Chinese Science Bulletin

Progress in the stratigraphy and geochronology of the Shuidonggou site, Ningxia, North China

LIU DeCheng[1,2†], WANG XuLong[3], GAO Xing[1,2], XIA ZhengKai[4], PEI ShuWen[1,2], CHEN FuYou[1,2] & WANG HuiMing[5]

[1] Institute of Vertebrate Paleontology and Paleoanthtopology, Chinese Academy of Sciences, Beijing 100044, China;
[2] The Joint Laboratory of Human Evolution and Archaeometry, Chinese Academy of Sciences, Beijing 100044, China;
[3] LLQG, Institute of Earth Environment, Chinese Academy of Sciences , Xi'an 710075, China;
[4] College of Urban and Environmental Sciences, Peking University, Beijing 100871, China;
[5] Institute of Archeology of Ningxia Hui Autonomous Region, Yinchuan 750001, China.

In the past years we carried out further stratigraphy division in field and it is found that rich stone artifacts can be found in fluvial-shallow lake-alluvial sediments on the terrace II of Biangou River, in Shuidonggou site, Ningxia and they are SDG1, 2 and 7. More luminescence and AMS ^{14}C dating in laboratory show that Paleolithic culture develops during the Upper Paleolithic period with ages of 35—20 ka. The Paleolithic culture of SDG 1 is a little earlier than that of SDG 2 similar to SDG 7. The sandy sediments on terrace II of Biangou River deposits in the past 72—18 ka, corresponding to Last Glacial. SDG2 has a stable sedimentary environment, resulting in the continuous stratigraphy, thickest deposits and rich environment and culture information, which can be regarded as the important and classic paleoanthropological section of Late Pleistocene in this region.

Shuidonggou site, luminescence dating, stratum correlation, depositional environment, Upper Paleolithic

Several excavations have been carried out in SDG site since it was first discovered in 1923, and unearthed rich cultural remains of the Paleolithic[1−3]. Domestic and internatinal scholars have paid extensive attention to the cultural properties and also its geochronology. The western scholars have ascribed it to the western cultural system of Paleolithic, a status between the developed Mousterian and developing Aurignacian culture[4]. In the early stage of researches Chinese scholars regarded the SDG site as the Middle Paleolithic, and then regarded it as the Upper Paleolithic site according to updated material[5]. Along with the wide application of radiocarbon and Uranium series dating technique, 6 ages were obtained from SDG1 which shoesit belongs to the late Pleistocene[6,7]. In the summer of 1999—2000, Sino-American archaeologists and geologists had made a further survey in SDG site, and obtained 8 samples of charcoal and ostrich eggshell from the second cultural layer of SDG Site 2, and the AMS ^{14}C dating is 29—24 ka BP, SDG site was further ascribed to the early stage of the Upper Paleolithic[8,9]. However, previous studies of both strata and dating focused on the SDG1, no intensive linkage among different sites has been carried out, and also the duration of cultural development is still inexplicit. To understand the stratigraphic characteristics and geomorphic evolution process, we conducted extensive investigation of the landform and Quaternary environment in the SDG region, took 22 OSL and 2 ^{14}C samples in SDG1, 2 and 7 to construct the timescale for this region, compare and intensively divide the stratigraphy in SDG site.

Received July 2, 2009, accepted September 7, 2009
doi: 10.1007/s11434-009-0652-y
†Corresponding author (email: liudecheng@ivpp.ac.cn)
Supported by the National Basic Research Program of China(Grant No. 2006CB806400), Basic Scientific Special Program of MST of China (Grant No. 2007FY110200) and National Natural Science Foundation of China (Grant No. 40602020)

Citation: Liu D C, Wang X L, Gao X, et al. Progress in the stratigraphy and geochronology of the Shuidonggou site, Ningxia, North China. Chinese Sci Bull, 2009, 54: 3880—3886, doi: 10.1007/s11434-009-0652-y

1 General geographic situation

The SDG site (38°17′N, 106°30′E, 1200 m in height) at Lingwu city, 28 km southeast of the Yinchuan, Ninxia, 18 km west of the Yellow River, is located in the eastern edge of Yinchuan basin, and the south part of Mu Us Desert, which belongs to the semiarid desert grassland environment (Figure 1).

