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Optical dating of the Jingshuiwan Paleolithic site of Three Gorges, China

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Abstract The Jingshuiwan Paleolithic site occupies the second terrace on the right bank of the Yangtze River. The lithic assemblage is characterized by choppers and scrapers made on pebbles and large flakes——the typical lithic industry of South China. Deposits of the site are mainly composed of fluvial sediments. Quartz grains extracted from these fluvial sediments from which the artifacts were uncovered were dated using the optically stimulated luminescence/single-aliquot regenerative-dose technique. The dating results show that ancient human activities at this site took place in the early Upper Pleistocene (ca. 70 ka). The successful age analysis of the Jingshuiwan site is considered as a major breakthrough in chronological analysis of Paleolithic open site in the Three Gorges region and even in South China. The dates obtained help to establish a more complete chronological framework of the Paleolithic cultural sequence in the region, and bear significant implications in studying modern human origins in China.

Keywords: Three Gorges region, Jingshuiwan Paleolithic site, optical dating, fluvial terrace, modern human origin.

The Three Gorges region is located in the transitional zone between the upper and middle reaches of the Yangtze River, known as an important area for studying human origins and cultural developments in China. In the mid 1990s, a large scale Paleolithic reconnaissance was launched in this region as part of the salvage archaeological project and 69 sites with lithic artifacts and animal fossils were discovered on the fluvial terraces of the Yangtze River[1]. Since 1995, 17 sites have been excavated by a joint archeological team consisting of archaeologists from the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences and the Chongqing Museum of Natural History, and a wealth of archeological remains and animal fossils have been unearthed, making the Three Gorges region a rich and important area in Paleolithic archaeological research in China and East Asia. The sites provide valuable data and information for studying ancient human technology, behavior, adaptation and paleoenvironmental change in the region during the late Pleistocene[2]. Among them the Jingshuiwan site is one of the most important Paleolithic sites characterized by the largest excavated area, the longest excavation seasons, and the most abundant cultural remains recovered in the region[3].

The Jingshuiwan site is an open-air site and is located on the second terrace of the right bank of the Yangtze River. It possesses the thickest sediment layers among the Paleolithic sites in the Three Gorges region and has a relatively complete stratigraphic section. However, for a long time, the archaeological team failed to obtain a reliable date for the site because there were no suitable dating materials such as organics and well-crystallized carbonate concretions for radiocarbon and U-series analyses. The recent development of optically stimulated luminescence dating (optical dating) techniques provides a possible tool for dating this site.

Currently, optical dating method has been widely applied to date Quaternary sediments[4], especially, in the case of organics-poor strata and cultural horizons beyond 40ka. The advantage of this dating method is evident[5－7]. This technique uses quartz or feldspar grains from sediments as dosimeters to record the radiation dose from the sample and its environments. In the laboratory, the intensity of optically stimulated luminescence (OSL) signals from a sample is measured, and used for estimating the radiation dose accumulated from its last exposure to daylight. This dose is termed paleodose or equivalent dose (D_e). Optical ages were calculated by dividing equivalent dose by dose rate (the dose per year). They represent the duration of burial of the sample because of its last exposure to light. The deposits from the Jingshuiwan site are fluvial and suitable sandy materials can be collected from the cultural horizons. In this paper, the techniques and procedures of dating these fluvial sediments using the optical method are reported, preliminary results are presented, and archaeological implication and significance are discussed.

1 Geology and cultural remains

The Jingshuiwan site is located near Xinwan Village, Sanhe Town, Fengdu County of Chongqing at the right bank of the Yangtze River (29°52′38″N; 107°43′05″E) (Fig. 1). The site was discovered on March 19, 1994, and was excavated during 1998—2002 for five successive seasons, exposing an area of about 2121 m^2. The site is buried in the second terrace of the Yangtze River. The base of the terrace consists of Jurassic feldspar sandstone, siltstone and shale, being nearly in the absence of gravel layer of bed phase, with a few pebble reserved in the depression of the river bed. The upper section is composed of fluvial deposits mainly clayey silver sand and silt lam, and 16 m in thickness. The altitude of the anterior margin of the terrace is 168 m above the sea level, which overtop the Yangtze water level by 42 m. The stratigraphic sequence of the site may be described from top to bottom as follows (section A):

1. Gray cultivated layer 0.5 m
2. Yellow silt lam interbedded with maroon lam, with several carbonate concretions interlayers 5—8 m
3. Yellow silt lam in the upper and maroon lam in the lower part 2.5 m
4. Carbonate concretion interbedded with yellow silver sand 1.2 m
5. Yellow silt lam, with horizontal bedding in the part layer 2.0 m
6. Hoar carbonate concretion, with grayish yellow gravel interbedded with silty sand in the lower part 1.5—2.0 m
7. Yellow-gray sandy silt and silty sand, with prunus clay interbedded in the bottom part, with a few pebble reserved in the depression of the bedrock. Most lithic artifacts and mammalian fossils were unearthed from the layer 0.5—2.0 m

