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Chronology of the Youfang site and its implications for the emergence of microblade technology in North China

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ABSTRACT

The Youfang Paleolithic site, located in the eastern Nihewan Basin, Hebei Province, China, was discovered in 1984. However, the microblade assemblages which were excavated from the site lacked reliable chronological data. In this study, an optical dating technique was applied to nine samples from Late Pleistocene eolian sequences at the site. The ages of three samples from artifact-bearing deposits were in the range of ca. 26–29 ka with depths between 2.1 m and 2.9 m obtained with medium-grained quartz, corresponding to Marine Isotope Stage 3 (MIS3). These displayed evidence of a longer-term climate trend, in which the climate became gradually warmer and more humid. The sample from the upper culture layer was dated to 26.4 ± 2.1 ka. Five samples taken from the lower culture layer yielded ages between ca. 28 ka and 43 ka. The results suggest that human occupation at the Youfang site ranged from ca. 26 ka to 29 ka. Indeed, the Nihewan Basin yields the oldest microblade site in northern high latitudes (40° N), and offers a unique opportunity to study the emergence and characteristics of microblade technologies in northeast Asia. Nevertheless, extensive archeological field surveys and excavations are still needed to understand further the developmental process of microblade technologies in the region.

1. Introduction

The transition from Early Paleolithic to Late Paleolithic in North China (ca. 30,000 years ago) was mainly marked by the appearance of both blade and microblade technologies, in addition to the presence of art/symbolism (Gao and Norton, 2002). Microblade technology included the making of microblade tools: typical examples of this category of artifact are microblade cores, microblades and tools made with microblades, generally mounted in bone or wood to form complex tools (An, 1978; Goebel, 2002; Elston et al., 2011), rather than 'small tools'. Microblade technology was a catalyst for a major revolution in lithic technology in northern China for societies based upon hunter–gatherer practices which then experienced high levels of mobility driven by socio-economic and climatic changes. Archeological discoveries of lithics were first made at the dawn of the 20th century, and numerous archeological sites with microblade assemblages have been found (and subjected to detailed study) since the early 1950s. There are now more than 200 archeological sites or site clusters with microblades identified throughout many provinces including Heilongjiang, Liaoning, Jilin, Inner Mongolia, Hebei, Shanxi, Sha'anxi, Henan, Ningxia, Gansu, Qinghai, Xinjiang, among others (see e.g. Tong, 1979; Chen, 1984; Chen and Wang, 1989; Bettinger et al., 1994; Lu, 1998; Gao et al., 2013; Qu et al., 2013) (Table 1 and Fig. 1).

At present, however, where and when microblade technology originated and how the technology developed remains controversial. For instance, most scholars subscribe to the view that the Lake Baikal region of Siberia was the cradle of microblade technology and North China was simply one of the areas to which it spread (see e.g. Pei, 1955; Keates et al., 2007; Kuzmin, 2007; Elston et al., 2011); some scholars (see e.g. Smith, 1974; Jia, 1978) have hypothesized that North China was the source of microblade technology and that, from there, the technology spread to other parts of Asia and across Beringia to North America.

The ages obtained for some typical Upper Paleolithic sites with microblades in northern China are shown in Table 1. Three sites, at Longwangchan in Sha'anxi Province, Chaisi/Dingcun 77:01 and the

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Table 1
The ages of the layers bearing microblades for Upper Paleolithic sites mentioned in the text of northern China.

