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Environmental reconstruction and dating of Shizitan 29, Shanxi Province: An early microblade site in north China

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ABSTRACT

Global cooling during the Last Glacial Maximum (LGM) posed significant challenges to peoples living in northern Eurasia. Using micromorphology, pollen and non-pollen palynomorphs (NPP), and faunal analyses, this study reconstructs the local paleoenvironmental contexts of repeated ephemeral occupations at Shizitan 29 in Shanxi Province, North China, across the LGM, from *ca.* 28 to 18 Ka cal BP, followed by a gap until a final occupation *ca.*13.5 Ka cal BP. Among the significant finds at Shizitan 29 are remains of 285 hearths and a rich lithic assemblage that contains the earliest radiocarbon-dated evidence for microblades in China, appearing first in Layer 7. The environmental data show that the low mountains and tributary river valleys of the Yellow River in the Loess Plateau provided abundant sources of water and food in spite of environmental fluctuations. Microblade-producing groups repeatedly visiting this locality survived severe climate change by making use of fire, selective herbivore hunting, processing plant foods with grinding stones, and symbolic ornamentation such as ostrich shell beads. NPP data also indicate the potential presence of flax and other fiber processing. The Shizitan 29 data demonstrate how humans adapted to challenging local conditions throughout the LGM, allowing them to stay within this northerly region without migrating to warmer southern latitudes.

1. Introduction

Understanding how Upper Paleolithic mobile hunter-gatherer groups adopted temporary or permanent solutions when faced with climate change raises the question of the sustainability of subsistence in the affected area. During the Last Glacial Maximum (LGM), groups that formerly survived for many generations in certain regions faced potential extinction unless they could adapt to worsening environmental conditions. Their options included technological innovation and cultural, economic, and social change to stay in place, or long distance migration to regions with better conditions: any of these would have an impact on the archaeological record where these groups lived. In this paper, we describe research on the changing environmental conditions at the Shizitan 29 site (Song and Shi, 2017) whereby we can establish the environmental contexts of the various technological and cultural adaptations indicated in the archaeological record.

Shizitan 29 was occupied ephemerally but repeatedly from ca. 28 Ka cal BP to 18 Ka cal BP (dating discussed below), meaning humans were active at the site from before and throughout the LGM. Because of its location and long sequence during one of the most severe cold ages of the Pleistocene, studying Shizitan 29 offers a unique opportunity to learn about adaptations to LGM climate

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change in the northern latitudes of eastern Eurasia. The LGM is signified by the largest extension of land-based ice sheets and a continuous reduction in air surface temperatures causing drier conditions (Clark et al., 2009). However, although colder, many mid-latitude glaciers retreated at this time due to increasing aridity, including in East Asia (Hughes et al., 2013; Hughes and Gibbard, 2015). The substantial cooling during the LGM as defined in the Greenland Ice Core record is correlated with Greenland Stadial 3, which represents the period 27.54 to 23.34 Ka cal BP. The end of the LGM event is marked by Heinrich Event 2, the period marking the onset of the collapse of the Laurentide Ice Sheet at ca. 24 Ka, along with other ice sheets in the North Atlantic region. Earlier publications on the Chinese Upper Paleolithic often refer to the LGM as falling between ca. 24-18 Ka cal BP, so this more recent chronological definition that is based on the coldest period, i.e., Greenland Stadial 3 (Hughes et al., 2013; Hughes and Gibbard, 2015), forces us to look carefully again at correlations with the archaeological record, which indicates a progressive depopulation in Europe and North Asia after 25 Ka BP (Gamble et al., 2004), and in China possibly around the same time period north of 41° latitude (Barton et al., 2007; Gao and Dennell, 2014; Ji et al., 2005; Yi et al., 2016).

The Loess Plateau of northern China already provides preliminary clues concerning the impact of the LGM on the distribution of sites: although the number of dated Upper Paleolithic sites is limited, there is a clear decrease during the LGM (Barton et al., 2007; Qu et al., 2013; Yi et al., 2016). The northernmost sites that remain during this period include Youfang in Hebei Province (40°14′ N, 114°41′ E) (Nian et al., 2014), the Shuidonggou localities in Ningxia Province (38°21 N, 106°29′ E) (Pei et al., 2012), the Shizitan localities in Jixian, Shanxi Province (36°2′ N, 110°35′ E), Longwangchan in Shaanxi Province (36°9′45″N, 110°26′15″ E) across the Yellow River from Shizitan (Yin and Wang, 2007; Zhang et al., 2011), and Xiachuan, also in Shanxi (35°25′ N, 112°00′ E) (Wang et al., 1978; Shi, 1989; Chen, 1996; Tang, 2000). The excavations of these sites show ephemeral occupations during the LGM. The evidence from Shizitan 29 facilitates testing the impact of LGM climatic conditions on humans at this locality.

Shizitan 29 is one of a cluster of localities first discovered in the 1980s situated on the terrace of the Qingshui River in the loess highlands of Jixian County (Fig. 1). The first excavated and reported site, then called Shizitan (Linfen Administrative Bureau of Culture, 1989), is now referred to as Locality 1 (Fig. 1). From 2000 to 2010, excavations were carried out at Locality 9 (Shizitan Archaeological Team, 2010; Liu et al., 2013; Song, 2012; Sheahan et al., 2014), Locality 12 (Zhao, 2008; Shizitan Archaeological Team, 2013b), Locality 14 (Shizitan Archaeological Team, 2002, 2013a; Liu et al., 2013), and Locality 29 (Song and Shi, 2017). Shizitan 29, discussed here, is a locality with deposits spanning across the entire LGM, and so its study provides us a rare insight into hunter-gatherer behaviors in northern latitudes in China throughout this cold period.

The present study of Shizitan 29 is unique for its acquiring of a systematic series of radiocarbon dates and the combined application of soil micromorphological, pollen and non-pollen palynomorph (NPP), and faunal analyses in order to reconstruct the paleoenvironmental background of human occupations and cultural adaptations. Furthermore, the large scale of the 1200 m^2 of excavated deposits, reaching 15 m in depth, provides a rich dataset unmatched by other local LGM sites. The NPP analysis is also new to China. In other world regions, the potential of NPP studies for environmental reconstruction has been demonstrated, most often in lake boreholes, but in this study we further show the potential for NPPs to reveal not only evidence for the immediate environment of the site but also for human activities (e.g., Van Geel, 1998; Van Geel and Aptroot, 2006). Although further research and analyses are necessary to clarify NPP findings of fibers in the Shizitan 29 samples, there are indications of the presence and perhaps processing of flax fibers and wool. These materials have not previously been found in Paleolithic contexts in China, but their microscopic presence in the cultural strata at the site, which still should be supported by additional studies before further conclusions can be drawn, may indicate that such fibers were part of the suit of local adaptations to cold climate.

2. Stratigraphy and cultural components

2.1. Stratigraphy

Shizitan 29 (36°2′54″N, 110°35′22″ E) is located 723 m above sea level approximately 500 m east of Shizihe Village, Jixian County, Shanxi Province (Figs. 1 and 2). It is the largest excavated site among the Shizitan group, and it provides a continuous depositional sequence through the LGM, with wide horizontal exposures showing human activity (e.g., 285 hearths) in multiple layers through 15 m of deposits (Figs. 3 and 4). The 1200 m^2 area was excavated because a new highway was being constructed through the site. The excavations were carried out by a joint team from the Shanxi Provincial Museum and Shanxi University Archaeology Department from March 2009–October 2010, with breaks during colder weather, typically with a team of at least 30 members excavating. During the excavations, eight cultural layers (defined below) up to 1.5 m thick [Level 7]) were exposed, with the basic excavation unit being 1 m × 1 m squares divided into quadrants and typically dug in spits of 10 cm. Proveniences of lithics and other cultural materials were recorded in three dimensions during excavation using a level for depth measurements from datum and tape measurements for horizontal distances from the site datum. Smaller artifacts and ecofacts were also recovered through dry and wet screening of fill and recorded by square and depth. Of the eight assemblages, those from Layers 7-1 are characterized by the presence of microblades (Table 1). Hearths and artifacts were exposed in every cultural layer, with a total of 285 hearth features and more than 75,000 artifacts. Only very few artifacts were found in the 0.5–1.5 m thick, mostly redeposited loess accumulations that separated each of the cultural Layers 1–7. Micromorphological study of samples from the cultural and natural layers is included in this study (below) and informs us of several shifts in the depositional history of the site that could be tied to environmental changes during LGM.

It should be noted that the term “cultural layer” is the common terminology used in Chinese archaeological literature for defining a layer within which human occupation, artifacts, and other signs of anthropogenic inputs are exposed. Hence, a “cultural layer” is also a well-defined stratigraphic unit, similar to the “ethno stratigraphic unit” as discussed in Stein (1990). Such cultural layers form the archaeological sequence. For consistency with the literature, we retain the use of the term in this report. The natural layers between the cultural layers are distinguished by their apparent lack of anthropogenic inputs, but low numbers of artifacts can sometimes be found within them, either from ephemeral and limited human activity or post-depositional agencies.

A large number (285) of exposed hearths in the various layers at Shizitan 29 provides a rare dataset into human behavioral patterns and activities associated with pyrotechnology over the long history of the site (Fig. 5). Features recognized to be hearths were uncovered in every cultural layer. The criteria to identify features as hearths were combinations of the following: their rounded shapes in plan view and lens shape in profile; the presence of reddened earth, likely from firing, thicker at the central area of the lens; the presence of burnt bone and charcoal; and the occasional presence