The Biangou River goes through from north to south in SDG area, and finally into the Yellow River. SDG site distributes in both sides of downstream of Biangou River, and several sites have been excavated in past years, among them, SDG1, 2 and 7 have been studied before, and their profile is fully outcropped that is easy for field working. In this region 6 terraces have been found and our field investigation found that most of SDG culture relics are deposited on Terrace II, and its deposit is mainly power sand (Figure 2).

2 Strata dividing and comparison

Field observation suggested that the strata at the archaeological sites are mainly composed of deposits from braided river, shallow lake and lakeshore. The strata are described in details as below, based on sedimentology and characteristics of the remains.

2.1 SDG1 strata

This exposure was first excavated in 1980, with the thickness of about 15 m. 8 substrata include Late-Pleistocene fluvial-lacustrine deposits and Holocene lacustrine bog deposits. The bedrock is late Tertiary reddish-brown mudstone (Figure 3(a)).

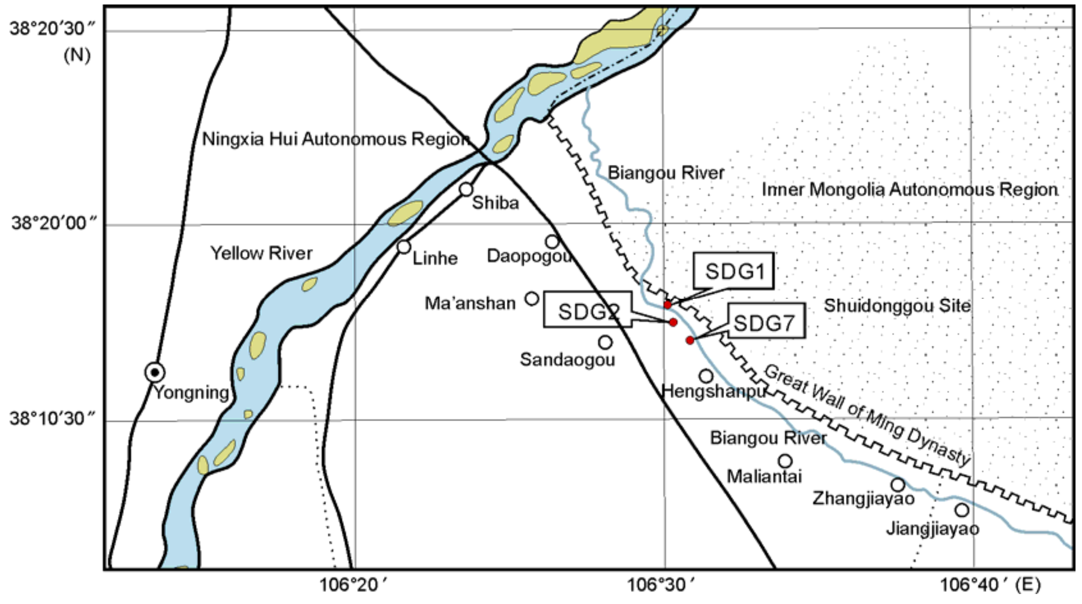

Figure 1 The geographic position of the Shuidonggou site.

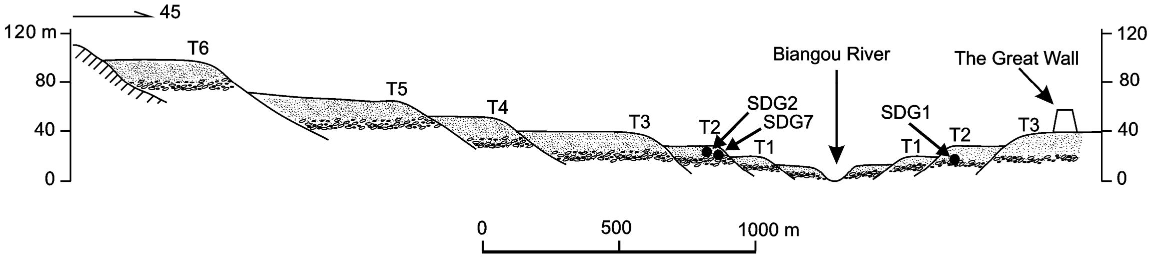

Figure 2 The sketch of Quaternary geomorphy in the Shuidonggou region.