Sites name	Longitude/ Latitude	Layer	Material	Lab no.	Dating method	Age			Reference
						Uncal. BP	Cal. BP (68%)	ka	
Longwangchan Loc. 1, Shaanxi	N36°09′45″, E110°26′15″	Layer 4 (0.43 m)	Charcoal	BA06005	AMS ^{14}C	21,405 ± 75	25,189–25,854	–	Zhang et al., 2011
		Layer 4 (0.63 m)	Charcoal	BA06006	AMS ^{14}C	20,915 ± 70	24,683–25,232	–	Zhang et al., 2011
		Layer 4 (0.73 m)	Charcoal	BA06009	AMS ^{14}C	20,995 ± 70	24,771–25,498	–	Zhang et al., 2011
		Layer 4 (0.73 m)	Charcoal	BA091131	AMS ^{14}C	20,710 ± 60	24,489–24,931	–	Zhang et al., 2011
		Layer 5 (1.18 m)	Charcoal	BA06008	AMS ^{14}C	21, 920 ± 80	25,963–26,673	–	Zhang et al., 2011
		Layer 5 (1.23 m)	Charcoal	BA06007	AMS ^{14}C	21,740 ± 115	25,455–26,531	–	Zhang et al., 2011
		Layer 5 (1.43 m)	Charcoal	BA091132	AMS ^{14}C	22,105 ± 50	26,185–26,870	–	Zhang et al., 2011
		Layer 5 (1.53 m)	Charcoal	BA091133	AMS ^{14}C	22,200 ± 75	26,260–27,353	–	Zhang et al., 2011
		Layer 6 (2.23 m)	Charcoal	BA091129	AMS ^{14}C	24,145 ± 55	28,551–29,303	–	Zhang et al., 2011
		Layer 6 (2.43 m)	Charcoal	BA091130	AMS ^{14}C	22,230 ± 55	26,288–27,395	–	Zhang et al., 2011
		Layer 4 (0.2 m)	*FG quartz	L1387	OSL	–	–	21.4 ± 1.1	Zhang et al., 2011
		Layer 4 (0.4 m)	FG quartz	L1388	OSL	–	–	23.0 ± 1.0	Zhang et al., 2011
		Layer 4 (0.6 m)	FG quartz	L1389	OSL	–	–	26.8 ± 1.2	Zhang et al., 2011
		Layer 5 (0.8 m)	FG quartz	L1390	OSL	–	–	24.2 ± 1.0	Zhang et al., 2011
		Layer 5 (1 m)	FG quartz	L1391	OSL	–	–	22.6 ± 1.0	Zhang et al., 2011
		Layer 5 (1.2 m)	FG quartz	L1392	OSL	–	–	22.8 ± 1.1	Zhang et al., 2011
		Layer 5 (1.4 m)	FG quartz	L1393	OSL	–	–	23.1 ± 1.1	Zhang et al., 2011
		Layer 5 (1.6 m)	FG quartz	L1394	OSL	–	–	25.2 ± 1.3	Zhang et al., 2011
		Layer 6 (1.8 m)	FG quartz	L1395	OSL	–	–	25.6 ± 1.2	Zhang et al., 2011
		Layer 6 (2 m)	FG quartz	L1396	OSL	–	–	25.1 ± 1.2	Zhang et al., 2011
		Layer 6 (2.2 m)	FG quartz	L1397	OSL	–	–	25.8 ± 1.2	Zhang et al., 2011
		Layer 6 (2.4 m)	FG quartz	L1398	OSL	–	–	28.7 ± 1.4	Zhang et al., 2011
		Layer 6 (2.6 m)	FG quartz	L1399	OSL	–	–	27.7 ± 1.3	Zhang et al., 2011
		Layer 6 (2.8 m)	FG quartz	L1400	OSL	–	–	28.6 ± 1.3	Zhang et al., 2011
		Layer 6 (3 m)	FG quartz	L1401	OSL	–	–	28.8 ± 1.4	Zhang et al., 2011
Chaisi/*DC 77:01, Shanxi	N35°50′, E111°25′	Sand-gravel layer	Shell	ZK-0635	*Conv.^{14}C	25,650 ± 800	29,683–31,318	–	IA-CASS, 1991
Xiachuan Loc.1, Shanxi	N35°27′, E112°02′	IT1(2)	Charcoal	ZK-0385	Conv.^{14}C	15,940 ± 900	18,212–20,266	–	IA-CASS, 1991
		IT2-6(2)	Charcoal/mud	ZK-0384	Conv.^{14}C	21,090 ± 1000	24,042–26,668	–	IA-CASS, 1991
		IT8(2)	Charcoal	ZK-0417	Conv.^{14}C	23,220 ± 1000	26,484-29120	–	IA-CASS, 1991
Xiachuan Loc.2, Shanxi		–	Charcoal	ZK-393	Conv.^{14}C	20,700 ± 600	23,964–25,608	–	Chen and Wang, 1989
Xiachuan *SSY, Shanxi		IIIT1-2(2)	Mud	ZK-0494	Conv.^{14}C	17,860 ± 480	20,716–22,125	–	IA-CASS, 1991
		IVT101-103(2)	Peat	ZK-0497	Conv.^{14}C	18,040 ± 480	20,937–22,274	–	IA-CASS, 1991
Xiachuan *SWP, Shanxi		–	Charcoal	ZK-762	Conv.^{14}C	13,900 ± 300	16,534–17,492	–	Chen and Wang, 1989
		–	Charcoal	ZK-634	Conv.^{14}C	19,600 ± 600	22,746–24,210	–	Chen and Wang, 1989
Shizitan, Shanxi	N36°02′, E110°32′	*C-zone (0.35–0.5 m)	Burnt bone	BA 93186	AMS ^{14}C	10,490 ± 540	11,404–12,823	–	Yuan et al., 1998
		C-zone (0.5–0.8 m)	Burnt bone	BA 93187	AMS ^{14}C	12,660 ± 190	14,606–15,444	–	Yuan et al., 1998
		C-zone (1.15–1.3 m)	Burnt bone	BA 93188	AMS ^{14}C	13,590 ± 220	15,991–16,966	–	Yuan et al., 1998
		C-zone (1.46–1.78 m)	Burnt bone	BA 93189	AMS ^{14}C	14,340 ± 250	17,208–17,849	–	Yuan et al., 1998
		*E-zone (2.7 m)	Bone	BA 93190	AMS ^{14}C	11,490 ± 110	13,245–13,536	–	Yuan et al., 1998
		East zone (5.3 m)	Bone	BA 93191	AMS ^{14}C	14,720 ± 160	17,635–18,395	–	Yuan et al., 1998
Xueguan, Shanxi	N36°24′, E111°05′	–	Charcoal	BK81016	Conv.^{14}C	13,170 ± 150	15,659–16,536	–	IA-CASS, 1991
PY-03, Ningxia	N 35.8°, E106.6°	–	Charcoal	CAMS94203	AMS ^{14}C	18,350 ± 70	21,688–22,323	–	Ji et al., 2005
PY-04, Ningxia	N35.8°, E106.6°	–	Charcoal	CAMS94202	AMS ^{14}C	10,670 ± 40	13,422–13,688	–	Barton et al., 2007
Pigeon Mountain, *QG3, Ningxia	N38.04°, E105.85°	*S-profile, stratum E	Charcoal	Beta 97241	Conv.^{14}C	10,230 ± 50	11,808–12,099	–	Elston et al., 1997
		S-profile, stratum F	Charcoal	Beta 86731	Conv.^{14}C	11,620 ± 70	13,373–13,646	–	Elston et al., 1997
		S-profile, stratum G2	Charcoal	Beta 97242	Conv.^{14}C	12,710 ± 70	14,793–15,415	–	Elston et al., 1997
		*SW-profile, stratum D	Charcoal	Beta 86732	Conv.^{14}C	10,020 ± 60	11,373–11,708	–	Elston et al., 1997
		SW-profile, stratum D	Charcoal	Beta 97346	Conv.^{14}C	10,130 ± 70	11,522–11,946	–	Elston et al., 1997
Shuidonggou Loc. 12, Ningxia	N38°19′40″, E106°29′49″	Layer 11	Charcoal	LUG06-54	AMS ^{14}C	9797 ± 91	13,078–13,296	–	Liu et al., 2008;
		Layer 11	Quartz	IEE1110	OSL	–	–	11.6 ± 0.6	Pei et al., 2012
Youfang, Hebei	N40°14′, E114°41′	Upper layer of the artifact horizon	FG quartz	–	OSL	–	–	14 ± 4	Tsuneto et al., 2009
			Polymineral	–	OSL	–	–	14 ± 3	Tsuneto et al., 2009
			FG quartz	–	OSL	–	–	16 ± 3	Tsuneto et al., 2009
			Polymineral	–	OSL	–	–	16.2 ± 2	Tsuneto et al., 2009