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8. Jurassic feldspar sandstone, siltstone, argillaceous siltstone and shale

About 968 cultural remains were excavated from the site, including 910 lithic artifacts and 58 mammalian fossils. The lithic assemblage includes 304 cores, 382 flakes, 118 retouched tools, 102 chunks and 4 stone hammers. Stone raw materials exploited at the site were pebbles, locally available from ancient riverbeds. Predominant types (85.8%) of the lithic assemblage are cores, flakes and chunks, and only a small portion (12.9%) is retouched tools. Choppers and scrapers are the dominating tool types, followed by points and notches.

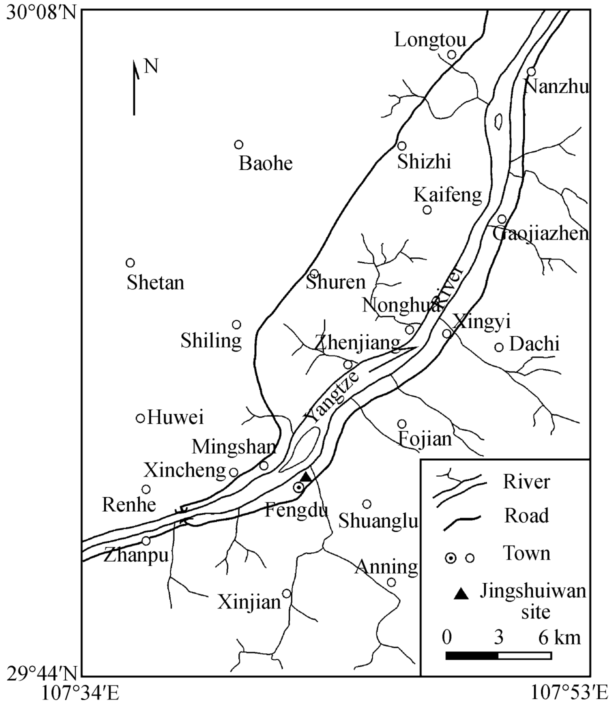

Fig. 1. Map showing the location of the Jingshuiwan Paleolithic site.

Because of the acid soil commonly encountered in South China, mammalian fossils unearthed from the site are mostly fragmental; only some teeth and large mammalian bones are relatively complete. Identified species include *Stegodon orientalis*, Cervidae and Bovidae, belonging to the *Ailuropoda-Stegdon* fauna typically found in South China during the Middle and Late Pleistocene.

2 Chronological analysis

2.1 Sampling and sample preparation

Samples for optical dating were taken from cultural and overlying layers in profiles A and B in 2000 and 2001 (Fig. 2). These two profiles are the western and eastern walls of the excavation pit respectively and are 40 m apart, clearly exhibiting the same stratigraphic sequence. Samples were collected by pushing opaque PVC tubes into freshly cleaned sections. The tubes were completely filled with sediments in order to avoid materials mixing during transport. After being removed from the section, the tubes were immediately sealed tightly at both ends with plastic tapes in order to prevent light exposure and water loss.

