied to obtain the age of the deposit at SDG 1, and the age of the cultural layer were 28.7 ± 6 ka and 35.7 ± 1.6 ka, but without considering two outliers (S1-6, S1-7) (Liu et al., 2009). Recently, Peng et al. (2012) reported a new AMS $^{14}$C age of charcoal from lower part of the cultural layer that was 36200 ± 140 BP before calibration, with a corresponding calibrated $^{14}$C age of 39410 ± 183 BP with the OxCal 4.1 calibration program (Li et al., 2013b). Chronological control of SDG 1 sequence is very limited as the current age of Pleistocene deposits varies from ca. 25 ka to 40 ka, and this poor degree of control has affected our understanding of the characteristics of Palaeolithic assemblages.

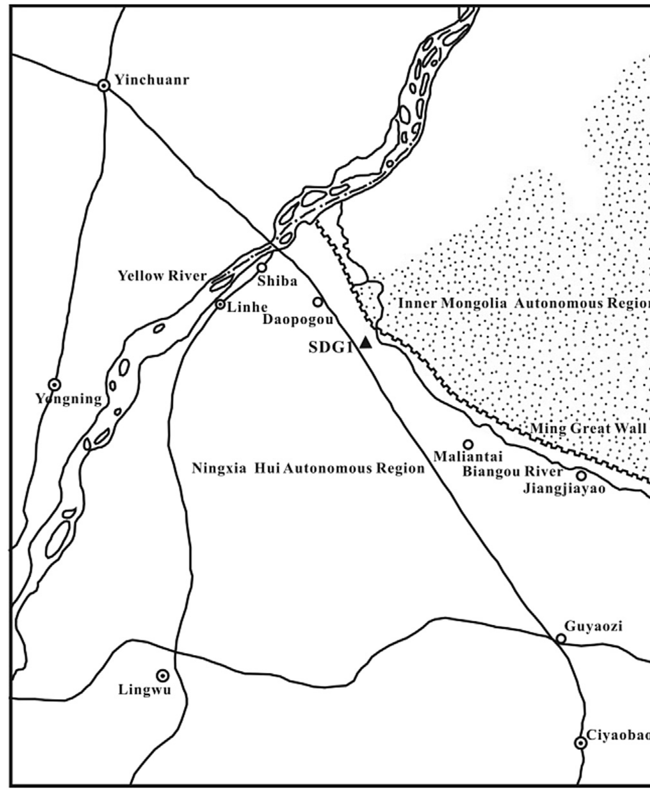


**Fig. 1.** Location map showing SDG 1 (after Ningxia, 2003).

**Table 1**
Previous dating results of SDG 1 using various dating methods.

| Sample no. | Material | Layer | Dating method | Age | | Reference |
|---|---|---|---|---|---|---|
| | | | | uncal. BP | ka | |
| PV-330 | Bone | Upper cultural layer | Conv. 14C | 5900 ± 70 | | Li et al., 1987 |
| PV-316 | Shell | Upper cultural layer | Conv. 14C | 8520 ± 150 | | Li et al., 1987 |
| S25 | Sludge | Upper cultural layer | Conv. 14C | 5940 ± 100 | | Sun et al., 1991 |
| S31 | Ash | Upper cultural layer | Conv. 14C | 7436 ±1 01 | | Sun et al., 1991 |
| S37 | Shell | Upper cultural layer | Conv. 14C | 8190 ± 120 | | Sun et al, 1991 |
| S1-1 | Quartz | Upper part of layer 1 | OSL | | 4.2 ± 0.2 | Liu et al., 2009 |
| S1-2 | Quartz | lower part of layer 1 | OSL | | 9.1 ± 1 | Liu et al., 2009 |
| BKY-82042 | Teeth | Lower cultural layer | U-series | | 38 ± 2 | Chen et al., 1984 |
| BKY-82043 | Teeth | Lower cultural layer | U-series | | 34 ± 2 | Chen et al., 1984 |
| PV-331 | Bone | Lower cultural layer | Conv. $^{14}$C | 16760 ± 210 | | Li et al., 1987 |
| PV-317 | Carbonate | Lower cultural layer | Conv. $^{14}$C | 25450 ± 800 | | Li et al., 1987 |
| | Bone | Lower cultural layer | Conv. $^{14}$C | 17250 ± 210 | | Ningxia Museum, 1987 |
| | Carbonate | Lower cultural layer | Conv. $^{14}$C | 26230 ± 800 | | Ningxia Museum, 1987 |
| S1-3 | Quartz | Upper part of layer 3 | OSL | | 28.7 ± 6 | Liu et al., 2009 |
| S1-4 | Quartz | Upper part of layer 4 | OSL | | 29.3 ± 4.1 | Liu et al., 2009 |
| S1-5 | Quartz | lower part of layer 4 | OSL | | 32.8 ± 3 | Liu et al., 2009 |
| S1-6 | Quartz | Layer 5 | OSL | | 15.8 ± 1.1 | Liu et al., 2009 |
| S1-7 | Quartz | Upper part of layer 6 | OSL | | 17.7 ± 0.9 | Liu et al., 2009 |
| S1-8 | Quartz | Middle part of layer 6 | OSL | | 34.8 ± 1.5 | Liu et al., 2009 |
| S1-9 | Quartz | Lower part of layer 6 | OSL | | 35.7 ± 1.6 | Liu et al., 2009 |
| UGAMS-9682 | Charcoal | Layer 3 | AMS $^{14}$C | 36200 ± 140 | | Peng et al, 2012 |