Table 1 (*continued*)

Sites name	Longitude/ Latitude	Layer	Material	Lab no.	Dating method	Age			Reference
						Uncal. BP	Cal. BP (68%)	ka	
		Lower layer of the artifact horizon							
		Cultural layer (2.1 m)	MG quartz	L2304	OSL	–	–	26.6 ± 2.1	Reported here
		Cultural layer (2.5 m)	MG quartz	L2305	OSL	–	–	25.1 ± 2.0	Reported here
		Cultural layer (2.9 m)	MG quartz	L2306	OSL	–	–	29.2 ± 2.0	Reported here
Hutouliang, Hebei	N40°10′, E114°9′	Terrace II of *XSD	Bone	PV-0156	Conv.^{14}C	10,690 ± 210	12,233–12,826	–	IA-CASS, 1991
		Layer 6 (up part)	Polymineral	–	OSL	–	–	9.2 ± 1.4	Tsuneto et al., 2009
		Layer 6 (lower part)	Polymineral	–	OSL	–	–	9.0 ± 1.3	Tsuneto et al., 2009
Jinsitai, Inner Mongolia	N45°13′, E115°22′	01DAJT4. 3B	Bone	BA04478	AMS ^{14}C	14,745 ± 60	17,773–18,408	–	Wang et al., 2010
Dadiwan component 4, Gansu	N35.015°, E105.904°	–	Charcoal	–	AMS ^{14}C & range estimated	–	ca. 13,000–20,000	–	Bettinger et al., 2010
Shibazhan, Heilongjiang	N52°25′, E125°24′	Layer B	–	IEE634	OSL	–	–	10.3 ± 0.6	Zhang et al., 2006
Xishi, Henan	N34°27′, E113°13′	Terrace II	–	–	AMS^{14}C and OSL		ca 25,000		PKGWX, 2011
Dagang, Henan	N33°40′, E113°42′	Layer4	–	–	*Estimated	Late period of Late Paleolithic			Zhang and Li, 1996
Donghuishan, Hebei	N39°48′, E118°49′	Grey-white sand layer	–	–					HBWY, 1989
Tingsijian, Hebei	N39°44′, E119°10′	Yellowish clay layer	–	–					Wang, 1997
Mengjiaquan, Hebei	N39°52′, E117°47′	Sand-gravel layer	–	–					HBWY et al., 1991
Jijitan, Hebei	N40°06′, E114°26′	Sandy clay layer	–	–					HBWY, 1993
Huichunbeishan, Jilin	[a]N42°53′, E130°21′	Yellowish mild clay	–	–					Chen and Zhang, 2004
Shirengou, Jilin	N42°11′, E128°49′	Yellowish mild clay	–	–					Chen et al., 2006

^{14}C ages were calibrated using CalPal v1.5 online software by Uwe Danzeglocke (http://www.calpal-online.de/index.html).

*FG: fine grain; MG: medium grain; DC 77:01: Dingcun 77:01; Conv.^{14}C: conventional ^{14}C; SSY: Shanshanyan; SWP: Shunwangping; C-zone: central zone; E-zone: east zone; QG3: Four Springs; S-profile: Southern profile; SW-profile: Southwestern profile; XSD: Xishuidi; Estimated: the chronology was estimated on the basis of human remains, sediments, or comparison with other archeological sites.

[a] The authors in the article gave the wrong geographic coordinates, and we checked it with the Google earth again.

Xiachuan site cluster in Shanxi Province, have been dated to ca. 25–29 ka, 30–31 ka and 17–29 ka, respectively, by ^{14}C or by a combination of ^{14}C and OSL methods (Chen and Wang, 1989; IA-CASS, 1991; Zhang et al., 2011). The Xishi Paleolithic Site found in Henan Province was the first site with microblade technology discovered on the Chinese central plain, and has been dated to ca. 25 ka by ^{14}C and OSL dating (PKGWX, 2011). The PY-03 site, located in Ningxia Province, and the Dadiwan Component 4, in Gansu Province, have been dated to 21,688–22,323 cal BP and 13,000–20,2000 cal BP, respectively, using the ^{14}C method (Ji et al., 2005; Bettinger et al., 2010). Shizitan and Xueguan in Shanxi Province, Jinsitai in Inner Mongolia, Shuidonggou Loc.12 and Pigeon Mountain in Ningxia Province, Youfang and Huotouliang in Hebei Province, and Shibazhan in Heilongjiang Province were dated by the ^{14}C or OSL technique, the estimated ages of which ranged from ca. 10 ka to 18 ka between the Holocene and last glacial period (IA-CASS, 1991; Elston et al., 1997; Yuan et al., 1998; Zhang et al., 2006; Liu et al., 2008; Tsuneto et al., 2009; Wang et al., 2010; Pei et al., 2012); the exact age ranges of these sites can be found in Table 1. Many Late Paleolithic microblade sites have few or no numerical ages, such as in Jilin Province, Heilongjiang Province and Hebei Province, but the chronologies of these sites have been estimated on the basis of artifacts, biostratigraphy, sediments, or comparison with other Paleolithic sites (Table 1).