Under subdued red light in the laboratory’s dark

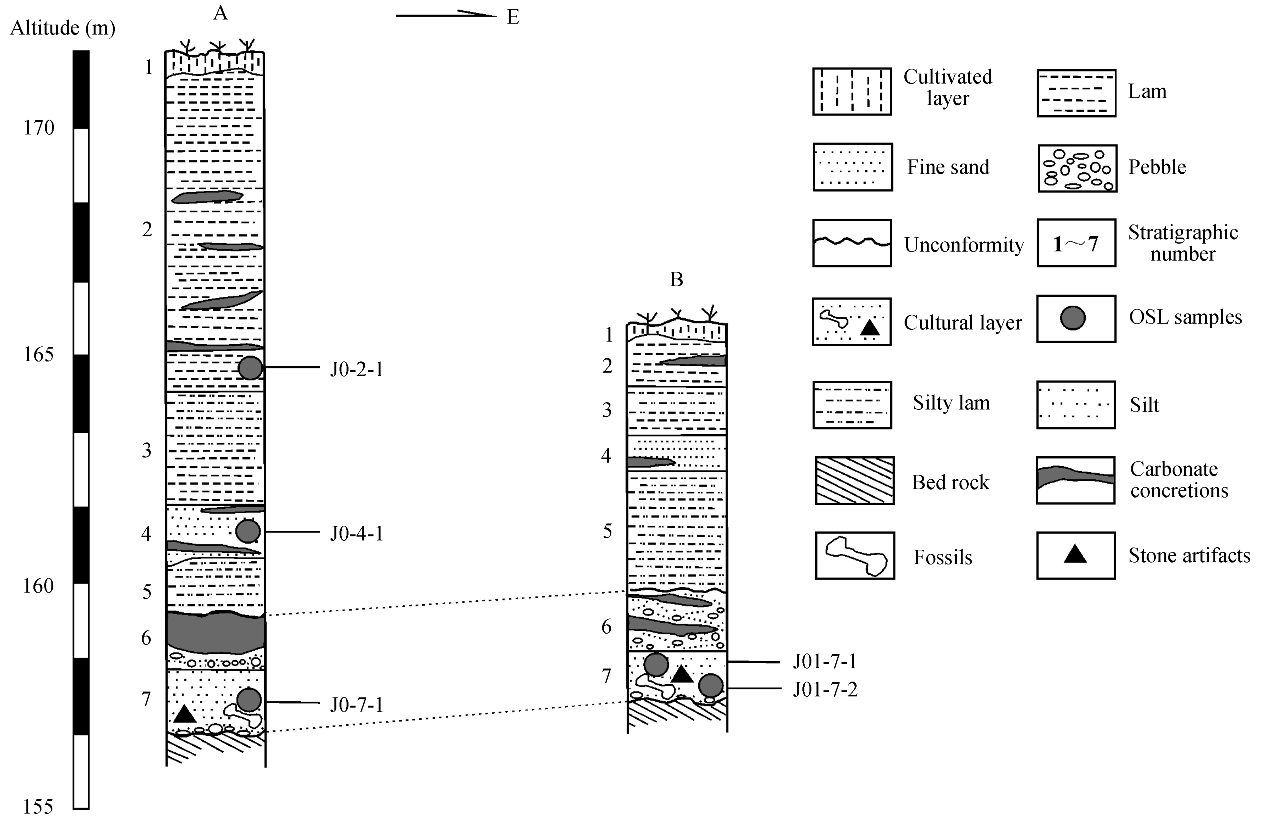

Fig. 2. Schematic stratigraphic sections showing locations of OSL samples.

room, materials from both ends of the tubes were removed. The remaining samples (interior parts) were then treated with hydrogen peroxide to remove organic material, and then dilute hydrochloric acid to dissolve carbonates. After removing clay by washing, the remaining detrital grains were dried, and then sieved for grains of suitable size for equivalent dose measurements. The samples were then etched by 40% HF to remove feldspar contaminants. The etching continued until the IRSL signal from the samples was negligible. The quartz grains extracted from these samples were fixed on 0.97 cm diameter aluminum discs using silicon oil.

2.2 Dose rate measurement

The radiation energy absorbed by a quartz grain comes mainly from the decays of ^{235}U, ^{238}U, ^{232}Th and their daughter products, and ^{40}K in the geological environments. The uranium, thorium and potassium contents of these samples were determined using Neutron Activation Analysis in China Institute of Atomic Energy. The cosmic ray contribution to the dose rate was calculated from the latitude, longitude and altitude, the burial depth of the sample and the density of the overlying sediments[8]. The water content (ratio of the weight of the water to the weight of the dry sample) was determined by weighing the sample before and after drying. Uncertainties in the water content were assigned to 10%. Finally, using the conversion factors[9,10], the elemental concentrations were converted into dose rate.

2.3 Equivalent dose determination

Equivalent dose measurements were performed using a TL/OSL reader (Risø-TL/OSL-15)[11] in the Luminescence Dating Laboratory, College of Environmental Sciences, Peking University. The stimulation source is blue light (470±10 nm) and the detected filter is U-340. The luminescence signal was detected by an EMI9235QA photomultiplier tube. Artificial irradiation was administered by the beta source ($^{90}Sr/^{90}Y$) attached to the reader.

Equivalent doses were estimated using the single-aliquot regenerative-dose (SAR) method[12]. The procedure is as follows: (1) preheating a single aliquot of a sample at a temperature for 10 s; (2) measuring OSL for 40s at the sample temperature of 125℃, and obtaining OSL decay curves for the aliquot; (3) giving a test dose to the aliquot; (4) heating the aliquot to 160℃ to remove unstable signals; (5) measuring the OSL signal induced by the test dose at 125℃ for 40s. The sensitivity-corrected signals were obtained by dividing the OSL intensity measured in step (2) by the one in step (5). The natural OSL signal from the aliquot was determined using the above procedure. After natural signal measurements, the sample was irradiated for various durations (regeneration doses), and steps (1) to (5) were repeated for each regeneration dose to measure the OSL signals produced by the regeneration dose. The sensitivity-corrected regenerative-dose-induced OSL signals were then plotted as a function of the regeneration doses, which yields a regenerative-dose growth curve for the aliquot. The single-aliquot D_e value was obtained by interpolating the sensitivity-corrected natural OSL onto the curve (Fig. 3).