Note: The layers of the samples measured by OSL and AMS $^{14}$C corresponded to the profile described by Liu et al. (2009). The others correspond to the profile described by Ningxia Museum (1987).

In attempting to improve the dating of the site, we applied OSL dating technique to the deposits from SDG 1. Five samples were collected from the north section, excavated in 1980, which consisted of grey-green silt (L1653–L1656) and yellow sand (L2360). The other five samples were collected from the other section that lay ca. 10 m southwest of the north section that was excavated in 1963 and which consisted of grey-yellow loess-like fine sand showing vertical joint (L2361–L2365) (see Fig. 3). According to the

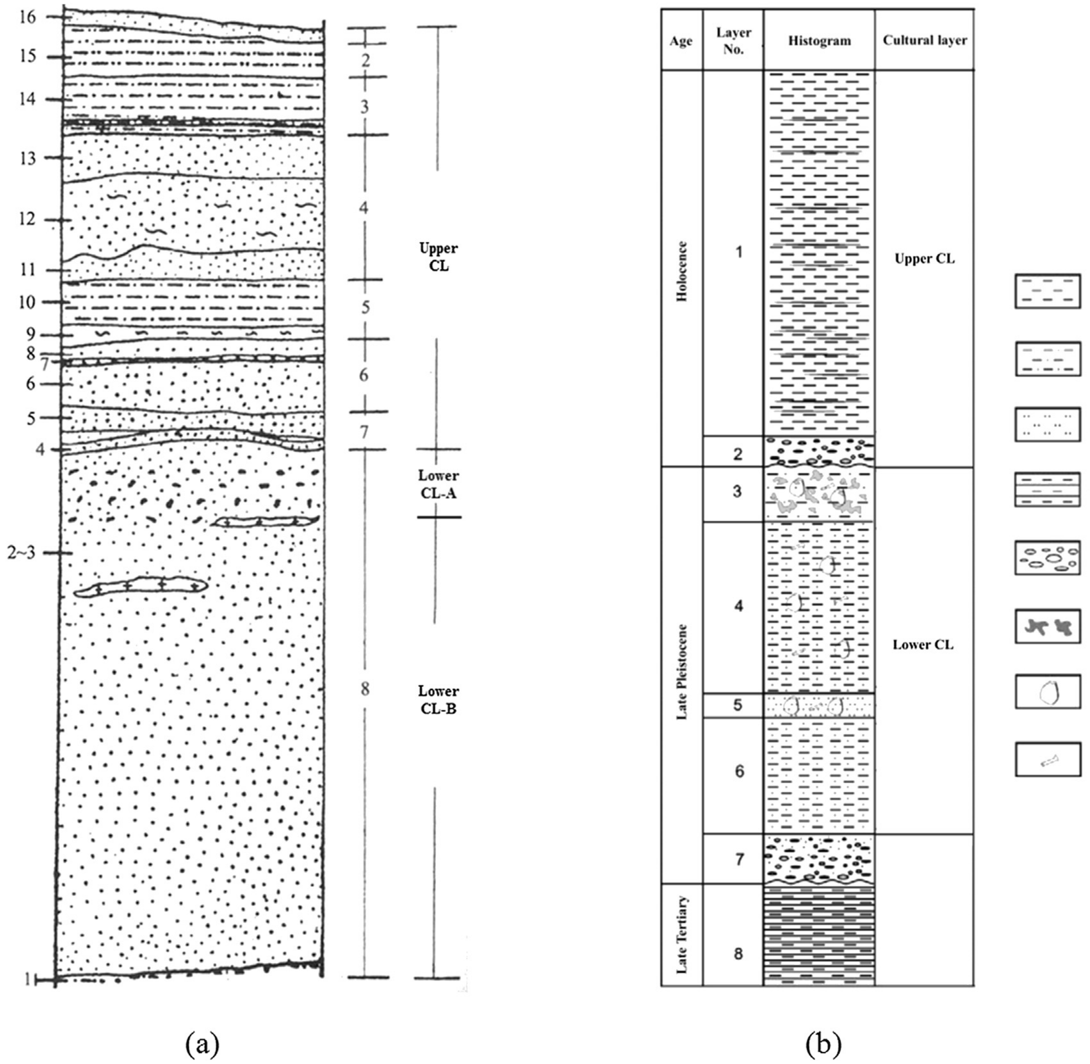


**Fig. 2.** Stratigraphic profiles of SDG 1 (a) and (b) profiles as described by Ningxia Museum (1987) and Liu et al. (2009), respectively. 1: clay-rich silt; 2: silt; 3: fine sand; 4: mudstone; 5: gravel; 6: carbonate nodule; 7: stone artifact; 8: animal fossil.

geological and geomorphological characteristics of SDG 1 described by Gao et al. (2008) (Fig. 4), the sampling horizons of the north section are equivalent to layer ⑤ within a small lake sediment (L1653–L1656) and layer ⑦ (L2360) and the sampling horizon of the southwest section corresponds to layer ⑥ which belonged to a valley flat, that was above and younger than layer ⑤.