The age of Xiachuan, a site complex comprising several localities, was determined by conventional ^{14}C dating (Chen and Wang, 1989; IA-CASS, 1991). However, the ages are problematic owing to poor stratigraphic control of the samples (see e.g. An, 1983; Chen and Wang, 1989). Chaisi/Dingcun 77:01 and Xueguan have only a single date between them, based on conventional radiocarbon dating published in the early 1990s (IA-CASS, 1991); individual dates were also obtained at PY-03 and PY-04 (Ji et al., 2005; Barton et al., 2007), but such single data should be treated with caution. Furthermore, the Xueguan and Hutouliang dates are also problematic owing to the position of the layer and the sample material (An, 1983). To date, early microblade sites (>13 ka) with relatively reliable chronologies include Longwangchan and Xishi as a prelude to the last glacial maximum (LGM, 23–19 ka), Dadiwan during the LGM, and Jisitan and Shizitan between the Younger Dryas and the LGM. The earliest microblade technology site was dated to ca. 25–29 ka at Longwangchan. Based on the above data, a microblade technology seems to appear first in Sha'anxi Province, followed by spreading to other parts of northern China.

A reliable chronological framework for any archeological site is a prime component in archeological research. Understanding the dispersal of microblade technologies and cultural relations between them depend on reliable site chronologies. From existing data, we found that the majority of the microblade sites are either not well

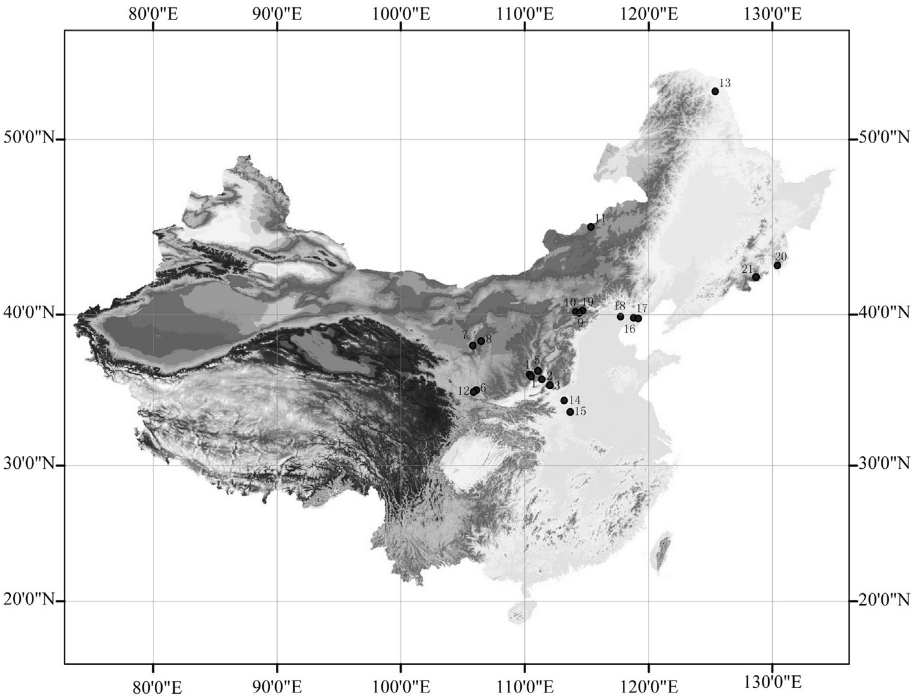

Fig. 1. Distribution map of the Late Paleolithic microblade-bearing sites in northern China mentioned in the text. 1. Longwangchan Loc. 1, Shaanxi Province; 2. Chaisi/Dingcun 77:01, Shanxi Province; 3. Xiachuan Loc.1, Shanxi Province; 4. Shizitan, Shanxi Province; 5. Xueguan, Shanxi Province; 6. PY-03, Ningxia Province; 7. Pigeon Mountain, QG3, Ningxia Province; 8. Shuidonggou Loc. 12, Ningxia Province; 9. Youfang, Hebei Province; 10. Hutouliang, Hebei Province; 11. Jinsitai, Inner Mongolia Province; 12. Dadiwan component 4, Gansu Province; 13. Shibazhan, Heilongjiang Province; 14. Xishi, Henan Province; 15. Dagang, Henan Province; 16. Donghuishan, Hebei Province; 17. Tingsijian, Hebei Province; 18. Mengjiaquan, Hebei Province; 19. Jijitan, Hebei Province; 20. Huichunbeishan, Jilin Province; 21. Shirengou, Jilin Province.

dated or they are restricted to old results, some of which are questionable because of the limitation of the experimental conditions and techniques during past times, or complicated sedimentary processes. The ^{14}C data obtained over the last 50 years are limited and may be in need of reconsideration due to pre-treatment of samples for dating and the selection of material (see e.g. Bird et al., 2002; Higham, 2011). Moreover, it has been shown that charcoal from archeological sites is readily contaminated by mixing with older charcoal during transport, thus failing to reflect the actual depositional age of the sediment (see e.g. Blong and Gillespie, 1978; El-Daoushy and Eriksson, 1998; Gillespie and Brook, 2006). Current data availability is insufficient to provide a solid foundation with which to discuss the origin of microblade technologies, the relation between industries, sites or districts with microblade components, and the dispersal and interactions of modern human groups, a topic discussed and debated fiercely in the past three decades.

Most of the Nihewan Basin is located in Hebei Province, which is also the key archeological area in northern China. Abundant Paleolithic remains have been excavated from the Nihewan strata, and the Basin has been recognized as containing the earliest presence of hominins at high northern latitudes in northeast Asia (see e.g. Barbour, 1924, 1925; Barbour et al., 1926; Zhu et al., 2004). Current research in the Nihewan Basin is mainly focused on early Pleistocene archeological sites, but at the same time, several Upper

Fig. 2. Artifacts from the Youfang site. a: microblades; b: microblade cores.