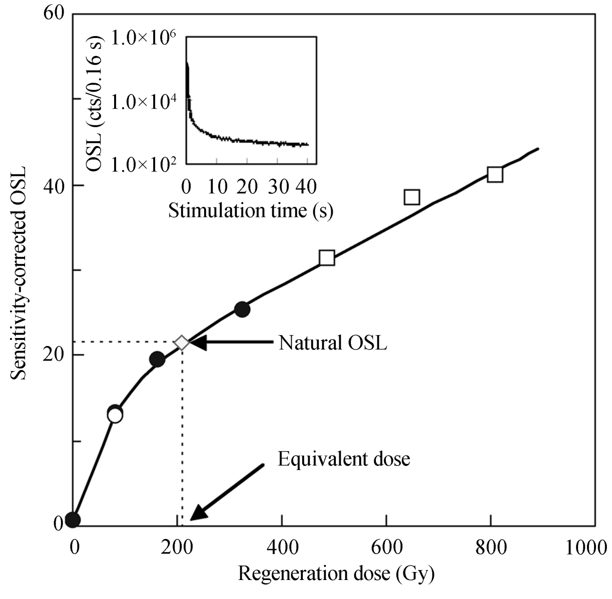

Fig. 3. Equivalent dose estimated for sample J01-7-2 using the SAR protocol (see text). An aliquot was preheated at 200°C for 10s. The test dose is 1.6 Gy, and the regeneration doses are 81.1, 162.0, 324.0, 0 and 81.0 Gy, respectively. The sensitivity-corrected regenerative-dose-induced OSL signals construct a growth curve for the aliquot. The D_e value of 208.5 Gy was obtained by interpolation between the regenerative points. To check whether the sample reached OSL saturation, relatively large regenerative doses of 481.0, 648.0 and 810.0 Gy were administered. The inset in the figure shows the natural OSL decay curve for the aliquot.

3 Dating results

3.1 Preheating plateau and OSL saturation

To determine appropriate preheating conditions for D_e estimation, and observe the charge transfer efficiency due to preheating, D_e preheating plateau tests were carried out. Single-aliquot D_e values were obtained using the SAR method at preheating temperatures of 160, 180, 200, 220, 240, 260 and 280℃ for 10 s. At least, four aliquots were measured at a temperature. The results for sample J0-7-1 are shown in Fig. 4. It can be seen that D_e is independent of preheating temperature at least in the range of 160—220℃. Therefore, preheating of 200℃ for 10s is employed in this paper.

In order to check whether the samples reached OSL saturation during burial, beta doses of up to 810 Gy were given to the sample. The regenerative-dose growth curve is illustrated in Fig. 3. The figure shows that the sample has not reached saturation at up to 810 Gy point. This implies that the samples are within the upper datable age limit of quartz optical dating methods.

3.2 Dose recovery tests

In order to test the reliability of D_e values obtained, dose recovery tests were designed for sample J01-7-1. The natural OSL signal from a sample was first removed completely by exposing the aliquot to the blue light in the OSL reader at room temperature. It was then given a known beta dose before any measurements.

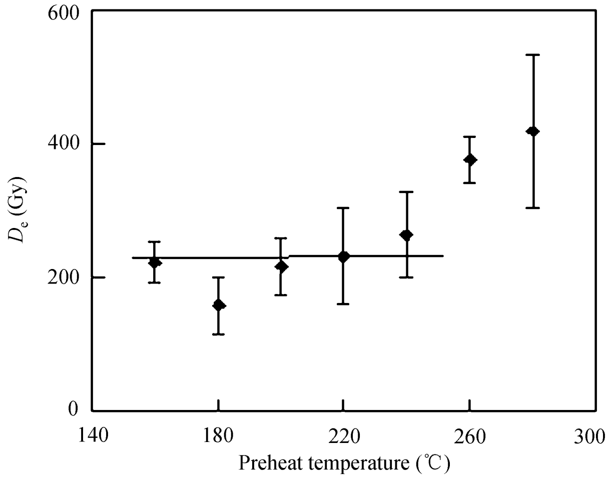

Fig. 4. The relationship between equivalent dose and preheating temperature for sample J01-7-1. Data points are the average of at least four aliquots, and error bars represent one standard deviation.

We assume that this given dose is an unknown natural dose, and can be measured using the SAR methods. This experiment was performed under the same preheating conditions as the D_e preheating plateau tests. Fig. 5 shows that the results are consistent with those of the preheating plateau tests, and the measured doses are in agreement within error limits with the given dose in the plateau. This suggests that the D_e values obtained for these samples are reliable.