## 3. OSL dating

The basic principle of OSL dating is that mineral grains are exposed to daylight during transportation, and thus the previously stored luminescence signals in the minerals are set to zero upon deposition. The decay of the radioactive nuclides in the sediments will generate radiation which interacts with the sediment grains, in essence, transferring energy from the ambient environment to the mineral grains, and the amount of the energy stored in these grains is proportional to the time since their last exposure to daylight (Aitken, 1998).

The samples were prepared under subdued red light. The outer layer of the samples were cut away, and then the remaining inner samples were treated with hydrochloric acid (10%) and hydrogen peroxide (30%) to remove carbonates and organic material, respectively. Medium-grained fractions (45–63 μm) which are the main grain-size fraction of the samples were obtained by sieving. Medium-grained quartz was extracted by etching the polymineral medium-grained fractions with silica-saturated fluorosilicic acid (30%) for 3 days, then dissolved with hydrochloric acid (10%) to remove any fluorides produced. The quartz grains were held as a monolayer on aluminium measurement discs with silicone oil. The purity of the quartz extracts was confirmed by the ratio of IRSL to OSL intensity (<3%) and TL measurement.

Luminescence measurements were carried out on a Risø-TL/OSL-15/20 reader equipped with a $^{90}Sr/^{90}Y$ beta source (Bøtter-Jensen et al., 2003) and blue light (470 ± 30 nm) emitting diodes (LEDs). The signals were detected by an EMI 9235QA photomultiplier tube with a 7.5 mm Hoya U-340 filters (290–370 nm). All OSL measurements were measured at 125 °C using a 5 °C $s^{-1}$ heating rate with the blue light LED stimulation set at 90% of the full power (50 mW $cm^{-2}$).