Paleolithic sites with microblade assemblages have been found (Xie, 2000). Youfang is one such site: since the discovery of the site and the rich collection of artifacts, it has been recognized as an important Late Paleolithic site in northern China. However, its age is still in doubt. In this study, we systematically collected nine eolian samples including quartz grains at the site. As a result, an accurate chronological framework for the site has been established using the OSL dating technique, the implications of which are discussed with reference to the microblade technologies of northern China.

Table 2
U, Th, K concentrations, dose rate, equivalent dose and OSL ages of the samples from Youfang site using the medium-grained quartz SAR protocol.

Lab no.	U (ppm)	Th (ppm)	K (%)	Dose rate (Gy/ka)	Depth (m)	No. of aliquots	D_e (Gy)	Age (ka)
L2303	2.28 ± 0.09	9.33 ± 0.28	1.85 ± 0.06	2.84 ± 0.16	1.6	10	75 ± 4	26.4 ± 2.1
L2304	2.48 ± 0.1	9.43 ± 0.28	1.86 ± 0.06	2.89 ± 0.17	2.1	10	77 ± 4	26.6 ± 2.1
L2305	2.35 ± 0.09	10.5 ± 0.29	1.93 ± 0.06	2.98 ± 0.17	2.5	10	75 ± 4	25.1 ± 2.0
L2306	2.13 ± 0.09	9.61 ± 0.29	1.78 ± 0.06	2.74 ± 0.16	2.9	14	80 ± 3	29.2 ± 2.0
L2307	2.62 ± 0.1	9.00 ± 0.27	2.04 ± 0.06	3.01 ± 0.17	3.6	11	84 ± 3	27.9 ± 1.9
L2308	2.43 ± 0.1	10.7 ± 0.3	1.89 ± 0.06	2.96 ± 0.18	4.1	11	91 ± 4	30.8 ± 2.3
L2309	2.52 ± 0.1	10.7 ± 0.3	1.88 ± 0.06	2.96 ± 0.18	4.8	7	98 ± 9	33.0 ± 3.6
L2310	2.66 ± 0.1	10.6 ± 0.3	2.08 ± 0.06	3.14 ± 0.18	5.4	7	109 ± 7	34.6 ± 3.1
L2311	2.34 ± 0.1	10.2 ± 0.29	1.83 ± 0.06	2.83 ± 0.17	6.1	6	121 ± 4	42.9 ± 2.9

2. The Youfang site

The Youfang site is located about 500 m south of Youfang village, Yangyuan County, Hebei Province, China (40°14′N, 114°41′E). It was discovered in 1984 and cultural remains were found in the middle and upper parts of a 6.5 m thick loess layer (1.9–3.1 m) believed to be late Pleistocene in age. More than 3000 stone artifacts, mainly made of local volcanic breccia or flint, were unearthed from a 28 m^2 excavation pit in 1986. At the same time, small areas of ash, burned bone, burned soil blocks, ostrich eggshell, fossil shells, fossil *Myospalax* and fossil antelope were also excavated at the section (Xie and Cheng, 1989). The artifacts included 72 cores, 475 flakes, 92 microblades, 13 microblade cores, and 45 stone tools (Fig. 2). Various types of stone implements included scrapers, points, hammer-stones, choppers, burins, backed knives and drills; a considerable proportion of the microblades were produced by indirect percussion and exhibited substantial pressure retouch (Xie and Cheng, 1989; Xie, 2006). Judging from the stratigraphic sequence and the characteristics of the loess, the geological ages of the cultural layer at the site were estimated to be in the latter part of the Late Pleistocene (Xie, 2006). The relative low-temperature (60 °C) infrared stimulated luminescence (IRSL) dating procedure was used to date the samples collected from the site, the ages of the upper cultural layer and lower cultural layer being ca. 14 ka and 16 ka, respectively, without any correction for anomalous dating (Tsuneto et al., 2009). Thus, the estimated IRSL dates were probably underestimates because of athermal loss of feldspar signals (Wintle, 1973, 1977; Spooner, 1992, 1994).

In order to determine the age of this site, quartz OSL signals were employed to isolate the ages of the samples described here. The Youfang sediment section can be divided into two major geological units from top to bottom, i.e. the upper modern soils and the lower loess sequence (Fig. 3) with thicknesses of 0.5 m and 6.8 m, respectively. The upper modern soil is grayish-yellow silt, loose and porous. The lower loess unit consists of grayish-yellow silt with no horizontal bedding but shows a vertical joints system, and archeological remains were discovered in the upper part of this layer (1.9–3.1 m). In late November 2012, we cleaned the Youfang sequence and collected nine OSL samples in order to provide a chronological framework for the site; the individual positions of the samples are shown as red-filled circles in Fig. 3. Three samples (L2304-L2306) from the cultural layer covered the time interval of interest; one sample (2303) and five samples (L2307-2311) from the overlying and underlying units, respectively, were taken in the form of large blocks wrapped with aluminum foil and yellow plastic tape to provide protection against light and breakage during transportation. The number, depth below the ground surface and U, Th, K concentration of the samples are displayed in Table 2.

3. OSL dating

The OSL dating technique was developed in the mid-1980s (Huntley et al., 1985), and is an invaluable technique for dating archeological sites. It has shown improvement in precision and range measurement during the past decade, especially the improved single-aliquot regenerative-dose (SAR) protocol for OSL dating in which a test dose is used to monitor and allow correction for sensitivity change during OSL measurements (Murray and Wintle, 2000). In establishing a chronology for Paleolithic archeological sites, a common approach involves dating of the sediments above and below the layers which yield artifacts or fossil remains. The ages of the sediments embracing the cultural layers provide constraints on the time of human occupation or other activities at the sites.