Upper part: Holocene

1. Yellowish green, grayish green silt or clay-rich silt, planar bedding. At least 7 black bands of peat. Thickness of the bands varies from 1 to 20 cm. Redoximorphic features of mottles developed. Coarser at the bottom, grayish yellow very fine sand. Oblique and wavy bedding. Contains thin lenses of gravels. Contains Neolithic antiques such as grinding stone tools, pottery pieces. Holocene deposits. 6 m
2. Mainly sand and gravel. Gravels are mainly limestone, siliceous limestone, and reddish quartz sandstone, with a small quantity of siliceous dolomite, French grey quartz sandstone. Gravels are mainly subangular; 3—10 cm in size, with the maximum of 30 cm, erosional contact on the underlying strata; the contact boundary is wavy, with clear evidence of erosion. 0.5 m

Lower part: Late Pleistocene

3. Grayish yellow silt, blocky structure, calcareous cement with some nodules, firm. Contains Upper Paleolithic stone artifacts and animal fossils, etc. 0.9 m
4. Grayish yellow silt, blocky structure, a few redoximorphic mottles. Contains Upper Paleolithic artifacts and animal fossils, etc. 2.8 m
5. Grayish yellow fine sand, coarse sand, plainar bedding. Contains artifacts, charcoal and animal fossils, etc. 0.4 m
6. Light grayish yellow silt, planar bedding, redoximorphic mottles. 1.9 m
7. Sand and gravel. Gravels are mainly limestone and reddish sandstone. 3—20 cm in size, subangular, erosional contact on the underlying strata. 0.8 m
8. Red mudstone, blocky structure, mud cracks developed. Thin layers of gympus locally. Not to bottom. 1.7 m

2.2 SDG2 strata

This site is interpreted as mainly lacustrine peat deposits. Strata of total thickness of 12.5 m include: the base, fine sand and gravel; the bottom, grayish black peat deposit; middle, light grayish green silt; and top, light grayish yellow silt (Figure 3(b)). 18 substrata are described as the following:

1. Grayish yellow silt, modern surficial loose silt. 0.2 m
2. Brownish yellow silt, blocky structure. 0.96 m
3. Grayish white silt, blocky structure, firm, planar bedding. Contains clay or calcium-rich aggregates, less than 5 cm in size, band in shape in some places, no regular pattern in distribution, with a few redoximorphic mottles and granular charcoals between 2.7—3.5 m. 2.34 m
4. Light yellow silt, contains stone artifacts, animal fossils and ashes, Upper Paleolithic, first cultural layer of SDG2. 0.14 m
5. Light yellow silt, blocky structure, planar bedding, some grayish white calcareous silt-clay aggregates, with the diameter of 5 cm. 1.12 m
6. Light yellow silt, contains stone artifacts, animal fossils and ash, Upper Paleolithic, second cultural layer of SDG2. 0.44 m
7. Grayish yellow silt, compact block, planar bedding with a few redoximorphic mottles. 0.56 m
8. Light yellow silt, contains stonewares, animal fossils and ash, Upper Paleolithic, third cultural layer of SDG2. 0.1 m
9. Light Grayish yellow silt, blocky structure, planar bedding with a few redoximorphic mottles. 0.44 m
10. Light yellow silt, contains chipped stone tools, animal fossils and ash, Upper Paleolithic, fourth cultural layer of SDG2. 0.1 m
11. Light Grayish yellow silt, blocky structure, planar bedding with a lot of redoximorphic mottles, some calcareous aggregates. 0.5 m
12. Grayish yellow silt, blocky structure, planar bedding with a lot of redoximorphic mottles. 0.5 m
13. Light yellow silt, contains stone artifacts, animal fossils and ash, Upper Paleolithic, fifth cultural layer of SDG2. 0.3 m
14. Light Grayish yellow silt, blocky structure, planar bedding with a lot of redoximorphic mottles, some calcareous aggregates. 0.6 m
15. Grayish green silt, blocky structure, planar and wavy bedding with a lot of redoximorphic mottles, some calcareous aggregates. 2.2 m
16. Grayish black peat, blocky, rumpled. Wormhole developed. A lot of plant remnants and small amount of gastropod, a few stone artifacts and animal fossils. 0.9 m
17. Grayish yellow silt and very fine sand, planar bedding, coarsening downward. Irregular upper and lower boundaries. 0.4 m
18. Gravel layer, mainly limestone, quartzite. Poorly sorted, poor rounded. Iron stains at the gravel surface. Can find reddish clay. Not to bottom. 0.7 m