The concentrations of external uranium (U), thorium (Th) and potassium (K) were determined based on neutron activation analysis (NAA). Water content was assumed to be 20 ± 5%. An alpha efficiency value (α-value) of 0.04 ± 0.02 for quartz was used to calculate the total dose rate (Rees-Jones, 1995). The calculation was performed using the 'AGE' program (Grün, 2009).

The SAR protocol was employed to determine equivalent dose ($D_e$) shown in Table 2. The samples were preheated at 260 °C for 10 s, and stimulated at 125 °C for 40 s. The quartz OSL signals were integrated over the initial 0.64 s, with background taken as the average of the last 8 s of the OSL decay curves, and the ratio of $L_x/T_x$ (Table 2) was used to define the natural/regenerative-dose response. The regeneration data were derived by fitting an exponential-plus-linear function for the interpolation of $D_e$, with error calculated from systematic and random (2%) errors.

**Table 2**
The SAR protocol (Murray and Wintle, 2000).

| Step | Treatment |
|---|---|
| 1 | Give dose, $D_i$[a] |
| 2 | Preheating at 260 °C for 10 s |
| 3 | Blue stimulation at 125 °C for 40 s, $L_x$ |
| 4 | Give test dose, $D_t$ (16.6 Gy) |
| 5 | Cut heat at 220 °C for 0 s |
| 6 | Blue stimulation at 125 °C for 40 s, $T_x$ |
| 7 | Return to step 1 |

[a] For the natural sample, $i = 0$, $D_i = 0$.

## 4. Results and discussion

The signal intensity of quartz OSL signals was bright and dominated by the fast component for all the samples presented in this study, and the fast component contributes more than 90% to the signals of the first 0.64 s. Recycling ratios are inside of 0.9–1.1, and recuperation ratio is below 5% for all the samples. A $D_e$ preheat plateau for sample L1654 is shown between 220 °C and 300 °C, with three discs at each 20 °C interval for 10 s and a cut-heat of 220 °C for 0 s (Fig. 5). Thus, a preheat of 260 °C for 10 s and a cut-heat of 220 °C for 0 s were employed for the SAR protocol. The applicability of the SAR protocol to determine the equivalent dose of the samples was further tested by means of dose recovery experiment (Murray and Wintle, 2003). Ten natural aliquots of sample L1654 was bleached by the SOL2 solar simulator of 15 h and then given a 119.3 Gy beta dose with a 16.6 Gy test dose, the ratio of recovered dose to given dose was 0.98 ± 0.03 from four discs. The above data show that the SAR protocol is suitable for the $D_e$ determination of the samples.

A summary of $D_e$ values and the OSL ages of the samples from SDG 1 is shown in Table 3 obtained with the SAR protocol. Fig. 6 provides an example dose–response curve of sample L2365. The ages of samples L2361, L2362, L2363, L2364 and L2365, which were collected from the cultural layer in the southwest section of