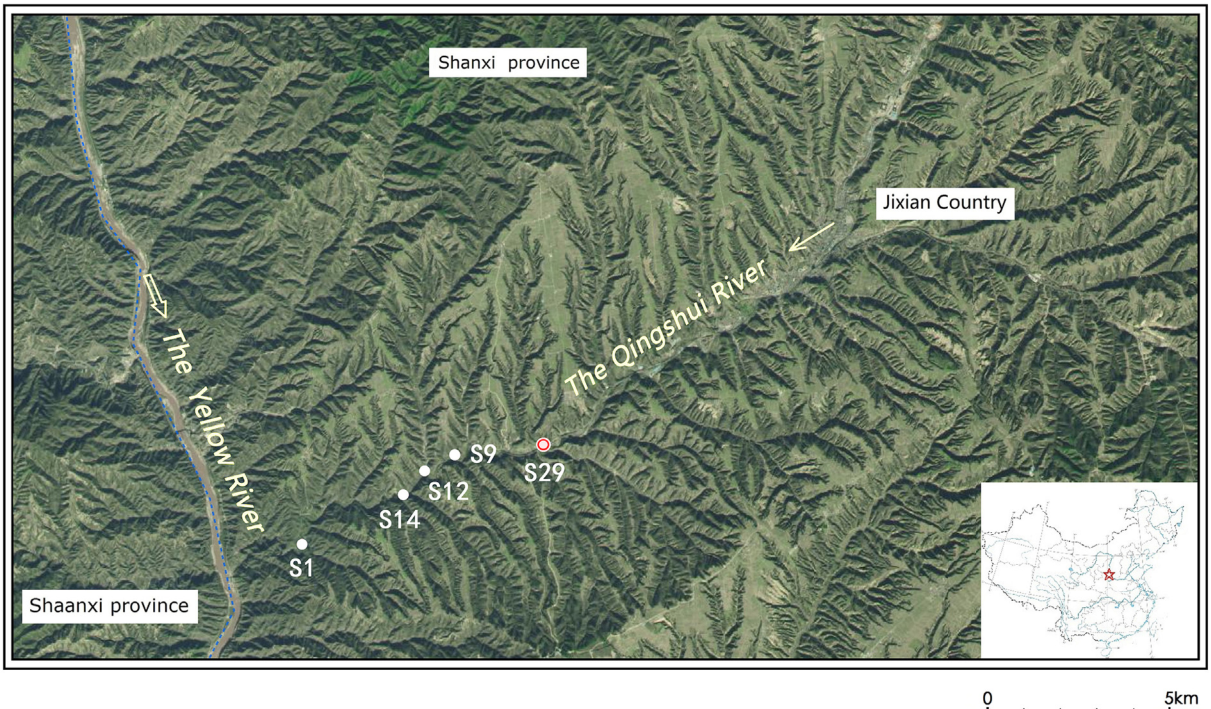


Fig. 1. The geographical position of Shizitan 29 and other Shizitan Paleolithic localities along the Qingshui River, Shanxi Province.

of burnt sandstone (recognized by color and by fissures on its surface).

The area of each hearth was less than 1 m^2, and they were generally of irregular, rounded shape. At the bottom of most, the underlying substrate was reddened, with the rubefication being thicker in the center and thinner at the edges of the hearths. 232 (81%) hearths featured artifacts (primarily lithics), animal bones, and charcoal specks distributed around them (Table 1; Fig. 5),

Fig. 2. The landscape of Shizitan 29 before the construction of the new highway across the site (from west to east).

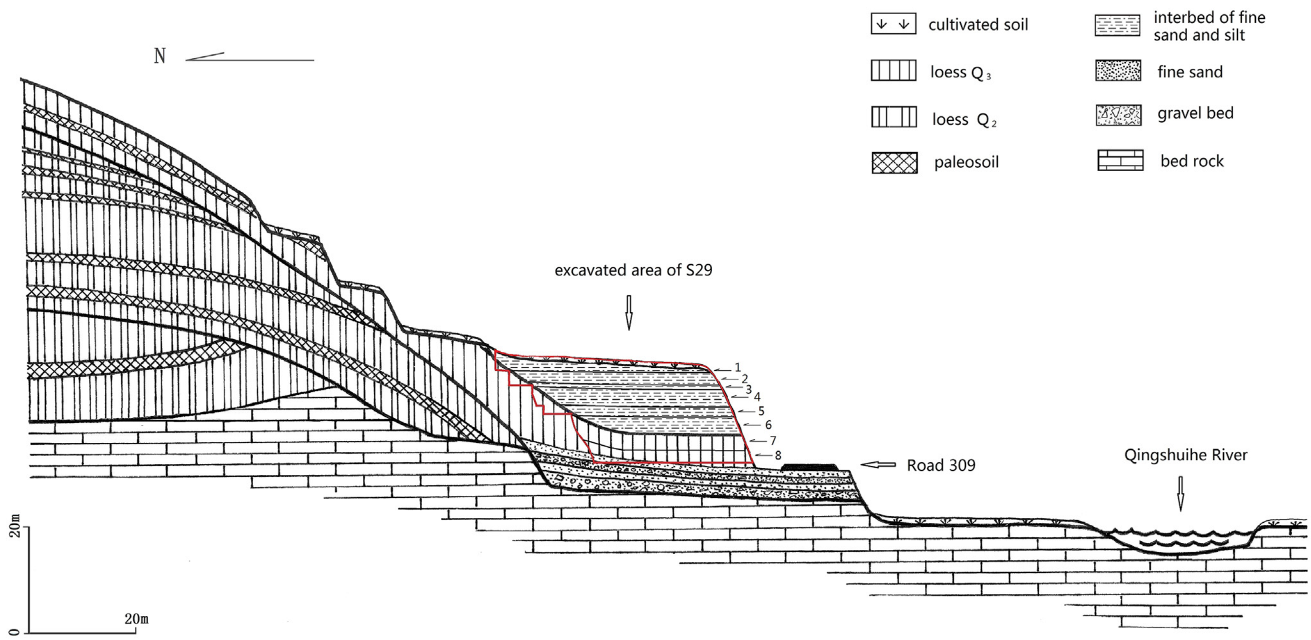


Fig. 3. Stratigraphic profile of the terrace and excavated area of Shizitan 29.

possibly indicating repeated use over a certain period. The associated artifacts include occasional grinding stones, pigments, and ornaments made of shells and ostrich eggshell (Song and Shi, 2013). The other 53 hearths were devoid of artifacts and charcoal: this may indicate shorter-term use, with the absence of charcoal perhaps the result of wind or runoff.

2.2. Stone artifacts

A rich assemblage of 74,735 lithic artifacts were retrieved during the systematic excavations at Shizitan 29 (Table 1). These combined with the stratified deposits and large series of radiocarbon dates provides an unprecedented opportunity to study changes in lithic

Fig. 4. The stratigraphic section and cultural layers at Shizitan 29. Left scale (in blue) is 11 m in length. Red vertical bars mark the thicknesses of cultural layers 1–8 (note: Layers 2 and 1 are seen in the north section, to left). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Excavated area and thicknesses of cultural Layers 1–8 at Shizitan 29 and counts of their cultural contents, including hearths, animal bones, stone artifacts, shell, and ostrich eggshell beads.

Cultural layer	Total excavated area (m^2)	Average thickness (min-max depth in cm below datum)	Hearth count	Bone count	Stone Artifacts (microcores, microblades)	Shell (perforated shell)	Ostrich eggshell beads
1	400	30 (35–65)	4	476	3410 (7, 109)	0	0
2	1000	120 (162–282)	75	680	2612 (64, 358)	1	2
3	1000	50 (279–336)	17	369	2120 (25, 187)	9	0
4	700	180 (465–640)	94	1162	10,691 (129, 722)	7	0
5	800	80 (747–828)	54	568	7153 (88, 609)	1	0
6	800	110 (961.5–1076)	38	1128	5655 (54, 803)	0	0
7	800	200 (1100–1300)	3	1308	42,928 (23, 2489)	5 (1)	18
8	300	200 (1300–1500)	0	58	166 (0, 0)	0	0
Total	5800	970	285	5749	74,735 (390, 5277)	23	20

technology across the LGM period, including one of the earliest appearances of microblade technology in China (e.g., Zhang et al., 2011; Yi et al., 2014, 2016). Stone raw materials are mainly flint and quartzite, with some quartz, as well as sandstone, mudstone, agate, and other cryptocrystalline rocks. The lithics consist mainly of hammers, cores, flakes, microcores, microblades, debitage (including chunks, chips, and other debris), and tools, including scrapers, end-scrapers, points, bifacial points, burins, notches, backed knives and grinding stones. The lithic types vary in relative frequencies through the different layers (Song and Shi, 2017).

Layer 8, the earliest cultural level and predating LGM, unlike Layers 1–7, contained no evidence for the production or use of microblades. Its quartzite assemblage is dominated by flakes produced by hard-hammer percussion. There are few tools, but the most common types are scrapers that have an uneven retouched edge (Fig. 6a) and pièce esquillées.

In Layer 7 (Table 1) microblade cores and microblades first appear in the upper part of the layer and continue through Layer 1; these appear with various types of tools (Fig. 6b–h). The presence of this new lithic technique at Shizitan 29 is one of the earliest examples for the appearance of microblades in northern China. The other site with early microblade production in northern China, but with limited reporting, is the nearby site (ca. 20 km) of Longwangchan (Shaanxi), which has overlapping OSL dates with Shizitan 29 (Zhang et al., 2011; Yi et al., 2016). In Layer 7, and occasionally in Layer 6, together with the microlithic bladelets, some typical blades, including blade-blank items, were found (Fig. 6i–k). Bifacial points are found in Layers 1–3 only, with sizes decreasing from Layer 3 to Layer 1 (Fig. 6l–m).

2.3. Faunal materials

During excavations, 5749 animal bones were plotted *in situ*, but the overall number of faunal materials recovered was much greater, with higher counts than the lithic materials (the faunal analysis is ongoing) (Table 1). Most animal bones were apparently affected by fire, turning black or gray, and some were fully burnt and broken into small pieces. Among a preliminary sample of bones analyzed, seven large mammal genera were identified based on diagnostic teeth and antler fragments (Table 2).

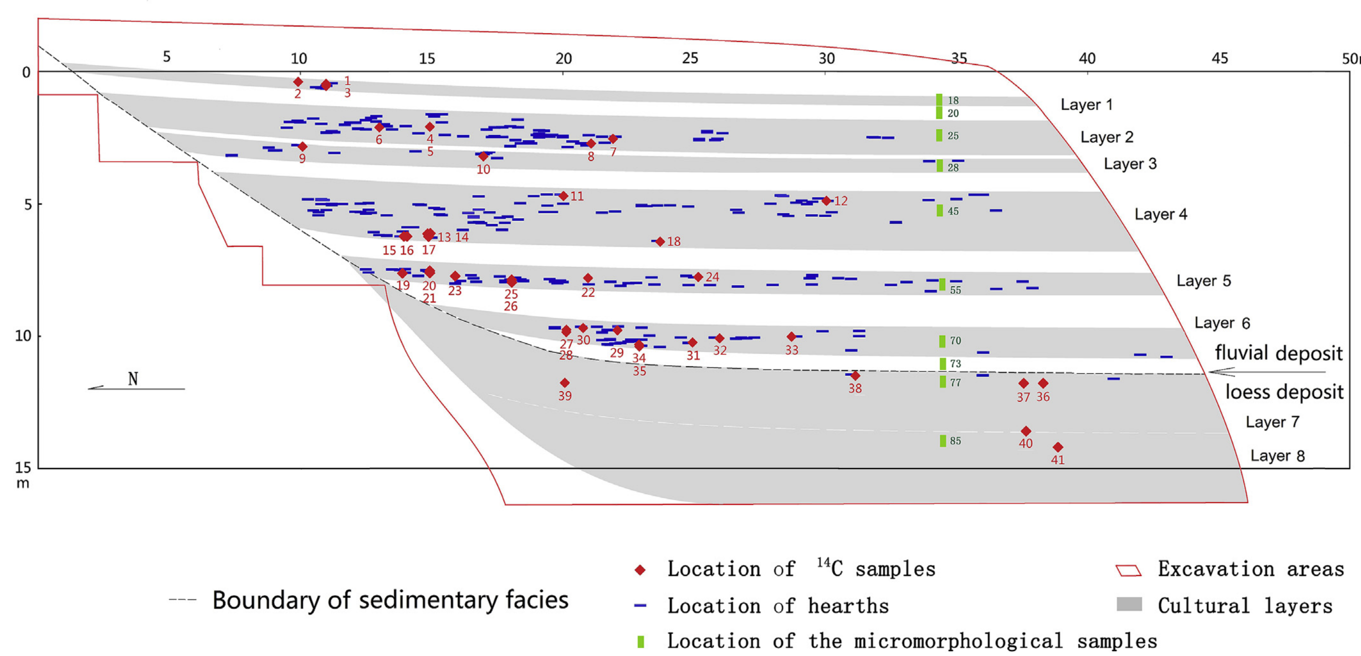


Fig. 5. East profile of Shizitan 29 showing the cultural layers and locations of the micromorphological samples, with superimposed vertical and north-south positions of the hearths ^{14}C samples.