2.3 SDG7 strata

SDG7 site was excavated from 2003—2005, thus exposing a complete section. Total thickness is 12 m and can be divided into 11 substrata, mostly Late Pleistocene fluvial-lacustrine deposits (Figure 3(c)).

1. Yellowish silt, loose, modern regolith. 0.1 m
2. Light grayish yellow silt, compact block, wavy bedding, and lower boundary is irregular. 1.1 m
3. Grayish white silt, blocky, calcareous cemented, firm. Planar bedding upper and wavy bedding lower. 1.45 m
4. Yellowish silt, Blocky, wavy bedding, some mottles. Irregular contact with strata above and below it. 0.35 m
5. Yellow or brownish yellow silt, planar bedding, some grayish white clay-rich silt aggregates. 0.6 m
6. Light grayish yellow silt, compact block, bedding not clear, grayish white silt band developed, wavy contact with the underlying stratum. 3.35 m
7. Grayish yellow silt, compact block, planar bedding, irregular contacts. 0.6 m
8. Light grayish yellow silt, blocky, planar and wavy bedding, contains carbonate nodules at the bottom. Grayish white silt band developed, horizontal, 40 cm long, 5 cm thick. Stone artifacts and animal fossils found at 8.50—8.75 m, Upper Paleolithic. 1.2 m
9. Light grayish yellow silt, compact blocky, firm, contains some black gray silt. 1.1 m