Medium-grained (45–63 μm) quartz was extracted and used for age estimation in this study. Sample preparation and OSL measurements were performed under low intensity red light conditions using standard methods in the laboratory (Aitken, 1985, 1998). External layers at least 3 cm thick were removed from the block samples as a means of ensuring that no contamination of the grains which had been exposed to daylight during sampling; these samples were retained for dose rate measurements. Etching procedures of the inner core, involving HCl (10%) and H_2O_2 (30%), were carried out to remove carbonates and organic material, followed by wet sieving to isolate the 45–63 μm material. Medium-grained quartz was extracted by silica-saturated hydrofluorosilicic acid (H_2SiF_6) (30%) treatment for three days, and then dissolved with 10% HCl for 60 min to remove any fluorides, and finally washed with distilled water several times. The resulting clean medium-grained quartz grains were mounted on discs as a monolayer (~1.5 mm diameter) with silicone oil for OSL measurements. Infrared (IR) stimulation and the 110 °C TL peak of the isolated quartz were used to check the purity.

The OSL measurements were performed with an automated Risø-TL/OSL DA-20 reader, equipped with a calibrated ^{90}Sr/^{90}Y 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 7.5 mm Hoya U-340 filters (290–370 nm) were used for the quartz OSL measurements. U, Th and K concentrations of all the samples were determined by

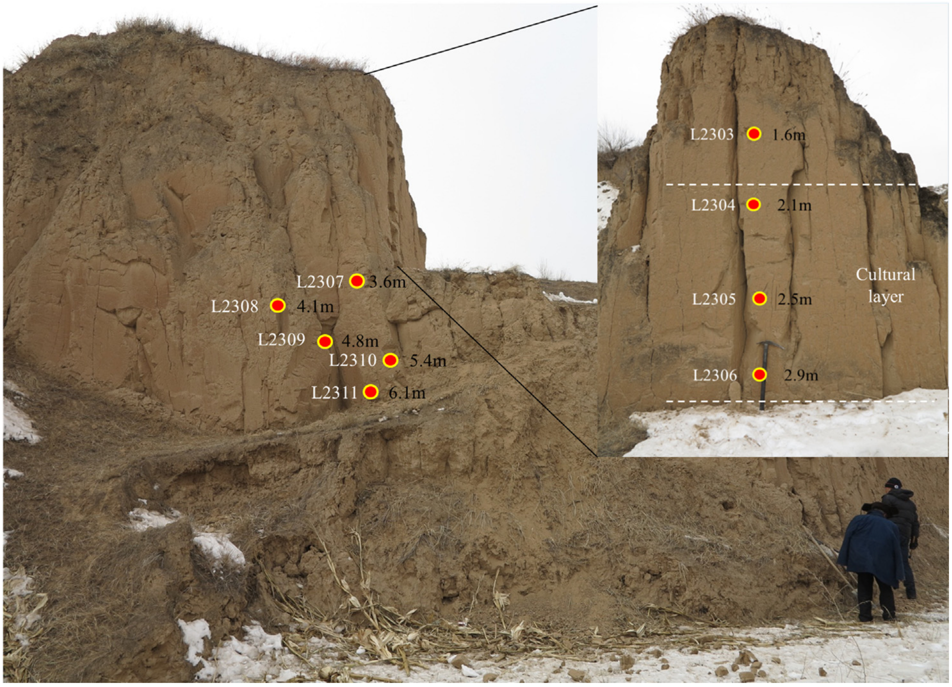

Fig. 3. Section and the sample collection position at the Youfang site.

neutron activation analysis (NAA) (Table 2). An alpha efficiency factor (α-value) of 0.04 ± 0.02 for quartz (Rees-Jones, 1995) was assumed to estimate the alpha contribution to the dose rate. Long-term water contents were assumed to be 20% assigned uncertainties of ±5% for each value in the age calculations. The calculation was performed using the 'AGE' program (Grün, 2009).

The SAR protocol (Murray and Wintle, 2000) was applied to the medium-grained quartz OSL measurements. The D_e value was estimated by interpolation of the natural luminescence signal onto the growth curve, which was built up using regeneration doses, including a zero dose for monitoring thermal transfer effect and repeated first regeneration dose for testing the accuracy of the sensitivity correction. A fixed small test dose (9.26 Gy) was undertaken after the natural/regenerative OSL measurement was used to correct for sensitivity change. A preheat at 260 °C for 10 s and a cut heat at 220 °C for 0 s were used, followed by stimulation of the quartz OSL samples using blue light at 125 °C for 40 s. The first 0.64 s integral of the initial OSL signals minus a background estimated from the last 3.2 s integral was used as a measurement of the last component for the D_e estimation. The Central Age Model (CAM) of Galbraith et al. (1999) was used for age calculation.

4. Results and discussion

The quartz-rich silty samples taken from the Youfang profile were found to give bright and rapidly decaying OSL signals dominated by the fast component, appearing to be well suited to OSL dating (Fig. 4). Dose response curves were fitted using an exponential-plus-linear function for the interpolation of D_e. Criteria of acceptances for the recycling ratio and recuperation ratio were in the range 0.9–1.1 (Wintle and Murray, 2006) and below 5% (Murray and Wintle, 2000), respectively, for the sample aliquots, which were used to screen equivalent doses. The effect of preheat temperature on the evaluation of D_e was examined; a preheat plateau was obtained with sample L2306 for preheat temperatures between 200 °C and 280 °C, with four discs at each 20 °C interval for

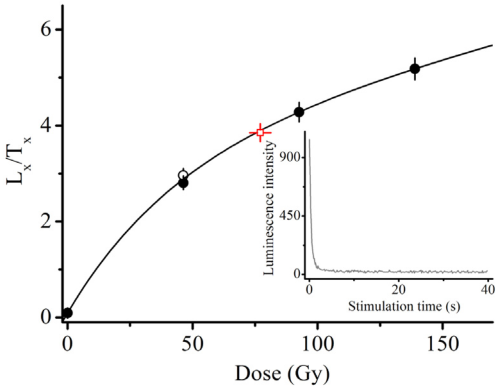

Fig. 4. OSL dose response curve obtained using the SAR protocol for medium-grained quartz of sample L2306; the inset figure shows the natural OSL decay curve for the corresponding sample. Closed circle: regenerative dose; open circle: repeated regeneration dose; open square: natural dose.