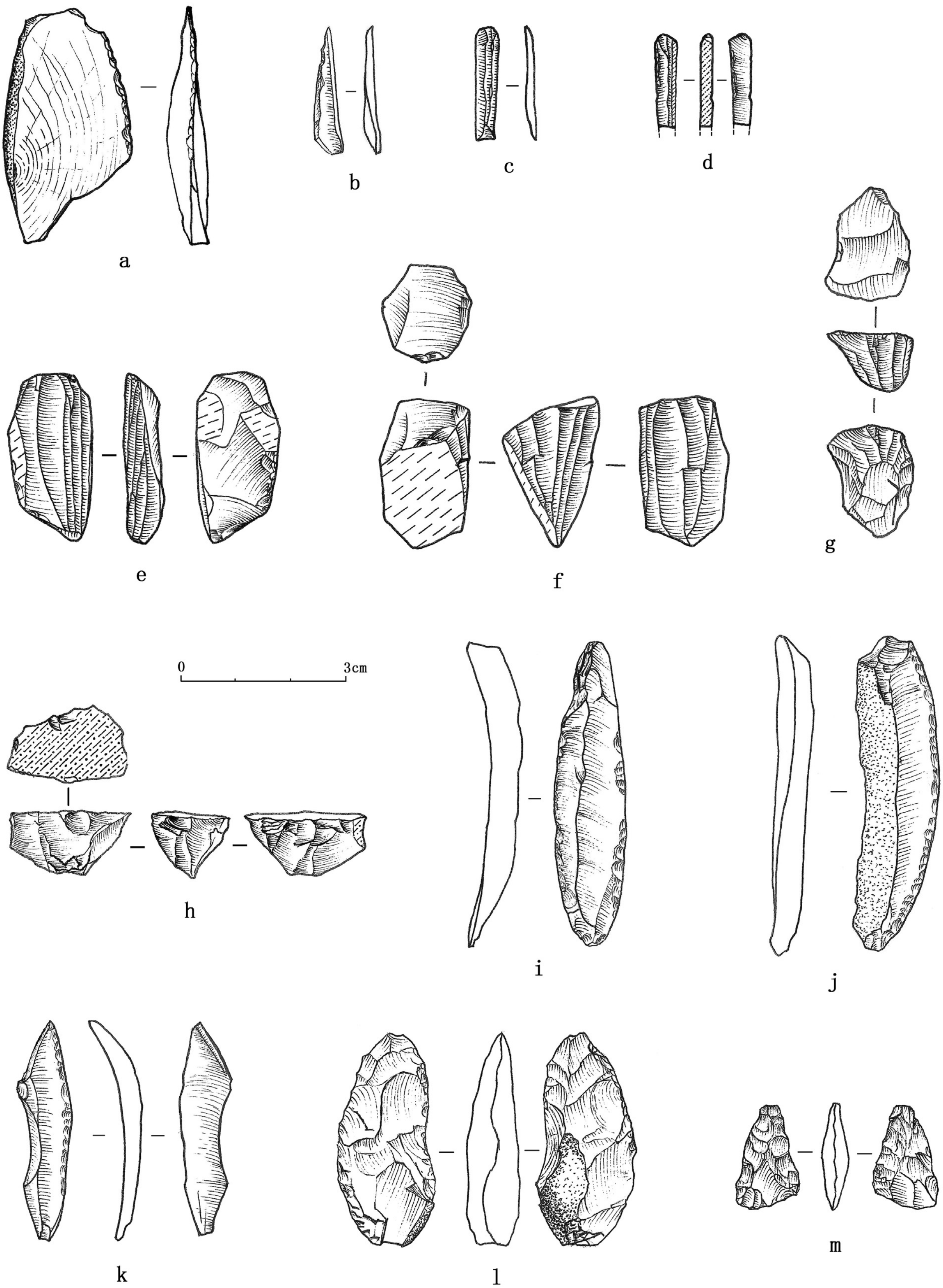


Fig. 6. Representative lithic artifacts from Shizitan 29. a. scraper (CL8:13,678); b-d. microblades (CL7:11,514; CL7:13,648; CL7:70-105); e-f. semi-conical microcores (CL7:11,368; CL7:12,785); g-h. boat-shaped microcores (CL1:640; CL6-7:11,222); i-j. retouched blade (CL7:67-100; CL7:61-94); k. blade-blanked burin (CL7:12,998); l-m. bifacial points (CL3:89-99-2; CL1:297).

Based on this information, here we only can offer preliminary observations. In Layer 8, all the identified bones were *Megaloceros ordosianus* (a giant deer species). In Layer 7, *M. ordosianus*, middle-sized Cervidae, and *Equus* sp. (likely *Equus caballus*/*Equus ferus* or *Equus hemionus*) are present. As browsers, most deer species can live in a variety of biomes ranging from tundra to tropical rainforest, but often prefer forested areas. Nearly all sites that yield bones of *M. ordosianus* were in transitional areas between forest and prairie (Xie et al., 1995), so during Layer 8, the region may have been more humid, with denser forests suitable for such browsers to live. Layer 7, with Equids appearing, may have seen continued forest cover but expanding steppe. In Layer 6, *Procapra przewalskii* (Przewalski's gazelle) appears. *Procapra przewalskii* as well as *Equus* often inhabit steppe or semi-desert zones (Dongwei and Li, 2008; Dengtao, 1999; Smith and Xie, 2008). Layer 5 may represent a major shift in the animals represented at the site, with *Equus* and Cervidae no longer present, and Ovibovinae and *Bos primigenius* (aurochs) appearing for the first time, along with *Procapra przewalskii*. The significance of this change, if not just due to sampling, needs to be investigated further to see if it is related to changing temperature and aridity that cause shifts in the ranges of these species, or if it is related to changes in exploitation patterns by humans. Bovidae such as *Bos primigenius* and Equidae are grazers that usually live in open grasslands (Zong, 1984; Dongwei and Li, 2008). In Layer 4, cervids and *Equus* return, perhaps indicative of ameliorating conditions, and they persist through Layer 3. In Layer 2, only *Procapra przewalskii* and *Equus* are represented, and no cervids are present. In Layer 1, after a five millennium gap, *Equus*, *Megaloceros ordosianus*, and *Bos primigenius* are present: the return of *M. ordosianus* may indicate the return of forests and warmer, more humid conditions.

The NPP analysis (below) indicates that wool fibers are present in the samples in a number of layers. Among the fauna identified at the site, wool fibers could have originated from certain Ovibovinae (such as muskox). We also ask if *Procapra przewalskii* could possibly have a cold-adaptation for woollier hair in LGM conditions, such as seen in the Tibetan Antelope (*Pantholops hodgsoni*), but this needs further investigation.

Table 2
Identified large mammalian bones from Shizitan 29 by layer.

Layer	Animals	NISP	%	MNI
1	*Equus caballus/Equus przewalski*; *Equus hemionus*	3	16%	1
	Megaloceros ordosianus	15	79%	1
	Bos primigenius	1	5%	1
2	*Equus caballus/Equus przewalski*; *Equus hemionus*	13	45%	1
	Procapra przewalski	16	55%	1
3	*Equus caballus/Equus przewalski*; *Equus hemionus*	52	38%	2
	Megaloceros ordosianus	20	14%	1
	Ovibovinae	41	29%	2
	Procapra przewalski	27	19%	2
4	*Equus caballus/Equus przewalski*; *Equus hemionus*	30	18%	2
	Ovibovinae	6	3%	1
	Procapra przewalski	51	30%	1
	Megaloceros ordosianus	48	28%	1
	Cervidae	37	21%	2
5	Ovibovinae	20	33%	1
	Procapra przewalski	26	42%	1
	Bos primigenius	15	25%	1
6	*Equus caballus/Equus przewalski*; *Equus hemionus*	119	59%	3
	Megaloceros ordosianus	34	16%	1
	Cervidae	8	4%	1
	Procapra przewalski	42	21%	2
7	*Equus caballus/Equus przewalski*; *Equus hemionus*	39	30%	2
	Megaloceros ordosianus	80	61%	2
	Cervidae	12	9%	2
8	*Megaloceros ordosianus*	6	100%	1

3. Radiocarbon dating

Shizitan 29 provides the longest series of radiocarbon dates for a microlithic site in China and a well-dated sequence across the LGM, which so far has been lacking from other sites. We consider here a total of 39 animal bone and charcoal samples collected with three-dimensional provenience from the cultural layers and dated by Accelerator Mass Spectrometry (AMS) at Peking University (Table 3) (see Supplementary Materials S4 for excluded samples). Most were collected from hearths (Fig. 5), except for samples 36, 37, 39, 40, and 41 from sediments in cultural layers 7–8.

In the Radiocarbon Laboratory at Peking University, all the samples were observed under the microscope, and the charcoal fragments were picked and separated carefully from roots. Clay particles adhering to the charcoal were removed by repeated ultrasonic cleaning, after which the charcoal samples were treated with an acid/alkali/acid process, and then dried in a vacuum oven. For the bone samples, preparation followed established methods (Talamo and Richards, 2011; Yuan et al., 2000): the outer surfaces were removed by drilling, leaving only clean and hard parts of the bone; these remaining parts were cut into small pieces and treated with the acid/alkali/acid process. Hydrolysis was carried out in pH3 acid solution at 90 °C for 24 h, after which ultra centrifugation results in a gelatin solution. The gelatin samples were ready for use after the lyophilization. The graphite for AMS measurements was obtained by hydrogen reduction on Fe powder. The calibrated ages were converted using the OxCal radiocarbon calibration program version is 4.2 and the IntCal13 calibration curve.