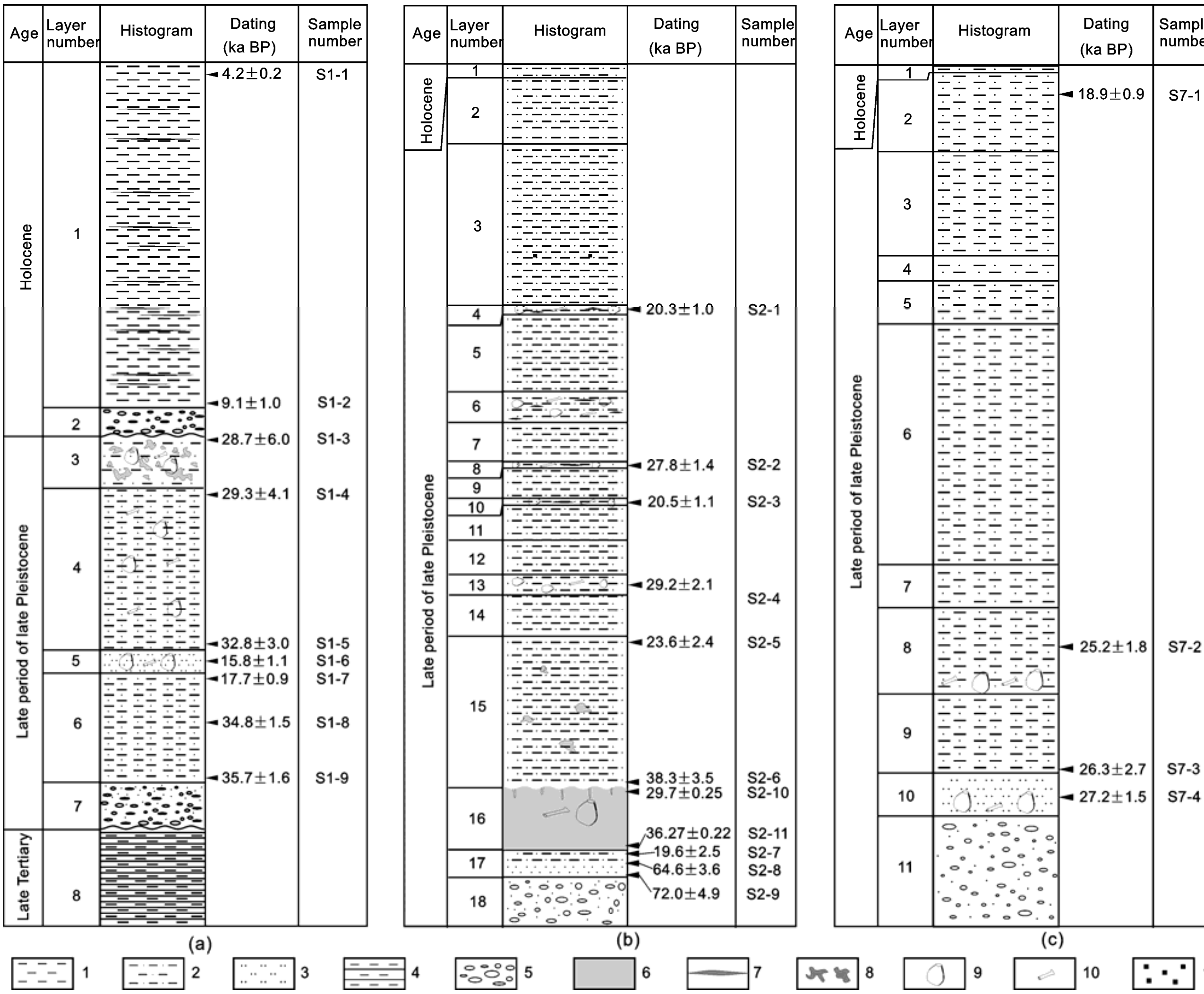

Figure 3 Strata and dating position of Shuidonggou site. 1, clay-rich silt; 2, silt; 3, fine sand; 4, mudstone; 5, gravel; 6, peat; 7, peat band; 8, carbonate nodule; 9, stone artifact; 10, animal fossil; 11, charcoal.

10. Light gray very fine sand, with a lot of stone artifacts and animal fossils, Upper Paleolithic. 0.6 m
11. Gravel layer, mainly limestone, quartz sandstone. Some gravels are 25 cm in diameter. Not to bottom. 1.55 m

2.4 Stratigraphic correlation

The strata at SDG can be classified into two units, representing different depositional environment. Upper part is mainly silt deposit, with the development of planar bedding and wavy bedding. Mire is developed, showing grayish green and grayish yellow in color; it is organic matter rich. All of above suggest hydrodynamically low-energy lake marsh or lakeshore environments. Lower part is imbricated thick gravel layer. Above the gravel layer is the fine sand or coarse sand with planar and cross bedding developed, indicating hydrodynamically high-energy fluvial environment. The upper part contains multiple phases of cultural layers, suggesting multiple times of human activity. Holocene lake-marsh deposit developed at upper part of SDG1; showing erosional contact on the underlying strata, thick gravel layers was deposited in early Holocene. In contrast, SDG2 and SDG7 were deposited mainly during late Pleistocene, without Holocene sediments overlying them, suggesting the Biangou River incised during late Pleistocene or early Holocene. Thus, no fluvial-lacustine sediments were preserved at SDG2 and SDG7 sites. The incision eroded part of old deposits of SDG1, and lake marsh were developed due to backwater during early to mid-Holocene. Thus, the lower parts of sediments are similar to other sites. SDG2 and SDG7 are close in distance, and the same strata can be traced and correlated, possibly deposited at the similar time. The three sites, SDG1, SDG2 and SDG7, are all located on the same geomorphic unit: the terrace Ⅱ of the Biangou River, late Pleistocene.