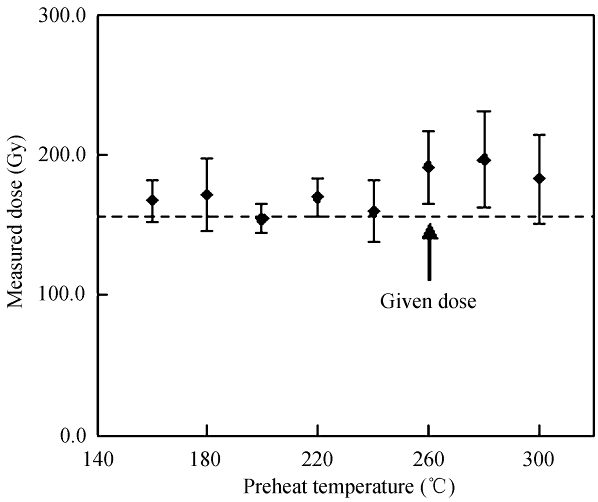

Fig. 5. The results of dose recovery tests for sample J01-7-1. The measured doses were plotted as a function of preheating temperatures. The dash line is the given dose. Data points are the average of four aliquots, and error bars represent one standard deviation.

3.3 *Equivalent dose*

The distributions of single-aliquot D_es for these samples are shown in Fig. 6. One of the luminescence properties of fluvial sediments is that the sediments have large scatter in single-aliquot D_es. This is ascribed to different sources and different bleaching histories of the grains from a sample[13−16]. The scatters in D_e, natural OSL signals, and the first regenerative-dose-induced OSL signal between aliquots can be represented by their relative standard deviation, respectively (RSD_{D_e}, $RSD_{\text{N-OSL}}$ and $RSD_{\text{R-OSL}}$ in Fig. 6). By comparing the values of $RSD_{\text{N-OSL}}$ and $RSD_{\text{R-OSL}}$, the measured aliquots can be divided into two groups: relatively well bleached and poorly bleached aliquots. The D_e averages of all measured aliquots and relatively well bleached aliquots are listed in Table 1. Since the OSL signal of an aliquot is mainly from a few brighter grains[1)], the OSL signal of an aliquot, to some extent, represents the OSL signal of a few grains of the aliquot. The average D_e value of relatively well bleached aliquots is believed to be very close to the true burial dose for a sample. Fig. 6 and Table 1 show that the average D_e values of all measured aliquots and relatively well bleached aliquots are similar, implying that the effect of bleaching on old fluvial sediments is not obvious. This is consists with the results obtained by Zhang *et al.*[14].

Based on the differences between the scatters in natural OSL and the first regenerative-dose-induced OSL (represented by relative standard deviation *RSD*), the measured aliquots (grains) are divided into relatively well bleached aliquots (on the left of the dash line) and incompletely bleached aliquots (on the right).

3.4 *Optical ages*

All dating results are listed in Table 1. Optical ages were obtained by dividing the equivalent doses by the dose rates, and the calculation was performed using the program AGE.EXE[2)]. Based on the two average D_e values, two ages were obtained for one sample. The age calculated from the average D_e value of all measured aliquots can be considered as the maximum burial age of the sample, and the one calculated from the average D_e values of relatively good aliquots is likely to be very close to the true burial age of the sample. The optical ages of samples J0-7-1, J01-7-1 and J01-7-2 from the cultural layers indicate that the age of the cultural layer in the Jingshuiwan Paleolithic site is about 70 ka, that is, the deposition time of the sediments in the cultural layer is ca.70 ka. The consistency between the ages of samples J0-2-1 and J0-4-1 from the fluvial sediment layers overlying the cultural layer and the ages of the cultural layer suggested rapid deposition rate for these fluvial sediments.

4 Discussion and conclusions

The Jingshuiwan Paleolithic site, with complete geomorphologic section remaining intact, was buried in the second terrace of the Yangtze River. Archeological materials described in this paper were unearthed from the early Upper Pleistocene deposits of sandy silt and silty sand. The “cultural horizon”, i.e. Layer 7, was sealed by several carbonate concretions, and archaeo-

1) Zhang J F. Development and application of luminescence dating to Quaternary sediments from China. Dissertation for the Doctoral Degree. Hong Kong University, 2000

2) Grün R. Age.exe, Computer program for the calculation of luminescence dates, Computer Program. RSES, Canberra, 2003