Four dates (samples 4, 21, 34 and 39) appear to be outliers, having significantly younger dates than others in their layer, possibly due to penetration of ground water, as suggested for aberrant dates at Longwangchan located 20 km west of Shizitan 29 on the opposite bank if the Yellow River (Zhang et al., 2011), or displacement by roots, as the site is on a hillside sloping down to the river. These dates were excluded from further consideration, although Sample 4, if derived from human activity could still indicate that people were using this locality at ca. 10.3 Ka cal BP.

The remaining 35 determinations show a clear overall trend from older to younger (Fig. 7). Layer 8 predates LGM, with the first occupation at the site at ca. 28 Ka cal BP. Layers falling within Greenland Stadial 3 LGM (27.54–23.34 Ka cal BP) would include Layers 7, 6, and 5, and possibly part of Layer 4. The earliest microblades and microcores at the site, from within the upper half of Layer 7, thus appear during LGM. Layers 4-2 continue the occupations until *ca*. 18 Ka cal BP, when the site is abandoned for 4–5000 years until the Layer 1 occupation from *ca.* 13.2 Ka cal BP. The end date of occupation for Layer 1 is uncertain, but Sample 4 could indicate that it was at the beginning of the Holocene.

The large series of radiocarbon dates also allows us to notice a recurrent pattern of charcoal dates in a given layer or hearth cluster being older by millennia (calibrated) than bone dates. For example, in Layer 2, the charcoal dates are 1000 years earlier (calibrated) than the bone dates, and in Layer 6, 3000 years earlier. The reasons for this need to be sought, as it is unlikely that the burning of old wood collected around the site could explain this phenomenon. We also suggest that bone dates overall may be more accurate. This observation demonstrates that caution is needed in comparing radiocarbon dates between sites in North China obtained on these different materials. We also note that most sites from this period

Table 3
Radiocarbon dates by layer from Shizitan 29.

	Lab No.	Material	Layer	Depth (cm)[a]	^{14}C age (yr BP)[b]	Calibrated age[c] (yr BP, 95.4%)
1	BA10129	Bone	1	63	11,175 ± 60	13,152–12852
3	BA101412	Bone	1	63	11,390 ± 50	13,332–13106
4[d]	BA101413	Bone	2	199	9190 ± 45	10,456–10245
5	BA101414	Bone	2	203	14,650 ± 70	18,026–17623
6	BA10132	Bone	2	200–206	15,725 ± 80	19,187–18793
7	BA10131	Charcoal	2	248	16,760 ± 65	20,443–20007
8	BA101416	Bone	2	276	15,390 ± 70	18,811–18502
9	BA101419	Bone	3	282	17,200 ± 50	20,936–20564
10	BA10133	Bone	3	303	17,360 ± 60	21,181–20711
11	BA101420	Bone	4	465	17,500 ± 70	21,398–20885
12	BA10134	Bone	4	469	16,170 ± 50	19,703–19316
13	BA10135	Bone	4	605	16,930 ± 50	20,598–20217
15	BA101422	Bone	4	620	16,750 ± 80	20,460–19979
16	BA101421	Bone	4	622	18,570 ± 60	22,587–22312
17	BA101423	Bone	4	624	19,210 ± 80	23,444–22892
18	BA10136	Tooth	4	640	17,040 ± 60	20,753–20340
19	BA10137	Bone	5	772	18,360 ± 70	22,426–21974
20	BA10485	Charcoal	5	787	20,420 ± 80	24,922–24268
21[d]	BA10486	Bone	5	787	11,980 ± 50	14,014–13722
22	BA101426	Bone	5	750.5	19,650 ± 100	23,977–23381
23	BA101427	Charcoal	5	751.5	19,510 ± 70	23,764–23193
24	BA101428	Charcoal	5	750.5	19,940 ± 70	24,233–23760
25	BA101429	Charcoal	5	804	19,710 ± 80	23,999–23484
26	BA101430	Charcoal	5	801.8	19,860 ± 70	24,135–23656
27	BA101431	Bone	6	968	18,140 ± 80	22,275–21761
28	BA101433	Charcoal	6	964	20,410 ± 80	24,910–24255
29	BA101434	Bone	6	964	19,850 ± 80	24,139–23629
30	BA121954	Tooth	6	961.5	20,155 ± 45	24,420–24016
31	BA10487	Charcoal	6	1004	20,500 ± 100	25,066–24337
32	BA10488	Bone	6	1004	18,090 ± 70	22,191–21682
33	BA121951	Bone	6	1004	18,280 ± 45	22,342–21927
34[d]	BA101436	Bone	6	1025	13,250 ± 60	16,137–15723
35	BA101438	Charcoal	6	1026	20,350 ± 90	24,835–24150
36	BA121960	Bone	7	1160	21,690 ± 80	26,100–25789
37	BA101439	Bone	7	1160	19,650 ± 80	23,945–23414
38	BA101442	Charcoal	7	1160	20,010 ± 70	24,302–23850
39[d]	BA101441	Charcoal	7	1250	12,540 ± 70	15,136–14353
40	BA101445	Bone	7–8 boundary	1355	20,510 ± 90	25,056–24363
41	BA101444	Charcoal	8	1425	24,185 ± 90	28,524–27925

BA = Radiocarbon Laboratory, Peking University.
[a] Note 1: Depth is centimeters below the datum of the excavations.
[b] Note 2: Half-life of the ^{14}C is 5568 years; BP means date before 1950.
[c] Note 3: Calibration done using OxCal 4.2 (https://c14.arch.ox.ac.uk/oxcal.html) and IntCal13 (Reimer et al., 2013).
[d] Dates considered to be outliers.

when microblade industries are common in North China have been dated using charcoal dates, and these dates may perhaps be "too old".

4. Paleoenvironmental reconstruction

4.1. Soil micromorphology

Ten sediment sample blocks for micromorphological analysis were collected from the east section of the excavation from each cultural layer and the natural layer between Layers 1 and 2, and the transitional boundary between 7 and 8 (Fig. 5). The consolidated blocks (20 × 15 × 10 cm) were bound tightly in soft paper and plastic tape for transport, and then dried and impregnated with polyester resin and processed into 20.5 × 13 cm thin sections at the School of Civil and Resource Engineering, University of Science and Technology, Beijing. The thin sections were sent to the Micro-Stratigraphy Laboratory, Boston University, where they were scanned at 300 dpi on a flatbed scanner and examined with a petrographic microscope from 20× to 200×. The nomenclature used follows that of Courty et al. (1989) and Stoops (2003).

Overall, the composition of the samples consists of silt-sized grains of quartz, mica (muscovite and biotite), calcite, and various heavy minerals, although the proportions vary from one slide to another. Most sediments are compact and massive, although sample 85 from Layer 8 is more granular, being a product of extensive bioturbation. For most of the samples, porosity is expressed in the form of small biovoids produced by soil fauna, but more characteristically of channels and pores resulting from rooting, presumably grasses.

The lowermost sample, sample 85 from Layer 8, is markedly different from the overlying ones: it is somewhat more clayey overall and was extensively and repeatedly burrowed; the latter is microscopically expressed as loose fine aggregates and loose packing voids between the bioturbated aggregates (Fig. 8a). It also contains some coarser, sand-sized grains. In light of its clay content, it does not appear to be aeolian silt (loess) but more likely a colluvial deposit. Furthermore, its extensive bioturbation points to incipient soil formation, which explains the temporal gap between it and the overlying Layer 7.

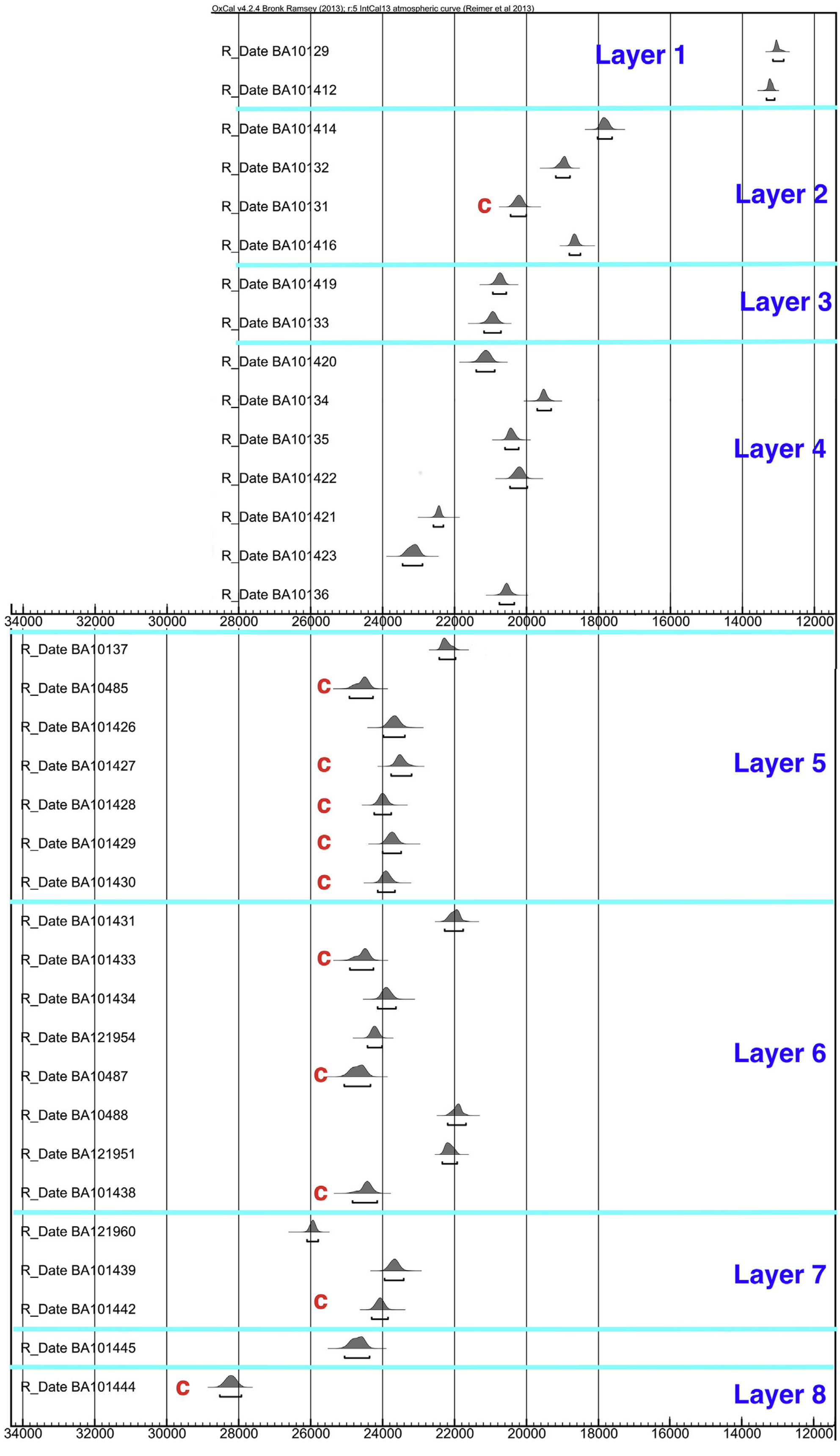


Fig. 7. Age distribution of the radiocarbon samples analyzed from Shizitan 29, excluding outliers (see Section 3). The samples are ordered according to stratigraphic depth following Table 3. "C" indicates charcoal samples, with the remainder being bone samples.