The Paleolithic cultural layer at SDG1 is buried at the bottom of the section; the cultural layer at SDG2 is at the middle of the section; it is at the middle and bottom section at SDG7. Based on their positions in the sections, we tentatively suggest that SDG1 cultural layer is earlier than SDG2, which is similar to SDG7. Absolute dating will give more definite results on this issue.

3 Geochronology

In order to get the independent ages of the cultural layer and the strata, systematic sampling and measurements were performed on SDG sites. Both OSL and radiocarbon dating are used: OSL samples were run in the Luminescence Dating lab, the Institute of Earth Environment, Chinese Academy of Sciences, and AMS radiocarbon dating was done in the radiocarbon dating lab in the Peking University.

3.1 Dating results

24 samples were taken for age determination, including 22 OSL and 2 radiocarbon samples. 9 OSL samples are from SDG1, 9 OSL samples are from SDG2 with 2 AMS radiocarbon samples, and 4 OSL samples from SDG7. The results show that the ages are mostly in the stratigraphic order, and the same stratigraphic units can produce consistent ages (Tables 1 and 2).

OSL samples were tested in 2006, and then more samples (in Table 1 sample No. with #) were obtained and dated in 2008. Equivalent dose was measured using multiple aliquot regeneration dose protocol for fine-grained quartz[10] and single aliquot regeneration dose protocol for coarse quartz[11]. For regeneration dose the preheating condition is 260℃ for 10 s and for test dose it is 220℃ for 10 s. Table 1 presented all dating results and it is found that the 22 OSL data range from 4.2 ± 0.2 ka B.P. to 72.0 ± 4.9 ka B.P., indicating late Pleistocene to mid-Holocene in age. The upper part of SDG1 was deposited early to mid-Holocene (9－4 ka B.P.), and the

Table 1 Luminescnece dating results in SDG sites

Filed No.	U (ppm)	Th (ppm)	K (%)	Dose rate (Gy/ka)	ED value (Gy)	Age (ka B.P.)
S1-1#	5.36±0.16	10.32±0.31	1.68	4.22±0.17	17.5±0.6	4.2±0.2
S1-2#	2.32±0.07	10.32±0.31	1.50	3.14±0.11	28.7±2.9	9.1±1.0
S1-3	2.37±0.09	10.13±0.23	2.00	3.30±0.14	94.8±19.3	28.7±6.0
S1-4#	2.38±0.07	11.43±0.34	1.75	3.48±0.12	101.8±14.0	29.3±4.1
S1-5#	2.41±0.07	11.37±0.34	1.92	3.64±0.12	119.4±10.2	32.8±3.0
S1-6#	2.30±0.07	11.56±0.34	1.85	3.55±0.12	56.2±3.2	15.8±1.1
S1-7#	2.18±0.07	10.62±0.32	1.84	3.42±0.12	60.6±2.4	17.7±0.9
S1-8	2.38±0.10	11.63±0.27	2.10	3.51±0.15	121.9±0.8	34.8±1.5
S1-9	2.36±0.09	10.75±0.24	2.04	3.38±0.14	120.8±1.6	35.7±1.6
S2-1	2.92±0.11	12.51±0.28	2.08	3.72±0.17	75.3±1.5	20.3±1.0
S2-2	2.82±0.11	11.18±0.25	2.10	3.60±0.16	100.1±2.4	27.8±1.4
S2-3	2.88±0.12	11.92±0.26	2.17	3.73±0.17	76.6±2.1	20.5±1.1
S2-4	2.89±0.13	12.74±0.28	2.18	3.81±0.17	111.0±6.1	29.2±2.1
S2-5#	3.36±0.10	11.93±0.36	1.79	3.86±0.14	91.1±8.6	23.6±2.4
S2-6#	2.87±0.09	11.69±0.35	1.82	3.71±0.13	142.1±12.0	38.3±3.5
S2-7#	2.74±0.08	11.79±0.35	2.11	3.94±0.14	77.5±9.5	19.6±2.5
S2-8	2.53±0.11	10.23±0.23	2.10	3.44±0.15	222.0±7.8	64.6±3.6
S2-9#	1.99±0.06	9.79±0.29	1.76	3.23±0.11	232.1±13.8	72.0±4.9
S7-1	2.51±0.11	11.23±0.25	2.18	3.58±0.15	67.6±1.0	18.9±0.9
S7-2	4.99±0.16	15.64±0.34	2.05	4.54±0.23	114.3±5.5	25.2±1.8
S7-3	5.01±0.16	13.16±0.29	2.00	4.30±0.22	113.±10.2	26.3±2.7
S7-4	3.75±0.14	11.84±0.26	2.18	3.98±0.19	108.3±2.5	27.2±1.5