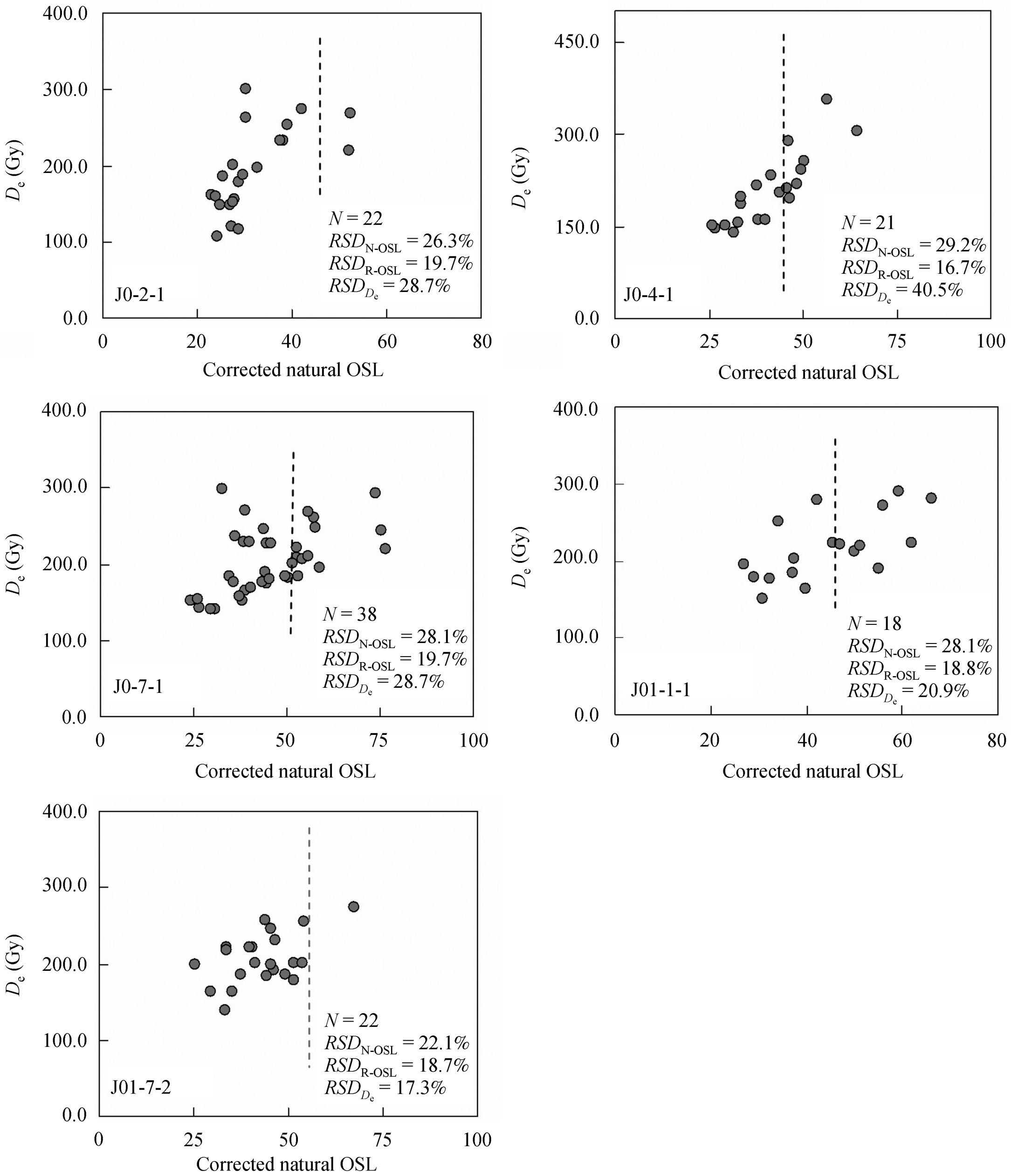

Fig. 6. The distribution of single-aliquot D_es values and sensitivity-corrected natural OSL signals.

logical materials were found from the layer in clear primary context, signifying that the site preserved valuable information of Paleolithic human occupation. The age of human occupation at the site has been determined to be 70 ka through OSL dating. The dating results are in accordance with geological structure and biostratigraphy at the site.

The dating results of the Jingshuiwan site is an important achievement in chronological analysis of Paleolithic industries in South China. It has long been recognized that chronology is a major bottleneck in studying human origin, migration and Paleolithic cultural development in South China[17,18]. In this vast area, organic materials cannot be preserved in the acid sediments, and therefore, relevant dating methods cannot be used. Ages of sites found in this region are mostly estimated by biostratigraphic comparison and even broad speculation. In the past decade, TIMS of U-series