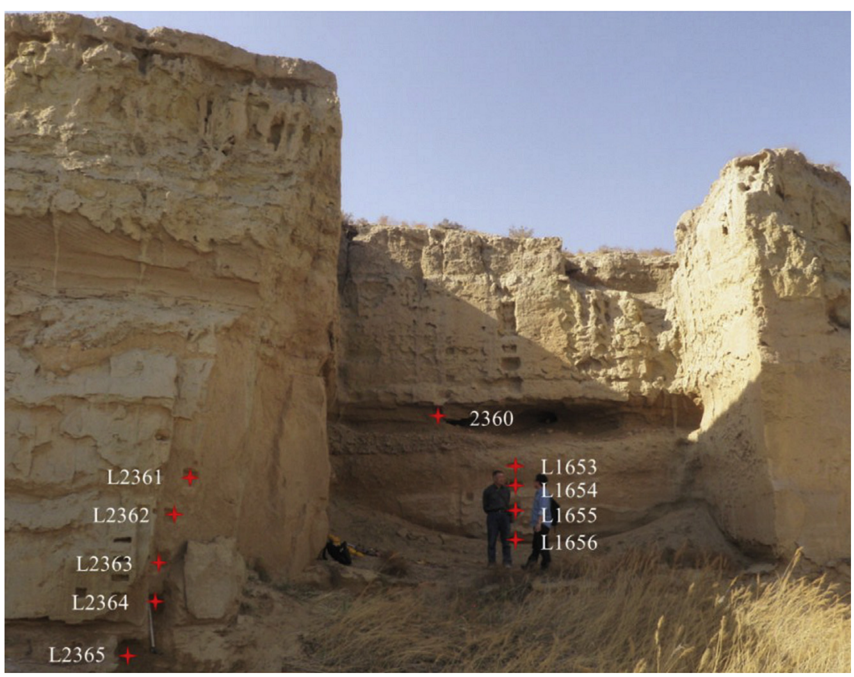


**Fig. 3.** SDG 1 and the sample collection position.

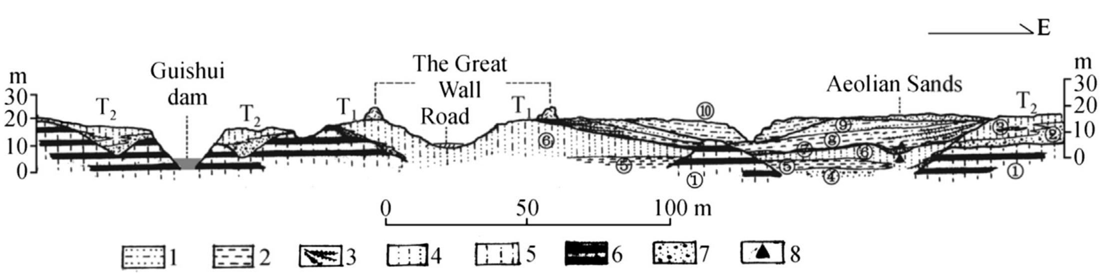


**Fig. 4.** Quaternary geological and geomorphological profile at SDG 1. 1: sandy loam; 2: loam; 3: charcoal belt; 4: silt; 5: loess-like soil; 6: red loam; 7: sand and gravel; 8: Paleolithic site. (Source: Gao et al., 2008, Fig. 3a.)

SDG 1, were 35 ± 3 ka, 35 ± 3 ka, 33 ± 3 ka, 33 ± 2 ka and 39 ± 3 ka, respectively. The age of sample L2360 from the sand layer was 22 ± 2 ka, and the ages for the samples from the cultural layer were 43 ± 3 ka, 43 ± 3 ka, 42 ± 3 ka and 46 ± 3 ka respectively for samples L1653, L1654, L1655 and L1656 in the north section of SDG 1 (Table 3 and Fig. 3). An erosional surface therefore exists between the two layers, which is consistent with our field observations. The optical ages of the samples tend to increase with depth within experimental error and follow the Law of Superposition.