Table 2 AMS C^{14} dating results in SDG 2

Field N.	Material	Radiocarbon age (a B.P.)	Layer
S2-10	Peat	29759±245	SDG 2, upper part of layer 16
S2-11	Twig	36329±215	SDG 2, down part of layer 16

lower units were from 28.7 ± 6.0 to 35.7 ± 1.6 ka B.P. (Figure 3(a)). SDG2 site yields the age range of 72.0 ± 4.9—20.3 ± 1.0 ka B.P., suggesting that it is late Pleistocene deposits; only the uppermost of section has thin layer of modern weathered loose sediments (Figure 3(b)). SDG7 is dated as 18.9 ± 0.9—27.2 ± 1.5 ka B.P., belonging to late Pleistocene (Figure 3(c)).

Two samples were took from the upper and under-part of turf in SDG 2 section, and their AMS radiocarbon ages were 30 and 36 ka B.P.

3.2 Dating result analysis

Generally the strata build up from the old to young. The age can be disturbed by tectonic movement, landslide, freeze-thaw and bioturbation. The three sections in this study show planar bedding, showing undisturbed depositional environment. Thus, stratigraphic correlation in the field will have no problems, but age reversal is possible in the absolute dating, possibly due to the complicated deposition process in ancient ruins**.**

9 samples from SDG1 clustered in two groups: one in early and mid-Holocene by S1-1 and S1-2, and the other in the Late Pleistocene by S1-3, S1-4, S1-5, S1-8, S1-9. S1-6 and S1-7 are rejected, because both are less than 18 ka B.P., much lower than the average of 30 ka B.P. (Figure 4(a)).

The data in SDG2 are earlier than the Holocene. S2-7 one is younger than most of them, so it is considered as outlier and thus rejected. The rest 8 samples cluster at 2 groups: one in 41.8—19.3 ka, produced by S2-1—S2-6 and S2-10—S2-11, and the other in 76.9—61 ka, produced by S2-8 and S2-9. Ages scatter from this section, so we use age group, instead of individual age, for further discussion (Figure 4(b)). Three data from SDG7 are in stratigraphic order, showing linear relationship for age-depth plot (Figure 4(c)).

Based on ages of the deposition units, we further determine the timing of the cultural layers. Cultural layers of SDG1 formed from 34.8 ± 1.5 ka B.P. to 28.7 ± 6.0 ka B.P., cultural layers of SDG2 formed from 29.2 ± 2.1 ka B.P. to 20.3 ± 1.0 ka B.P., and cultural layers of SDG7 formed at about 27.2 ± 1.5 ka B.P. In summary, the Paleolithic cultural layers at SDG were 35 to 20 ka B.P. In addition, a few chopping tools were found in the mire at the bottom of SDG2, in the strata dated back to 36 to 30 ka, which is possibly the same deposit of the SDG1 paleolithic cultural layer.

4 Conclusions and discussion

4.1 Conclusions

Stratigraphic division and dating results on the type section at SDG site suggest:

(1) The Paleolithic relics at SDG site are buried in the fluvial-lacustrine sediments of Biangou River terrace II. There were multiple archeological activities with long-lasting time. The cultural activities were from 35 to 20 ka B.P., a late Paleolithic Age, which is older than what it is previously concluded[12].