Table 1 Results of optical dating

Lab code	Field No.	Sediment	Depth (m)	Grains (μm)	U (μg/g)	Th (μg/g)	K (%)	Water content (%)	Dose rate (Gy/ka)	All measured aliquots			Relatively well-bleached aliquots		
										Number[a)]	Mean D_e (Gy)	Age (ka)	Number	Mean D_e (Gy)	Age (ka)
PKU-L056	J0-2-1	clayey silt	6.7	90~112	2.80±0.14	14.60±0.38	1.74±0.07	23.7	2.71±0.11	22(25)*	193.9±11.8	71.6±5.2	20	188.9±12.4	69.8±5.3
PKU-L057	J0-4-1	silty sand	9.8	112~160	2.48±0.13	10.60±0.32	2.07±0.09	21.0	2.71±0.10	20(23)	208.7±13.1	76.9±7.5	12	175.0±8.9	64.5±4.1
PKU-L058	J0-7-1	silty sand	12.1	112~160	2.35±0.13	13.00±0.33	2.11±0.08	22.0	2.82±0.10	38(41)	203.8±6.9	72.2±3.7	25	191.3±8.5	67.8±3.9
PKU-L60	J01-7-1	clayey silt, fine sand	7.2	112-160	2.37±0.13	12.10±0.33	2.06±0.09	18.3	2.81±0.10	18(22)	217.4±9.5	77.3±4.3	10	200.5±12.8	71.1±5.2
PKU-L061	J01-7-2	clayey silt, fine sand	7.2	112~160	2.27±0.13	12.70±0.34	2.01±0.09	24.6	2.68±0.10	25(29)	206.3±7.1	77.1±3.8	20	203.1±6.8	75.9±3.7

a) The number in brackets is the number of actually measured aliquots, and some aliquots were rejected because of inadequate sensitivity corrections (recycling values＞10%) and large recuperation OSL signal (ratio of recuperation to natural OSL＞5%).

method has been applied to highly purified carbonate sample usually available in cave sites, but for open-air sites, its application is very limited. The OSL age analysis on the Jingshuiwan samples is the first time that such a method has been applied in solving Paleolithic chronological problems in South China, and the results are both promising and encouraging because they are clearly in accordance with geomorphologic and biostratigraphic information and cultural characteristics at the site. The newly established age of the Jingshuiwan site might also provide meaningful comparison and estimate for other sites with similar geological structure and faunal and archaeological contexts. Quartz grains, as suitable sample for OSL dating, can be easily obtained from deposits of most Paleoanthropological and Paleolithic sites, indicating that OSL has the potential of becoming a major dating method in South China, therefore, improving the current chronological framework greatly in the region.

The Jingshuiwan dating results will contribute greatly to the establishment of a more complete Paleolithic cultural sequence in South China. For a long time, the Lower Paleolithic sites[19,20] and Upper Paleolithic sites[1] were known to exist in the Three Gorges region and even in South China, but the Middle Paleolithic site could not be confirmed because no reliable dates had been obtained in this period. Consequently, information on Middle Paleolithic technology, cultural features and human behavior could not be derived and regional cultural development sequence could not be established. The Jingshuiwan OSL dates are the first evidence of human occupation in the Three Gorges region and even in South China during the early Upper Pleistocene or the Middle Paleolithic, and therefore, helps to restore the “missing link” of a Lower→Middle→Upper Paleolithic archaeological chain in the region. The Jingshuiwan site is situated within the territory of “the Main Steam Paleolithic Industry” in South China where most stone tools during the Lower Paleolithic were made of pebbles but flake tools became predominant during the Upper Paleolithic[21]. The Jingshuiwan lithic assemblage shows a distinct and transitional feature: large pebble tools are present at the site, but the medium- to small-sized flake tools possess the majority. The percentage of middle-sized artifacts is 36% while the percentage of flakes is 73.6%; small scrapers and points, almost absent in the Lower Paleolithic assemblages, become major tool types in this collection[3]. Such features are commonly identifiable in Upper Paleolithic industries in South China. The Jingshuiwan industry clearly indicates that the developmental series of the regional Paleolithic cultures is a gradual and progressive one.

The dating results of the Jingshuiwan site bear great implications for studying the origin and evolution of modern humans in China. In the past two decades, molecular biology plays a major role in the research on modern human origins. According to new hypotheses derived from DNA analyses, the direct ancestors of modern humans living in China and even in East Asia migrated from Africa and West Asia before about 100—50 ka, and a major supporting evidence for this hypothesis is that both human fossils and cultural remains were absent in the archaeological record for that period of time in China and East Asia[22−24]. The OSL dates for the Jingshuiwan site provide strong evidence against this hypothesis; it testifies that human remains are present in South China during the critical 100—50 ka period, and human cultural developmental sequence in the region is a continued and progressive one. The Three Gorges region is situated in the east of the Qinghai-Tibet Plateau and the transition zone from upper to middle reaches of the Yangtze River. It is affirmed that a comfortable climatic condition and abundant living resources were suitable for human adaptation and reproduction during the entire Pleistocene. Since the mid 1980s, many early human fossils and archaeological remains have been discovered in the region[25,26], indicating a long history of human occupation in the area. The age of around 70 ka obtained places the Jingshuiwan site in a very sensitive and critical duration for the origin of modern Chinese defined by molecular biologists[27]. The result not only disproves the assumption of the nonexistence of human fossils and cultural remains during 100-50 ka in the region, but also gives evidence to the continuity nature of Paleolithic cultures in the region from the Lower to Upper Paleolithic. In a word, it can be concluded that the theory of hominids evolving successively in China and even in East Asia was supported by the cultural remains unearthed from Jingshuiwan site and its dating results, thus modern humans in China was of regional origin and continued evolution.