**Table 3**
U, Th, K concentrations, equivalent dose and OSL ages of the samples from SDG 1 using the SAR protocol.

| Field no. | Lab No. | Depth (m) | U (ppm) | Th (ppm) | K (%) | Dose rate (Gy/ka) | $D_e$ (Gy) | No. of aliquots | Age (ka) |
|---|---|---|---|---|---|---|---|---|---|
| SDG1-13-OSL3 | L2360 | 5.2 | 2.37 ± 0.1 | 9.19 ± 0.28 | 1.65 ± 0.06 | 2.63 ± 0.16 | 59 ± 3 | 6 | 22 ± 2 |
| SDG1-09-OSL1 | L1653 | 6.1 | 2.50 ± 0.11 | 7.98 ± 0.24 | 1.28 ± 0.07 | 2.27 ± 0.15 | 98 ± 3 | 17 | 43 ± 3 |
| SDG1-09-OSL2 | L1654 | 6.5 | 2.38 ± 0.11 | 9.91 ± 0.29 | 1.55 ± 0.05 | 2.58 ± 0.16 | 111 ± 3 | 15 | 43 ± 3 |
| SDG1-09-OSL3 | L1655 | 7 | 2.48 ± 0.1 | 9.89 ± 0.29 | 1.68 ± 0.06 | 2.71 ± 0.17 | 113 ± 3 | 18 | 42 ± 3 |
| SDG1-09-OSL4 | L1656 | 7.6 | 2.18 ± 0.1 | 8.96 ± 0.27 | 1.59 ± 0.07 | 2.5 ± 0.16 | 115 ± 2 | 29 | 46 ± 3 |
| SDG1-13-OSL4 | L2361 | 7.6 | 2.7 ± 0.1 | 9.09 ± 0.27 | 1.61 ± 0.06 | 2.64 ± 0.16 | 91 ± 4 | 9 | 35 ± 3 |
| SDG1-13-OSL5 | L2362 | 8.1 | 2.71 ± 0.1 | 9.53 ± 0.28 | 1.64 ± 0.06 | 2.69 ± 0.17 | 94 ± 6 | 8 | 35 ± 3 |
| SDG1-13-OSL6 | L2363 | 8.6 | 2.56 ± 0.1 | 10.4 ± 0.29 | 1.72 ± 0.06 | 2.78 ± 0.17 | 91 ± 5 | 9 | 33 ± 3 |
| SDG1-13-OSL7 | L2364 | 9.1 | 2.71 ± 0.1 | 11.7 ± 0.32 | 1.93 ± 0.06 | 3.07 ± 0.19 | 100 ± 2 | 9 | 33 ± 2 |
| SDG1-13-OSL8 | L2365 | 9.6 | 2.82 ± 0.11 | 11.6 ± 0.31 | 1.75 ± 0.06 | 2.94 ± 0.18 | 115 ± 6 | 8 | 39 ± 3 |

Note: Height values of the samples are relative to the ground surface.

OSL data published by Liu et al. (2009) is considered questionable and younger than the AMS $^{14}$C dates. This also happened in SDG Locality 2 for some unknown reason (Liu et al., 2009; Li et al., 2013a, 2013b). The Conv. $^{14}$C age of the sample from the lower cultural layer was 25450 ± 800/26230 ± 800 BP (Li et al., 1987), which is younger than the results by other methods. The ages obtained by the $^{14}$C method are thought to give a more reliable estimate of the ages in general, however, many results produced over the last 50 years are underestimates of their real ages caused by pre-treatment of samples for dating and the selection of material (e.g. Bird et al., 2002; Higham, 2011). Our OSL dating results of the samples from southwest section at SDG 1 were close to the U-series (Chen et al., 1984) and AMS $^{14}$C data (Peng et al., 2012), and the ages are between ca. 33 ka and 39 ka. The four OSL dates of the samples from north section at SDG 1 yielded ages ranging from ca. 42 ka to 46 ka, which are older than the chronologies by previous studies and the ages of the samples from southwest section. Based on the above data, the ages of Late Palaeolithic deposites at SDG 1 are varied from 22 ± 2 ka to 46 ± 3 ka.

SDG 2 is located on the opposite bank of the Biangou River, and less than 100 m from SDG 1. The sequence at SDG 2 was divided into a series of substrata and contained 7 cultural-bearing horizon layers from the top to the bottom (CL1–CL7) (Liu et al., 2009; Li et al., 2013a). Lower CL-B of SDG 1 (Fig. 2a) contained an assemblage of large blades, which was also found at CL7 (edge-faceted blade core), and CL5a contained a Levallois-like flat-faced core. The age of these layers was in the range of ca. 33–34 ka for CL5a, and ca. 34–41 ka for CL7. On this basis, a macroblade technology may have arrived at SDG 2 at ca. 41–34 ka from Mongolia or Siberia (Li et al., 2013a).

The rate and timing of the spread of the Upper Palaeolithic blade industry in North China is essential for understanding the dispersals of early modern humans across northeast Asia. The proposed route for the dispersal of modern humans in Asia was from Siberia and Mongolia, and into northern China (see e.g. Madsen et al., 2001; Gao et al., 2002; Derevianko, 2011). The earliest recorded blade-based Upper Paleolithic technocomplex in Siberia at Kara-Bom is ca. 43 ka (Derevianko et al., 2000), and the earliest record in Mongolia is dated to >41,050 BP (AA-79326) and 37,400 ± 2600 BP (AA-79314) by radiocarbon dating (Gladyshev et al., 2010). The present $^{14}$C data are limited and may be in need of reconsideration due to the limitation of the experimental methods and material (see e.g. Bird et al., 2002; Higham, 2011), so with the development of different dating techniques, some old dating data should be treated with caution.