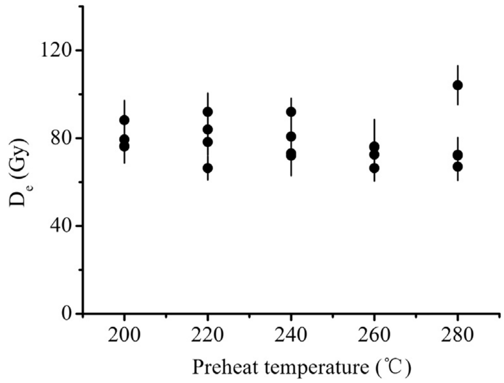

Fig. 5. Preheat plateau for sample L2306 from Youfang profile using medium-grained quartz.

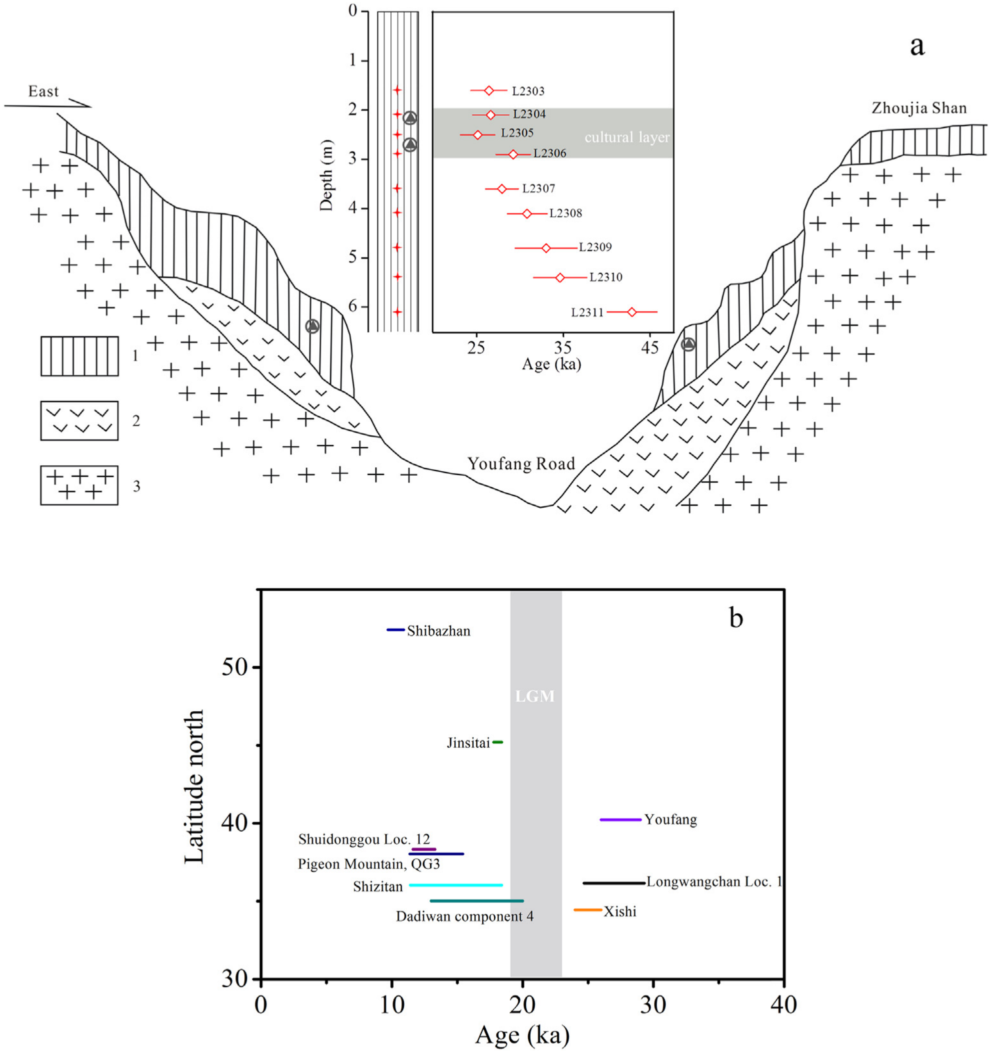

Fig. 6. a) The archaeological deposits of Youfang site showing the stratigraphy profile, OSL samples and their corresponding ages plotted against depth. 1. loess; 2. Jurassic breccia; 3. early Paleozoic volcanic breccia (after Xie and Cheng, 1989). b) The microblade-bearing sites with reliable absolute ages in the text plotted as a function of degrees latitude north.

10 s, a cut-heat temperature fixed at 220 °C for 0 s and a test dose of 9.26 Gy for the SAR protocol, each point representing the average data from four discs (Fig. 5). The preheat plateau test showed that over-dispersion of D_e values was dependent upon preheat temperature; thus a preheat of 260 °C for 10 s and cut heat at 220 °C for 0 s were used for OSL measurement. Finally, a dose recovery test (Murray and Wintle, 2003) was carried out on sample L2306, in which the natural quartz OSL signals were removed by a SOL2 solar simulator for 6 h, and a known laboratory dose of 92.6 Gy was recovered using the SAR protocol presented above; the dose recovery ratio (recovered/given dose) was 0.95 ± 0.03 from six aliquots. The data derived from all aliquots as described above satisfied quartz SAR acceptance criteria.