Layer 7 (**sample 77**) is massive, well-sorted silt and is consistent with being an aeolian deposit; a few, poorly developed hypocoatings were also observed (Fig. 8b) as well as in sample 70 from Layer 6. The occurrence of these weakly developed calcareous features in these sediments from the lower part of the profile might be significant and point to somewhat drier conditions during and after the accumulation of these layers, which is consistent with its probable aeolian origin.

Sample 73 (between Layers 7 and 6) is for the most part similar to sample 77 in its overall composition and compact silty nature, although it exhibits some brown silty clay void coatings, along with silty clay intercalations in what appears to be a small animal burrow.

Bedding is clearly present in most of the samples from Layer 6 to Layer 2. Commonly, these laminated bands had been reworked and appear in the samples as millimeter-sized clasts. For example, sample 45 from Layer 4 shows beds of millimeter-sized angular gravel composed of aggregates of silty clay, very localized quartz sand, rock fragments (e.g., shale) and a coarse sandy unit that could be seen to erode slightly the underlying silt (see the arrow in Fig. 8c). This sample also displays finely laminated fine silt and clay (Fig. 8c). Sample 70 from Layer 6 exhibits similar features, such as cross-bedding with intercalations of dusty reddish brown clay, fine silt and clay (Fig. 8d). In addition, one snail shell fragment occurs in sample 55 from Layer 5.

Some fissures occur in the layers, as seen in sample 18 from Layer 1. These could explain the aberrant date of radiocarbon Sample 4 at the top of Layer 2 (Table 3).

In sum, the micromorphology shows that the earliest deposits at the site (Layers 8 and 7) are aeolian, while the overlying layers are fluvial. At present, while climate change could be a factor, localized changes in the channel of the Qingshui River, with channel migration in the direction of the site, is a factor, too. Also, the river clearly overtopped its banks and flooded the site periodically in between occupations, but the low-energy overbank deposits did not disturb most of the well-defined hearths. With its location on a slope toward the river, there is a colluvial component, as well, as is also seen by the inclination of the units from north to south toward the river. The micromorphology shows that the Shizitan 29 locality was not in constant use by humans, but rather a location occupied ephemerally but repeatedly, sometimes in a relatively frequent manner, but also likely at times following extensive periods of non-use. However, based on the overlapping histories of occupation of other localities in this valley, we suggest that human groups were likely constantly in the general region during the LGM and after.

4.2. Pollen and NPP sampling

The study of non-pollen palynomorphs at Shizitan 29 is one of the first applications of this technique in archaeology in China. As

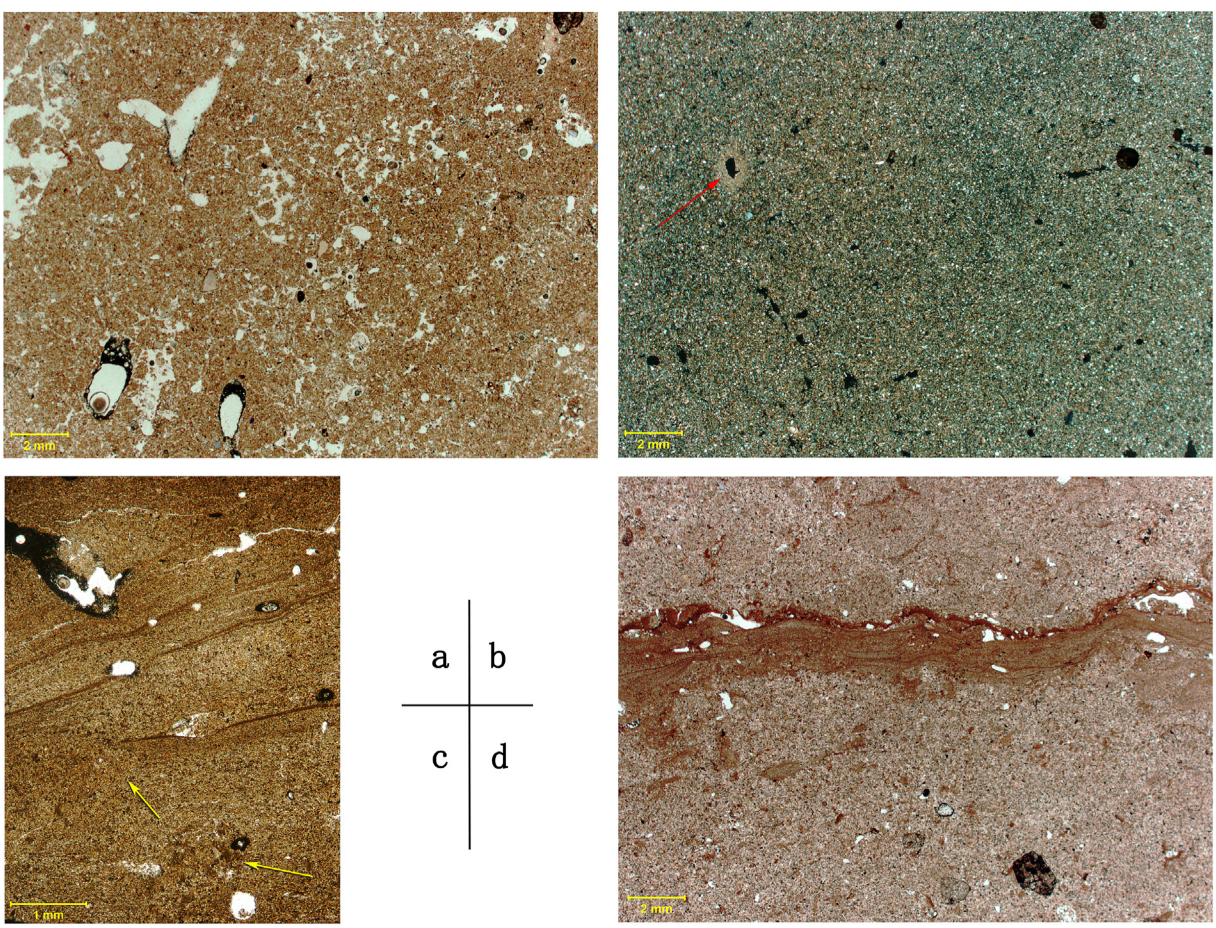


Fig. 8. Photomicrograph of micromorphological samples from the Shizitan 29 site. a. Sample 85 from Layer 8 with heavily bioturbated sediment resulting in loose, fine aggregates and packing voids between them. Plane-polarized light (PPL); b. Sample 77 from Layer 7 with red arrow pointing to calcareous hypocoating around smooth void within compact silt. Cross-polarized light (XPL); c. Sample 45 from Layer 4 with finely laminated silt and clay, along with graded bedding; some of the bedding has been erased by bioturbation, as shown by circular features (arrows). PPL; d. Sample 70 from Layer 6 showing fine cross-bedding and intercalations of dusty reddish brown clay, fine silt, and clay. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