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References

1 Wei Q, Lin S L, Li Y, et al. Survey of relics of the Old Stone Age and ancient human vertebral animal. In: China Three Gorges Construction Yearbook (in Chinese). Yichang: China Three Gorges Construction Press, 1997. 100－109

2 Pei S W, Feng X W, Chen F Y, et al. New advances in Paleolithic archeological investigations in the Three Gorges region, China. In: Deng T, Wang Y, eds. Proceedings of the Eight Annual Meeting of the Chinese Society of Vertebrate Paleontology (in Chinese). Beijing: China Ocean Press, 2001. 197－208

3 Pei S W, Gao X, Feng X W, et al. Preliminary study on Jingshuiwan Paleolithic site, Three Gorges region. Acta Anthropologica Sinica (in Chinese), 2003, 22 (4): 261－278

4 Aitken M J. An Introduction to Optical Dating: the Dating of Quaternary Sediments by the Use of Photon-Stimulated luminescence. Oxford: Oxford University Press, 1998

5 Pavlov P, Svendsen I, Indrelid S. Human presence in the European Arctic nearly 40000 years ago. Nature, 2001, 413: 64－67

6 Christopher S H, Francesco D E, Royden Y, et al. Emergence of Modern Human Behavior: Middle Stone Age Engravings from South Africa. Science, 2002, 295: 1278－1280

7 Bowler J M, Johnston H, Olley J, et al. New ages for human occupation and climatic change at Lake Mungo, Australia. Nature, 2003, 421: 837－840

8 Prescott J R, Hutton J T. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. Radiation Measurements, 1994, 23: 497－500

9 Adamiec G, Aitken M J. Dose-rate conversion factors: update. Ancient TL, 1998, 16: 37－50

10 Mejdahl V. Thermoluminescence dating: beta-dose attenuation in quartz grains. Archaeometry, 1979, 21: 61－72

11 Bøtter-Jensen L, Bulur E, Duller G A T, et al. Advances in luminescence instrument systems. Radiation Measurement, 2000, 32: 523－528

12 Murray A S, Wintle A G. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. Radiation Measurements, 2000, 32: 57－73

13 Zhang J F, Li S, Tso M Y W. Assessment of bleaching of K-feldspar grains. Radiation Measurements, 2001, 33: 103－108

14 Zhang J F, Zhou L P, Yue S Y. Dating fluvial sediments by optically stimulated luminescence: selection of equivalent doses for age calculation. Quaternary Science Reviews, 2003, 22: 1123－1129

15 Wallinga J. Optically stimulated luminescence dating of fluvial deposits: a review. BOREAS, 2002, 31: 303－322

16 Li S H. Optical dating: insufficiently bleached sediments. Radiation Measurements, 1994, 23: 563－567

17 Chen T M. A review and prospect of chronological studies for Paleolithic archeology in China. Acta Archaeologica Sinica (in Chinese), 1988, 3: 357－367

18 Shen G J. Origin of modern humans: chronological evidence from hominid fossil localities in Southern China. Earth Science Frontiers (in Chinese), 2004, 11(2): 543－548

19 Feng X W, Pei S W, Chen F Y. A study on Yandunbao site, fengdu, Three Gorges region. Acta Anthropologica Sinica (in Chinese), 2003, 22 (3): 177－191

20 Huang W, Ciochon R, Gu Y M, et al. Early *Homo* and associated artifacts from Asia. Nature, 1995, 378: 275－278

21 Zhang S S. Advances in Chinese Paleolithic archeology in the past 20 years and some comments. Quaternary Sciences (in Chinese), 2002, 22 (1): 11－19

22 Jin L, Su B. Natives or immigrants: modern human origin in east Asia. Nature Genetics, 2000, 1: 126－133

23 Ke Y, Su B, Song X, et al. African origin of modern humans in East Asia: A tale of 12000 Y chromosomes. Science, 2001, 292: 1151－1153

24 Ke Y H, Su B, Li H Y, et al. Chromosome Y genetic evidence sustain Chinese modern human origin from Africa. Chin Sci Bull, 2001, 46(5): 411－414

25 Huang W P, Gu Y M, Ciochon R, et al. Whose teeth? Nature, 1996, 381: 202

26 Gao X, Huang W B, Xu Z Q, et al. 120－150 ka human tooth and ivory engravings from Xinglongdong Cave, Three Gorges region, South China. Chin Sci Bull, 2004, 49 (2): 175－180

27 Wu X Z. On the origin of modern humans in China. Quaternary International, 2004, 117: 131－140