Table 2 provides a summary of dose rate and the ages of the samples obtained by the SAR protocol with medium-grained quartz grains, at least six aliquots having been measured for each sample. The ages of samples L2304, L2305 and 2306 from the cultural layer with a thickness of 1.2 m were 26.6 ± 2.1 ka, 25.1 ± 2 ka and 29.2 ± 2 ka at depths of 2.1 m, 2.5 m and 2.9 m, respectively. The sample L2303, located above the cultural layer at a depth of 1.6 m below the ground surface, was dated to 26.4 ± 2.1 ka. The five samples, taken from the lower part of cultural layer, yielded the ages of 27.9 ± 1.9 ka, 30.8 ± 2.3 ka, 33 ± 3.6 ka, 34.6 ± 3.1 ka and 42.9 ± 2.9 ka for the samples L2307, L2308, L2309, L2310 and L2311, respectively. It can be seen that nine OSL ages of the samples from the Youfang profile (Table 2) increase from 1.6 m down to 7.1 m and are self-consistent within the limits of experimental error (Fig. 6a). Quartz OSL signals of the eolian loess are usually assumed to be well bleached prior to deposition and so yield reliable OSL ages younger than ~70 ka (see e.g. Qin and Zhou, 2009; Lai, 2010). There is no evidence that the samples from the Youfang site experienced a problem of incomplete bleaching.

The OSL dating of the samples from the artifact-bearing layer at the Youfang site yielded ages of between 26 ka and 29 ka, results implying that microblade assemblages in the Nihewan Basin appeared between 26 ka and 29 ka, thus preceding the LGM. The Youfang deposit is equivalent in age to MIS 3 and the upper part of Loess L1, a period of relatively warm and moist climate. During MIS 3, a series of transitions between warm and cold indicate that temperatures oscillated, which may be the reason for human migration accompanied by microblade tool industries. In the Nihewan area, the loess-paleosol sequence formed after the disappearance of the Nihewan Lake in the Late Pleistocene; for example, the lower boundary of loess-paleosol at Haojiatai site has been dated to ca. 130 ka (Nian et al., 2013), corresponding to the initial phase of the S1 paleosol. The stone artifacts at the Youfang archeological site were found in the top half of the loess profile, the stratigraphic approach pointing to the latter period of the Late Pleistocene based on classic lithostratigraphic analysis (Xie and Cheng, 1989). Thus, our dating results of the profile coincide with the stratigraphic analysis. According to previous studies, the only microblade site with a reliable age earlier than the LGM was Longwangchan in Sha'anxi Province, regarded as a likely pioneer of microblade technology during the period from 25 ka to 29 ka at around 36 °N latitude in the middle reaches of the Yellow River. The Youfang site lies to the northeast of the Longwangchan site, and is located in the Nihewan Basin at ca. 40 °N latitude. Based on the new dating results presented here, it is the oldest microblade site currently known in northernmost China (Fig. 6b).

Yi et al. (2013) recently proposed that microblade technology in north-central China experienced the following two distinct stages of development. In the early stage, microblade technology was uncommon (i.e. before the Younger Dryas), but the technology developed and prospered in the later stage (i.e. the onset of the Younger Dryas), which may be a result of the rise of a microblade technology and high winter mobility driven by the extremely cold environment. The distribution of microblade technology was restricted by the physical (geographical) environment, paleoclimate and resource environment, with differences in microblade manufacture indicating the adaptation of human movements to changes in the environment. During the harsh conditions of the LGM, many groups of forgers moved southward in order to survive (Bettinger et al., 2007), giving rise to frequent population migration and interaction after the LGM.

The OSL ages from the Youfang site presented here are stratigraphically self-consistent within the error limits between ca. 26 ka and 29 ka, suggesting that the OSL ages reflect the true depositional age of the layer. These new ages mark Youfang as the earliest microblade site in North China, given its location farther north compared to the Longwangchan site (ca. 25–29 ka). These results shed new light on a reconsideration of the microblade sequence of North China and hunter–gatherer groups' responses to environmental change during the late Upper Pleistocene. Based on the data obtained above, we can deduce that microblade technologies were introduced from the north, possibly from the Lake Baikal region of southern Siberia and across the Mongolian Plateau (ca. 28–29 ka) (e.g. Kuzmin, 2007); northern hunting peoples migrated southward following the migration of animals during the last glacial period. The Nihewan Basin may be the earliest stopover site, because it is close to the Baikal-Mongolia region and there is no natural barrier against animal and human migration between these two areas. Based on rich archeological discoveries, the Nihewan Basin might well have been an important center of human development in North China and northeast Asia, probably serving as a refuge for humans and animals in harsh environmental conditions with rich food resources, a reliable water supply and suitable lithic raw materials. Therefore, the Youfang archeological site and the large Nihewan Basin, were probably the earliest habitat of hunters–gatherers with microblade tools in North China, and both possess considerable significance for future studies of the emergence of microblade technologies in the region and hunter–gatherer adaptations to environmental change.

5. Conclusions

The ages of the samples from the Youfang Paleolithic site were estimated using the medium-grained quartz SAR protocol. The loess strata bearing microblade assemblages at the site were dated by the OSL technique to ca. 26–29 ka for samples L2304-2306 lying at a depth between 2.1 m and 2.9 m. The OSL ages are self-consistent, their stratigraphic order corresponding to MIS 3 prior to the LGM. The chronology of the deposits indicates that microblade technology appeared in the Nihewan Basin at ca. 26–29 ka, this being the oldest microblade site found so far in the northern high latitudes of China (40 °N) in harmony with a locally suitable environment. Based on the new data, we suggest that one dispersal route for such microblade technologies was the Baikal-Mongolia region, from which human populations migrated southward with their microblade technology, following migrating animals, ultimately appearing in the Nihewan Basin of North China. The early microblade technology in the Nihewan Basin provides significant insights into human adaptability to environmental change at high-latitudes. The Youfang Paleolithic site represents a crucial phase in the origin and dissemination of microblade technologies in North China and the Northeast Asia. Further excavations are needed to improve our understanding of the characteristics and spatial distribution of microblade technologies and the relations between regions.

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