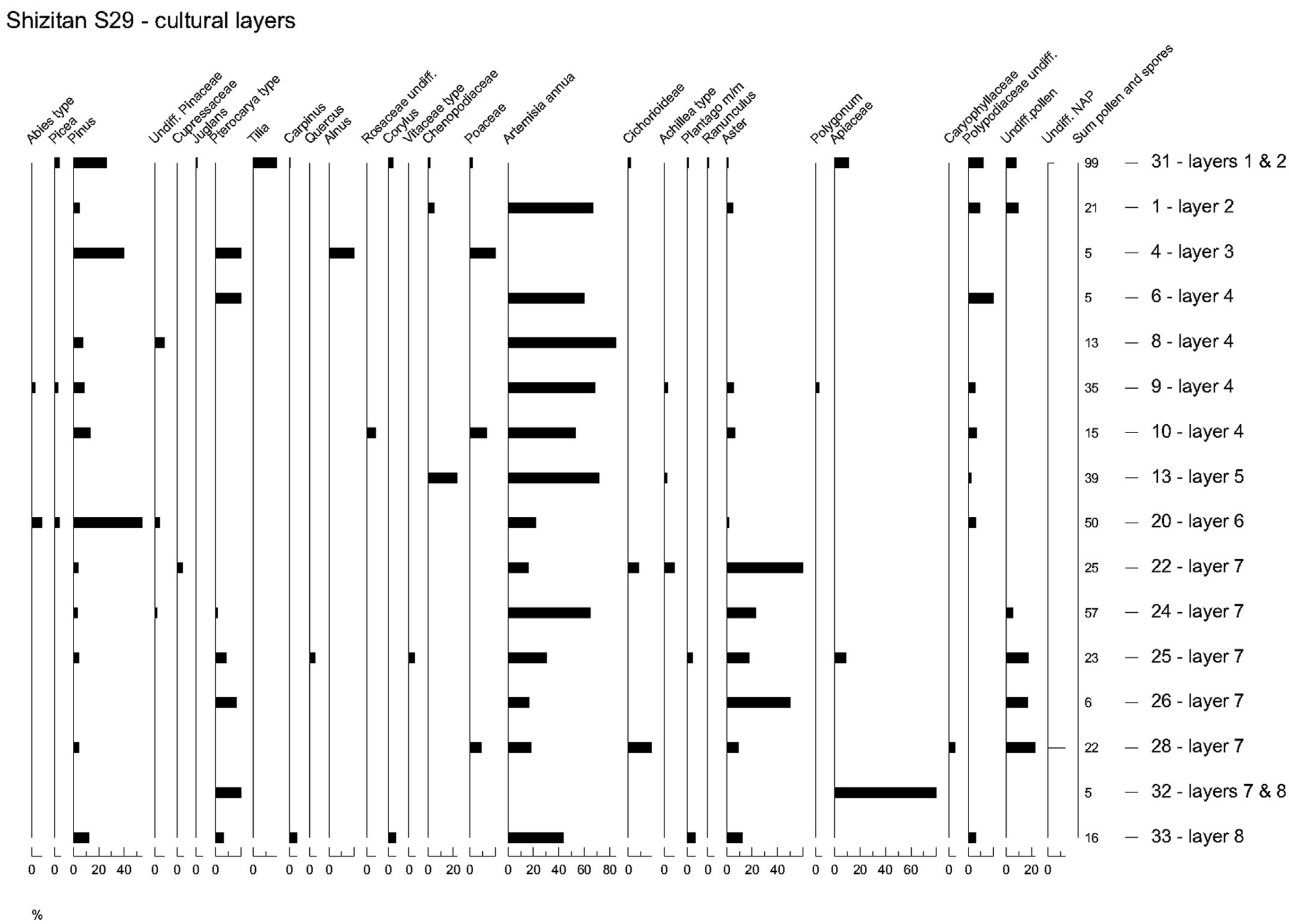
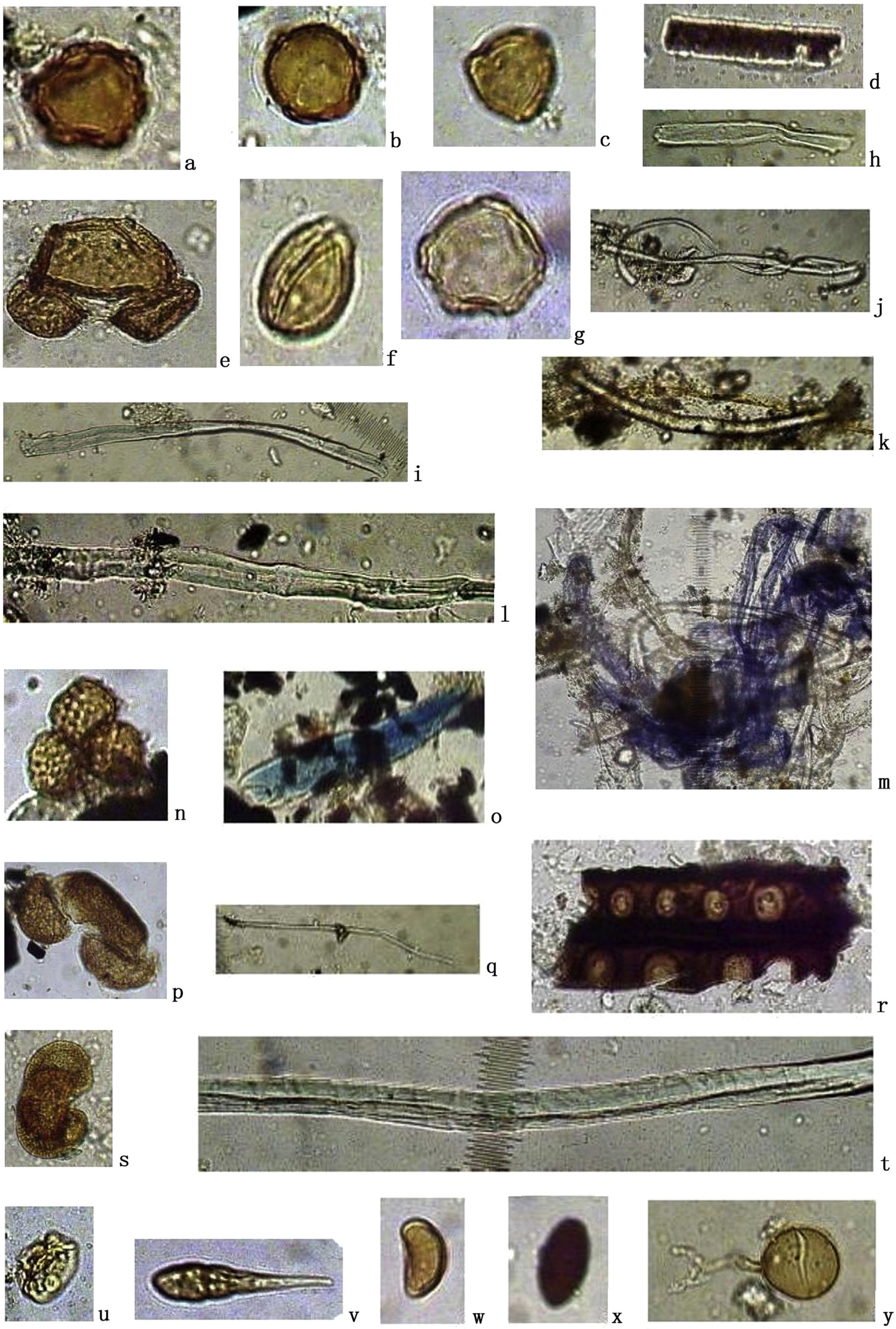


Fig. 9. Pollen diagram of 16 samples from the cultural layers at Shizitan 29.

NPP analysis is not often applied to archaeological deposits, we provide a short introduction to help clarify its potential contributions. For the first century of pollen research, palynologists generally studied samples from boreholes and only infrequently those directly from archaeological deposits. As palynological studies developed, palynologists began to consider other elements that were present on the same slides with the pollen: these are now known as non-pollen palynomorphs (NPP). NPP analysis was first developed by B. van Geel in the early 1980s: early papers summarized the technique and offered a selection of taxonomically identified fossils that can serve as paleoenvironmetal indicators (e.g., Van Geel et al., 1981; Van Geel, 2001; Van Geel et al., 2003; Revelles and Van Geel, 2016). While palynologists were attracted to a variety of organisms such as algae, bacteria, eggs of aquatic flatworms, stomates, and more from early on, the onset of systematic identification of NPP, including spores of fungi and remains of algae, cyanobacteria, and invertebrates, increased the number of paleoenvironmetal indicators at investigators' disposal, and researchers came to realize that some NPP potentially could be used to identify human activities (Van Leeuwen, 2006).

More recently, NPP analysis has started to be employed for the environmental study of archaeological sites (e.g., Revelles and Van Geel, 2016; Revelles et al., 2016; Kvavadze et al., 2010a,b). While excavated deposits produce a certain amount of pollen, when taken together with NPP, they can better reflect anthropogenic involvement. For example, for the Neolithic period, the comparison of pollen and NPP from archaeological sites near lakes to those from lake sediment cores can provide a range of data concerning human impact on the immediate environment. Furthermore, in addition to information on the immediate environment of the studied site, pollen and NPP also provide data directly related to past human activities that often are not preserved in the macro-remains of the site, such as small, processed fibers. We apply the analysis of NPP residues in this study to gain a greater understanding of the paleoenvironment and human activities during prehistoric occupations of Shizitan 29.

Sixteen archaeological NPP samples (about 60 g each) from the cultural layers were analyzed and compared to seven modern samples collected in a range of environments around the site (Tables S.1-2 and Figs. S1–8). For the archaeological samples, Sample 31 was taken from the profile of the site from the "natural layer" between Layers 1 and 2. Samples 25, 26, 28, 32, and 33 came from Layers 7 and 8, with Samples 32 and 33 being taken from the profile and the others from exposed horizontal surfaces. The remaining 10 samples were collected from within the hearths or from the areas of dense artifact scatter around the hearths in Layers 2–7. Each sample was processed according to standard methodology (e.g., Grichuk, 1937; Moore et al., 1991; Van Geel, 2001), and palynological and NPPs were identified, counted, and photographed. At least 250–300 pollen grains and the same amount of NPPs were counted in each sample, and quantitative analysis was obtained by using the palynological software Tilia.



The results, by layer, are as follows (see Supplementary Materials S3 for additional identifications and photomicrographic images):

4.2.1. Layer 8

In sample 33, the pollen spectrum (Fig. 9) includes arboreal species represented mainly by warm-loving deciduous species, including wingnut (*Pterocarya*) (Fig. 10a), hornbeam (*Carpinus*) (Fig. 10b) and hazel (*Corylus*) (Fig. 10c), and also evergreen pine (*Pinus*). The herbaceous species included single grains of wormwood (*Artemisia*), aster (*Aster*), plantain (*Plantago* m/m), and spores of Polypodiaceae. The group of NPP was quantitatively rich, with many phytoliths (Fig. 10d) and tracheal cells of wood, but no cells from coniferous species. Initial identifications also show flax (*Linum*) fibers are well represented, with lesser amounts of hemp (*Cannabis*) fibers, along with other unidentified fibers. For fungi, only spores of *Alternaria*, a plant pathogen, were found. Zoological material included micro-remains of a bird feather and insect setae (Fig. 11).

4.2.2. The boundary of layers 7 and 8

Sample 32 is distinguished by its small amounts of arboreal and herbaceous pollen, with only *Pterocarya* and *Apiaceae* pollen found (Fig. 9). There are more phytoliths than Layer 7 and many tracheal cells of wood, but none from conifers. Fungi spores include *Alternaria*. There are flax and unidentified fibers. A black animal hair and other zoological material were found (Fig. 11).

4.2.3. Layer 7

Samples 22, 24, 25, 26 and 28 contained small quantities of pollen from arboreal species, characterized by warm-loving deciduous species such as wingnut (*Pterocarya*) (Fig. 10g) and oak (*Quercus*), but Vitacea and Cupressaceae (Fig. 10f) are also recorded, indicating a changing climate. These warm-loving species become absent in Layer 6. Across the spectrum of herbaceous plants, greater changes are shown by the appearance of Cichorioideae, *Achillea* and Caryophyllaceae, and increasing quantities of *Aster* pollen (Fig. 9). NPP show a predominance of wood tracheal cells. There is a high flax fiber content, with up to 80 fragments identified, as well as hemp fibers. Some fibers also appear as colored in the prepared samples, including one blue wool fiber and some other unidentified fibers (Fig. 10). Future studies will have to determine if these fibers give evidence of dyes being used. Phytoliths of Poaceae and other herbs were found in large quantities (Fig. 11). There were single spores of *Alternaria* fungus in some samples. The zoological material is represented by scales of butterfly wings, setae of insects and arthropods. The presence of deciduous plants and hazel in Layers 8 and 7 reflect warmer and damper conditions than in Layers 6, 5, and 4 above them.