(2) Both field stratigraphic correlation and dating indicate SDG1 cultural layers are slightly earlier than those of SDG2, which are similar in age to SDG7.

(3) SDG2 can be regarded as typical profile of SDG sites in late Pleistocene. It is composed of continuous,

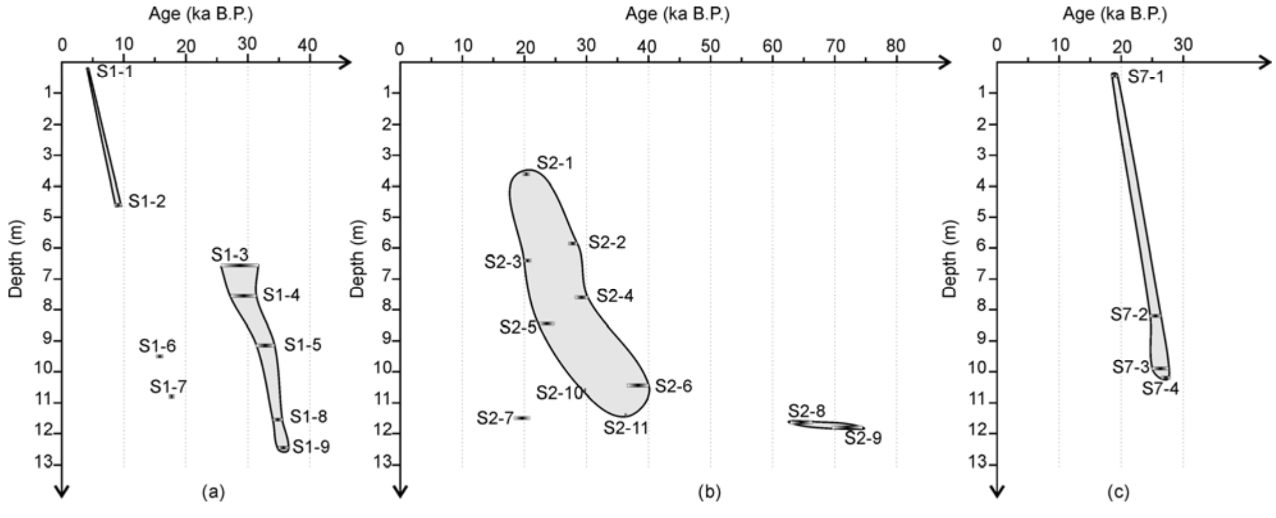

Figure 4 Age-depth plot. (a) SDG1, (b) SDG2(2), (c) SDG7.

thick deposits, with the distinct variation of the depositional environment. Multiple layers of Paleolithic culture were preserved, recording rich information on paleoenvironment and early human activities. The sediments were deposited from 72.0 ± 4.9 ka to the end of the Pleistocene, covering a long time period.

4.2 Discussion

The strata preserving the Paleolithic cultural relics are mainly shallow lake and lakeshore deposits, which generally has planar, wavy or cross beeding. The sediments are grayish green or light grayish green in color, and some aquatic shells were scattered. Gravel lense is imbricated, interpreted as alluvial fan deposits. The uppermost part of strata are grayish yellow, without bedding, indicating the shrinkage of paleolake at SDG.

At the end of the late Pleistocene, Terrace Ⅱ formed, suggesting river incision. Lake marsh was deposited where backwater presented. Another distinct downcutting was in late Holocene. Both geomorphic events correspond to climatic transition, suggesting some linkage to the late Quaternary climate change.

Human activities flourished in the late MIS3, a time period of warm-wet climate worldwide[13,14]. In northern China it also experienced similar warm-wet climatic condition[15–18], thus the bloom of human activities at SDG may be related to the paleoclimate.

Thanks were given to Zhangxiaoling, Zhang Yue, Zhang Shuangguan, Ma Xiaoling, Guan Ying, Zhou Zhengyu, Ma Ning, Peng Fei, Wang Chunxue, Zhang Dongju, Mei Huiji and Zhu Zhiyong for their help in field investigation and sampling in the excavation of 2004 —2007.

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