With the re-evaluation of SDG 1, based on OSL dating, the first appearance of large blade technology can be dated back to as early as ca. 43 ka, and therefore a Levalloisian-blade technology may have appeared in the Shuidonggou area earlier than indicated in previous studies. The groups of *Homo sapiens* with a blade technology probably dispersed to the Shuidonggou area from the west, however, the presence of a blade technology at Shuidonggou area seems to have had no impact on the local tradition of core-and-flake technology, and this may reflect a complicated and dynamic pattern of migration, adaptation and biological interaction during the last glaciation (see e.g. Gao et al., 2002, 2013). The main weakness of investigations at SDG 1 is the lack of detailed stratigraphic information about the precise stratigraphic context of

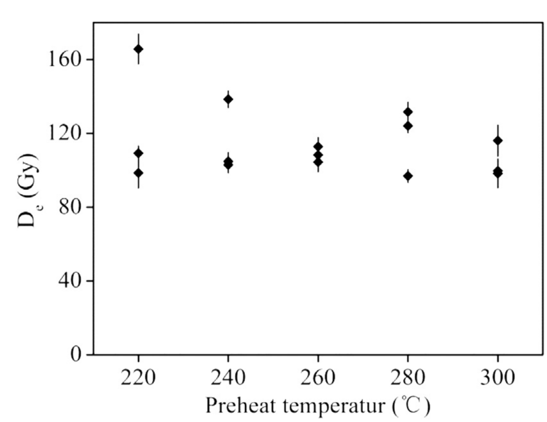


**Fig. 5.** $D_e$ values for sample L1654 as a function of preheat temperature.

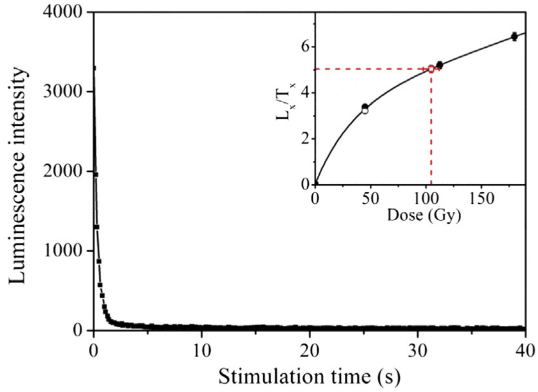


**Fig. 6.** Quartz OSL decay curve of sample L2365; the inset figure shows dose–response curve obtained with the quartz SAR protocol for the corresponding sample L2365.

Paleolithic remains, because earlier studies usually assumed that all the artifacts were from the same horizon and from within the same period of time. Further excavation together with stratigraphic analysis is therefore required to clarify the exact position of the artifacts at SDG 1.

## 5. Conclusion

The ages of SDG 1 have been determined using the OSL technique, yielding ages from 33 ± 3 ka to 39 ± 3 ka for the samples from the southwest section excavated in 1963, and from 43 ± 3 ka to 46 ± 3 ka for the samples from the north section excavated in 1980. The age of the cultural layer at SDG 1 is within the range of ca. 22 ka–46 ka. The OSL ages obtained from the medium-grained quartz fraction are internally and stratigraphically consistent within errors, and agree well with newly calibrated AMS $^{14}$C date, indicating the complete bleaching of quartz OSL signals and the reliability of OSL age estimates.

Based on our OSL dates, a large blade technology appeared ca. 43 ka in the Shuidonggou area, somewhat earlier than indicated by previous dates, and had no obvious impact on local core-and-flake technology. This appears to indicate the persistence of a local cultural development, and a complex trajectory of dispersal and interaction by early *H. sapiens*. Systematic excavation is needed to establish the precise stratigraphic information of the lithic assemblages in order to understand the technical characteristics of the artifacts in the Shuidonggou area and their connection with the early Upper Paleolithic industries of Eurasia.

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