4.2.4. Layer 6

The pollen spectrum of sample 20 demonstrates a taxonomic composition that differs significantly from that of the underlying layers. The arboreal complex consists only of coniferous species that were absent in the earlier layers. Pine pollen predominates (Fig. 10e). Fir is well represented, together with spruce (*Picea*) and other Pinaceae. The spectrum of herbaceous plants also changes, and wormwood (*Artemisia annua*) pollen is predominant together with *Aster* and spores of ferns (Polypodiaceae) (Fig. 9). The NPP group is relatively rich. Tracheal cells of wood predominate. Phytoliths of Poaceae and other herbaceous taxa are well represented. There are many flax fibers (Fig. 10j, l), with some appearing as gray, black, or pink in color in the samples (Fig. 10m). Longer, twisted fiber remains are also noted, and their source needs to be further investigated: a possibility includes the making of cordage (thread, rope, string) through twining. Wool fibers (Fig. 10k) and a bird feather were found, as well as spores of *Chaetomium*, *Glomus*, and *Alternaria* fungi. In this particular case, *Glomus* points to an increase in erosive processes that can take place during periods of cooling (see Van Geel, 2001). There are also unidentified ascospores. Acarisetae and zoological material of a different character are found in small quantities (Fig. 11). Layer 6 pollen spectra reflect a substantially cooler climate than Layer 5 above it.

4.2.5. Layer 5

No pollen grains of arboreal plants are found in the spectrum of sample 13. Herbaceous species *Artemisia annua* and Chenopodiaceae (Fig. 10n), which were absent in the underlying layers, are predominant in this layer, along with small quantities of Achillea pollen and spores of Polypodiaceae (Fig. 9). In the NPP group, there were many tracheal cells of wood, including those of pine. Phytoliths of Poaceae and other herbaceous species were the second most dominant component. Setae of insects and ticks (*Acari*) were recorded in significant quantities. Many flax fibers were found, as well as unidentified fibers (Fig. 10o and Fig. 11). During this time period, steppe and forest-steppe vegetation were the dominant associations, and upland dry steppe may have been present in the study region. Wormwood (*Artemisia*) might have been widespread, and the climate was cold and dry.

4.2.6. Layer 4

The pollen spectra of samples 6, 8, 9, and 10 are poor but feature predominantly coniferous species (Fig. 10p), especially pine (Fig. 10s). The presence of dark coniferous species (spruce and fir) in samples 8 and 9 may indicate a cooler climate. There was one pollen grain of *Pterocarya* in sample 6 and one Rosaceae in sample 10. Among herbaceous plants, an increasing amount of wormwood pollen could also be indicative of cooling. *Aster, Achillea,* Poaceae, and *Polygonum* pollen are also recorded, as are fern spores (Fig. 9). In the NPP groups, large quantities of tracheal cells of pine wood support the large amount of pine pollen (Fig. 10r). Many phytoliths of Poaceae and other herbaceous plants were found in samples 9 and 10. Flax fibers are found in all the samples, and a substantial number of them are colored gray, blue, and pink. Wool fibers are present, including colored fibers, such as a brown wool fiber in sample 9 (Fig. 10t). Colonial blue-green algae *Rivularia* was also found. Insect and Acari setae are better represented than in the later Layer 3. Zoological material of a different character is observed, as well as ascospores, including single spores of the dung fungus *Sordaria* and spores of the fungus *Alternaria*. In samples 6 and 10, microscopic remains of bird feathers are found (Fig. 10q and Fig. 11).

4.2.7. Layer 3

In Sample 4, the pollen spectrum is characterized by a very low content of pollen. Single pollen grains of pine (*Pinus*), alder (*Alnus*),

Fig. 10. Pollen and non-pollen palynomorph (NPP) observations on samples from archaeological samples from Shizitan 29. a. Pollen of *Pterocarya* type (Layer 8); b. Pollen of *Carpinus* (Layer 8); c. Pollen of *Corylus* (Layer 8); d. Phytoliths of Pooideae (Layer 8); e. Pollen of *Pinus* (Layer 6); f. Pollen of Cupressaceae (Layer 7); g. Pollen of *Pterocarya* type (Layer 7); h. Fiber of hemp (*Cannabis*) (Layer 7); i. Unraveled fibers of flax (*Linum*) (Layer 7); j. Twisted fibers of flax (Layer 6); k. Wool (Layer 6); l. Unraveled fibers of flax (Layer 6); m. Flax remains (Layer 6); n. Pollen of Chenopodiaceae (Layer 5); o. Undifferentiated fiber (Layer 5); p. Pollen of *Abies* (Layer 4); q. Down of bird (Layer 4); r. Tracheal cells of wood pine (Layer 4); s. Pollen of undifferentiated Pinaceae (Layer 4); t. Fibers of wool (Layer 4); u. Poacea (Layer 3); v. *Alternaria* fungi spore (Layer 3); w. Spore of Polypodiaceae (fern) (between Layer 2 and 1); x. *Cercophora* (between Layer 2 and 1); y. *Glomus* (between Layer 2 and 1). (a-k, u-y. 300×; l-n, p, s. 400×; o, q, r, t. 500×).

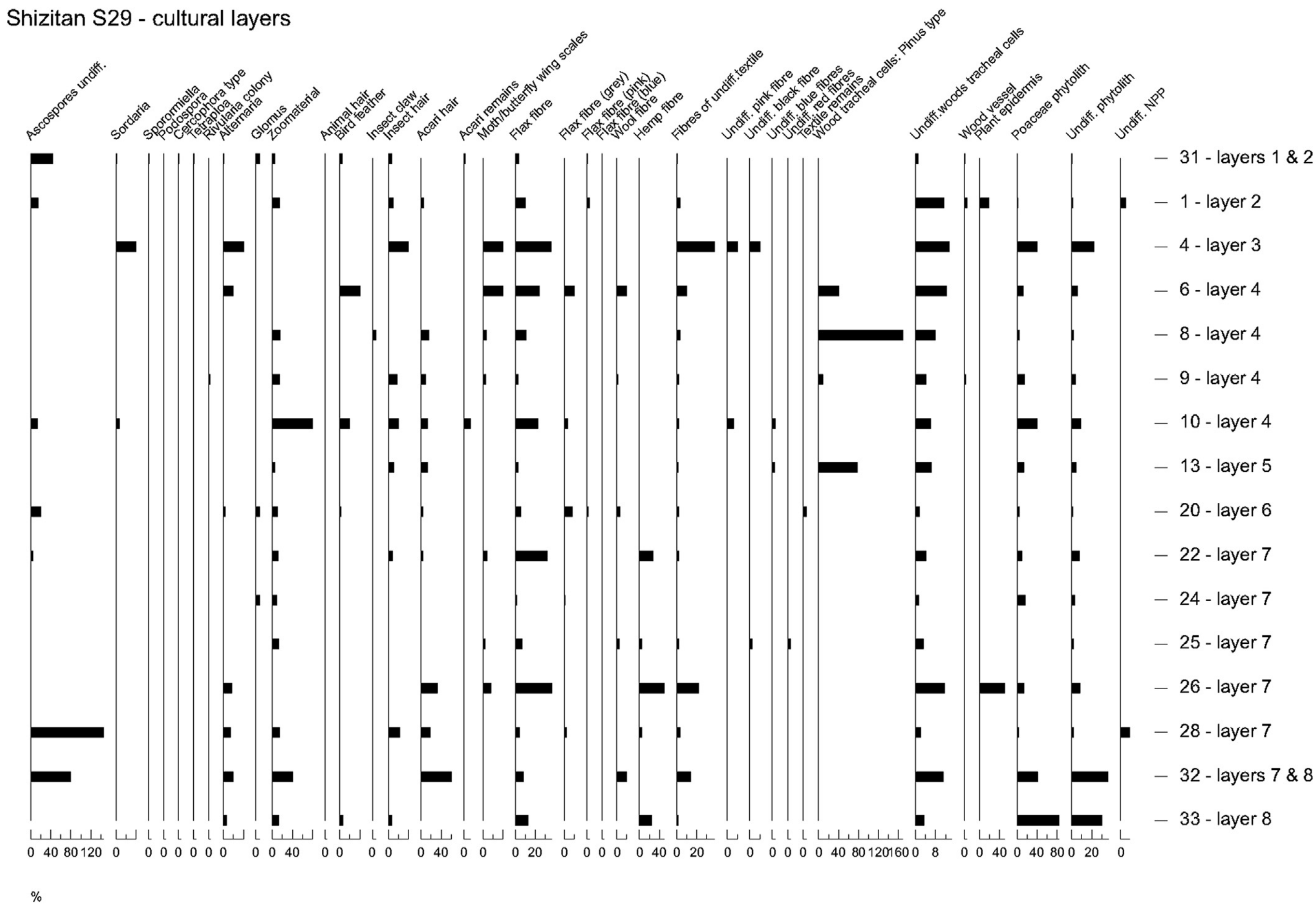


Fig. 11. Non-pollen palynomorphs (NPP) diagram of samples from the cultural layers at Shizitan 29.

wingnut (*Pterocarya*), and grasses (Poaceae) (Fig. 10u) are found (Fig. 9). The NPP group is well represented. Charred tracheal cells of various kinds of wood predominate. There are many phytoliths of Poaceae and other herbaceous species. Flax fibers, some of which are black and pink, are found, as well as undifferentiated fibers. Spores of dung fungi and of *Alternaria* fungus (Fig. 10v) are found in small quantities. Lesser amounts of insect setae and scales of butterfly wings were recorded (Fig. 11).

4.2.8. Layer 2

In Sample 1, the pollen spectrum is characterized by a very poor assemblage of arboreal and herbaceous pollen. Single pollen grains of pine, Chenopodiaceae, and asters are found. A somewhat larger amount of wormwood pollen grains was recorded. Fern spores are found (Fig. 9). The NPP group contains many charred tracheal cells of wood and wood vessels. In one field of vision, more than 50–60 cells were counted. There are also many flax fibers, including pink ones, as well as unidentified fibers. Poaceae and plant epidermis were recorded. Not many fungi spores were found. There were some setae of insects and other arthropods, and other animal remains (such as cuticula, claws, and epidermis) (Fig. 11).

4.2.9. The layer between layers 2 and 1

In sample 31, the spectrum of arboreal pollen predominated over that of herbaceous species. Among the arboreal species, there were large quantities of pine and lime (*Tilia*) with smaller quantities of spruce (*Picea*) and hazel (*Corylus*), as well as a few pollen grains of hornbeam (*Carpinus*) and walnut (*Juglans*). Among herbaceous plants, Apiaceae and fern (Polypodiaceae) were predominant (Fig. 10w). Poaceae, Cichorioideae, *Aster, Ranunculus, Plantago* m/m, and Caryophyllaceae pollen were recorded (Fig. 9). The NPP group shows great diversity, predominated by charred tracheal cells of various kinds of wood. A substantial number of phytoliths of Poaceae and other herbaceous species is present. Flax fibers are well represented, including some blue and pink fibers. There are many spores of fungi, especially of species that grow on herbivore dung including the ascospores of *Sordaria*, *Cercophora* (Fig. 10x), *Sporormiella,* and *Podospora*. Spores of *Glomus* (Fig. 10y) fungus are well represented. Remains of *Tetraploa* that, like *Glomus,* grow in cultivated or disturbed soils, were recorded, as were spores of *Alternaria* fungus. The zoological material contained animal hairs and remains of insects and other arthropods (Fig. 11).

In sum, pollen and NPP analysis indicates that Layers 8 and 7 formed under warm and damp climatic conditions, as is shown by the abundance of deciduous plants and hazel, as well as higher numbers of ascospores and relatively lower amounts of coniferous species. Layers 6, 5, and 4 formed under cooler climatic conditions, as is shown not only by the coniferous species, but also by the amount of insect and arthropod remains, which increase in these layers. In all the studied cultural layers, fire is indicated by the tracheal cells of wood, identified to the genus level of pine cells and several other coniferous species.

Poaceae phytoliths found in the layers are an anthropogenic indicator (Kvavadze et al., 2011). Wild *Poaceae* was a very important component of human diet from Upper Paleolithic times, and micro-remains of these plants (pollen, phytoliths, starch, stems, and epidermis) are observed in the cultural layers. The exploitation of grasses for food is further supported by the presence of grinding stones in Layers 2–7, and starch analysis of grinding stones from neighboring Shizitan 14, dating ca. 23-18 Ka cal BP, identified the processing of wild Paniceae grasses (Liu et al., 2013).

The explanation of the presence of flax and other fiber remains in most of the layers at Shizitan 29, and the appearance of some among them as colored (and thus likely dyed), will require further sampling and analyses, but they lead us at the moment to hypothesize that humans may have been processing flax and hemp plants (as well as animal wool fibers) at the site for use of their fibers, perhaps in cordage (such as rope, thread, or twine) (see Abbo et al., 2015). Detailed studies on worked bone from Shizitan 29 also show that eyed bone needles were being made for sewing at the onset of the LGM at the site (Song et al., 2015). If truly present and not due contamination of the samples, the fibers could also serve as an indicator of occupation density.

Because wild flax processing for cordage is known from other Eurasian Upper Paleolithic contexts, finding flax remains at Shizitan 29 would not be unprecedented or necessarily unexpected. As Dzudzuana and Satsurblia caves in Georgia demonstrate, humans have been twining fibers of wild flax species for making thread, twine, and string since at least 30 Ka cal BP (Kvavadze et al., 2009, 2010a,b; Kvavadze, 2011; Bar-Yosef et al., 2011), while the earliest evidence for domesticated flax dates to 12 Ka cal BP, as found in southwestern Asia (Zohary et al., 2012). Appropriate conditions for wild flax growth existed in this time period in China, as well. Furthermore, nine species of flax are found distributed across northern China in recent times, with historical texts recording their use for oil, medicine, and rope (Liu et al., 2011a,b).

5. Discussion

The stratified contexts at Shizitan 29, along with its series of radiocarbon dates and micromorphological, pollen and NPP, and faunal analyses provide insights into paleoenvironmental changes through the LGM and allow us to correlate them with culturally adaptive behaviors and the intensity of human occupation.

During the time preceding LGM represented by Layer 8 (ca. 28 Ka cal BP), overall indications are of a warmer and damper climate than LGM conditions. Micromorphology shows incipient soil formation. Pollen and NPP characterized by prevalent warm-loving, deciduous species and the absence of coniferous trees corroborates the micromorphological observations, as perhaps does the presence of one hunted deer species.

Layer 7 (ca. 26-24 Ka cal BP) reflects in the shift to aeolian sediments and in particular in the pollen and NPP spectra a gradual climate change at the beginning of LGM. In this layer, a cooler climate is indicated by the increasing amounts of *Pinus* and wormwood (*Artemisia annua*) pollen. *Equus caballus/E. hemionus* appear, indicating a steppe or encroaching semi-desert environment.

The pollen spectra (Fig. 9) of Layers 6-4 (ca. 24–19.5 Ka cal BP) demonstrate substantial cooling and drying as deciduous woodlands gave way to coniferous forest consisting of dark coniferous species characterized by pine (*Pinus*), spruce (*Picea*), and fir (*Abies*). Wormwood (*Artemisia annua*) and Chenopodiaceae pollen were predominant in the group of herbaceous species. In the NPP, rather considerable quantities of tracheal cells and phytoliths of pine wood are found. The presence of spores of *Glomus* fungus, especially in Layer 6, may indicate erosive processes, in this case associated with climatic cooling, as the presence of *Glomus* fungus is a known indicator of soil erosion and land degradation (Van Geel, 1998). The increase in the amount of insects and arthropods could also reflect these conditions (Van Geel, 1998). Faunal remains may indicate continuous cooling as well, with a majority of equids, indicative of open grasslands, the low presence of deer, and the presence of *Procapra przewalskii* (Przewalski's gazelle), a species well-adapted to colder conditions that often inhabits open valleys between mountains.

In Layer 5, Bovidae increase, including the Przewalski's gazelle. Deer reappear in Layer 4, the sedimentological nature of which is characterized by bedded silty deposits that accumulated slowly from overbank flooding of the river. This geological process did not disturb the archaeological remains, as indicated by the preservation of the hearths. In retrospect, it seems that the occupations of layers 6-4 took place during the peak of colder and drier LGM conditions in this area.

Layer 3 (ca. 20 Ka cal BP) shows the continuation of these conditions, while Layer 2 (ca. 19-18 Ka cal BP) marks the end of LGM conditions. The site was then abandoned from *ca.* 17 to 13 Ka cal BP, with Layer 1 at *ca.* 13 Ka cal BP indicating Shizitan 29's last occupation. In general, the environment became warmer during the deposition of the thick geological deposits of the human occupational gap between Layer 2 and Layer 1. During this gap, the wetter and warmer conditions could be indicative of the local environment of the Bølling-Allerød period. During this time, the percentage of deer among large mammalian species in the area must have increased, leading to the higher deer percentages exploited in Level 1 (Table 2). The warming trend also is reflected by the appearance of pollen of spruce and hazel arboreal species and of Apiaceae, and spores of fern (Polypodiaceae) in the herbaceous plants. Many spores of fungi, especially those growing on herbivore dung such as spores of *Glomus*, were identified in the NPPs, as well as increasing numbers of ascospores, indicating warmer and damper climatic conditions: this interpretation is supported by their presence in the modern samples collected near the site on the river plain under bean and millet crops (Fig. 11; see S2.3 and S2.4 in Supplementary Materials). The new prevalence of forest by Layer 1 is also reflected in the palynological spectra showing the presence of lime (*Tilia*) and other deciduous trees similar to associations recorded for the early Holocene (Wu, 1980; Yan et al., 2009).

Shizitan 29 was a location occupied ephemerally but repeatedly by humans, as is reflected in the stratified deposits, the number of hearths and their spatial arrangement, and the stone artifacts. Hearths with clear outlines appear in the upper horizon of Layer 7 at the onset of the LGM and prevailed in all the following cultural layers. Firewood could be identified to the genus level as pine and several other coniferous species, based on the tracheal cells of wood in NPP samples. The use of fire provides direct evidence of human adaptations to cold conditions, as could the flax fibers, such as for sewing hides or producing cordage for bags, etc., but the use of flax and other fibers at the site requires further testing and analysis.

The diachronic change in lithic industries at Shizitan 29 may also signify cultural adaptation to LGM conditions. A major change in the lithic industry occurs between Layer 8 and the deposits above it. Layer 8 features a "core and flake" industry (recently also referred to as "flake and shatter"; Barton, 2009; Barton et al., 2007; Bettinger et al., 2010). In Layer 7, the industry changes, with one of the earliest appearances of a microblade industry in China; however, other tool types such as end-scrapers and burins were made on flakes. What drives this change is unknown, but possibilities include migration of a new population bearing this technology into the region or cultural exchange. The correlation of this change with the onset of LGM conditions, however, is likely significant.

The gathering of plant foods and processing them by grinding is also an important subsistence feature at Shizitan 29. More than ten grinding stones were excavated in Layers 8, 7, 4, and 2. Macroscopic use wear and starch residue analysis on contemporaneous grinding stones uncovered at Shizitan 14 (Liu et al., 2013) show their use in processing grasses and starchy foods. Similar exploitation patterns at Shizitan 29 could be supported by Poaceae phytoliths in the NPP, which are also an anthropogenic indicator (Kvavadze et al., 2011). In the human diet, wild Poaceae (a ubiquitous family of monocotyledonous flowering plants) became important by the Upper Paleolithic, and microremains of these grasses (pollen, phytoliths, starch, stems, epidermis) were observed in all the cultural layers at Shizitan 29 (Figs. 9 and 11). The faunal, pollen, NPP, lithic, and other data combined, even though certain details are missing, indicate the wide range of food sources exploited by the Shizitan population through the LGM.

6. Conclusions

This study provides important information regarding the survival of humans in the valley along the Qingshui River in the south of Shanxi Province in North China during the LGM and the reconstruction of the paleoenvironment of the site during its repeated occupations from ca. 28-18 Ka cal BP and again at ca. 13 Ka cal BP. Globally, the LGM climate during Greenland Stadial 3 (27.54–23.34 Ka cal BP) was colder than the preceding millennia. In East Asia, most regions north of Shizitan are abandoned during this time period, but groups of hunter-gatherers remained in the Shizitan regions throughout this extended period in spite of the deterioration of the climatic conditions and local environment as described here. The low mountains of the Loess Plateau and the broad valley of this area, with abundant sources of water and plant and animal food, played an important role as a local refugium for humans throughout the LGM. The first steps in understanding cultural adaptations and behaviors during LGM is the diachronic reconstruction of changing environmental conditions. The deep, stratified deposits at Shizitan 29, the systematic series of radiocarbon dates, and the diachronic series of pollen and NPP, faunal, and soil micromorphological samples analyzed here provide detailed understanding of the environmental contexts and chronology of cultural changes at site and allow more robust interpretations of the archaeological evidence for evaluating how human populations survived in North China during the LGM. At Shizitan 29, key cultural adaptations to LGM conditions reflected in archaeological remains include pyrotechnology and the use of hearths, the microblade industry, selective herbivore hunting and carcass processing, exploitation of new ranges of plant foods and processing using grinding stones, new symbolic behaviors seen in ostrich shell beads, and perhaps flax and other fiber processing. All of these may be indicators of the sustainable solutions allowing the viability of forager populations living in the Shizitan region throughout the LGM and camping at this locality.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2017.01.007.

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