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Late Pleistocene climate change and Paleolithic cultural evolution in Northern China: Implications from the Last Glacial Maximum

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Abstract

Temporal and spatial patterns in archeological data from Pleistocene north China suggest strong correlations between climate change and culture change, but only in extreme cases. In these cases, climate has an immediate impact on human mobility, which is severely constrained during the pronounced cold/dry intervals of the Pleistocene. As high mobility becomes incompatible with the environmental limitations of extreme intervals, such as the Last Glacial Maximum, previously disparate mobile human groups aggregate and compete for limited and spatially segregated resources. During such times, regional cultural variation evolves in isolation and natural selection acts on group-level adaptations, facilitating the evolution of cohesive and cooperative social networks. The process of group selection further allows for the rapid diffusion of cultural and technological innovation and may explain the rapid diffusion of microblade technology throughout northeast Asia during the post-glacial period. While climate change does present challenges to human survival and may promote alternative adaptive strategies, rapid cultural evolution is driven primarily by group formation, between-group competition, and the mechanics of cultural transmission. The degree to which climate change mediates these interactions is the extent to which climate should be implicated in cultural evolution.

1. Introduction

The influence of climate change on human cultural evolution is regularly assumed but rarely demonstrated. In truth, we have a relatively poor understanding of how individuals, much less groups, respond to long-term environmental change. What we do understand, we understand on relatively short time scales and our limited experience provides us with little ability to suggest how individuals, traditions, or institutions will react or respond to sustained or punctuated environmental change. This situation is due, in part, to the difficulty of collecting and identifying the appropriate data sets with which to track the correlation between environment and culture and to the difficulty of controlling the many interactions that separate a suspected cultural effect from a proposed environmental cause. Perhaps more importantly, our perspective is limited by an historical adherence to the recent Holocene, a period of relatively subtle environmental change marked by rapid, cumulative cultural evolution maintained and accelerated by large numbers of continuously interacting individuals. That is not to say that climate has no bearing on Holocene human history, merely that recognizing the impact of climate change on cultural evolution is exceedingly difficult. For this reason, we turn our attention to the Pleistocene.

Paleolithic hunter-gatherers had a range of potential strategies with which to adapt to the dramatic environmental variability of the late Pleistocene. Independent invention of unique tool types or modification of existing tool types are technological solutions to local problems. Changes in mobility, food storage, or diet-breadth are organizational adaptations. And risk-buffering strategies such as long distance resource exchange, codified rules for mate selection and exchange, territorial defense and land ownership, and internal divisions of labor and class are institutional adaptations that require coordinated behavior from a range of individuals to evolve. In all likelihood, some combination of technological, organizational, and institutional adaptation enabled Paleolithic foragers to cope with the often-punctuated and, by comparison to the Holocene, extreme, environmental change characteristic of the Pleistocene.

Equating cultural evolution with climate change is complex. Clearly, changes in the local environment evince local reactions, most of which are regular features of a very flexible repertoire of human behavior. In a constantly variable world, flexibility itself is an adaptation that evolves to meet the challenges of a relatively brief window of evolutionary relevance, perhaps on the order of only a few human generations. Overly rigid or specialized adaptations do not emerge in variable environments. The issue is clearly a matter of scale – a question of how much and how fast environments change (see Madsen and Elston, this volume), and whether or not the mechanics of human cultural evolution generate behavioral adaptations capable of tracking this change. Any adaptation that initially evolves *because* of its ability to cope with the resource stresses associated with environmental variation is naturally trained to accommodate most subsequent variations in climate and environment. Essentially, most environmental change will have little impact on the range of human behaviors specifically adapted to environmental

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variability itself. Therefore, we must look to periods marked by significant departures from the environmental context of Pleistocene cultural evolution to see if and how human culture responds to environmental change.

Here, we focus on the degree to which environmental change affects the settlement–subsistence strategies of Paleolithic foragers. Our analysis begins with a brief discussion of human mobility as an adaptive strategy. We then present a simple method for evaluating change in human mobility using radiocarbon data drawn from Pleistocene archeological sites across northern China. The patterns in these data enable an assessment of the correlation between environmental change and human biogeography. Recent archeological research focused on human occupation of the western Loess Plateau during the Last Glacial Maximum (LGM) helps to illustrate the behavioral and demographic context of human cultural evolution during periods of extreme environmental change. We conclude by suggesting that the LGM played a critical role in shaping human demographic processes and advance an hypothesis to account for the rapid and widespread changes in human cultural evolution during the post-glacial period. The prolonged environmental deterioration characteristic of the LGM was unprecedented in the environmental history of northeast Asia, and it stands to reason that such conditions may have engendered novel behavioral solutions from the human populations that survived it.

2. Hunter-gatherer Mobility

The migratory patterns of *Homo sapiens* are the subject of considerable study and debate. Much of our understanding of hunter-gatherer mobility comes from ethnographic observation and historical reconstruction of extant hunter-gatherers during the twentieth century (e.g., Steward, 1938). Inasmuch as subsistence–settlement patterns, and therefore mobility, can be considered adaptations, it may also be true that multiple adaptations will emerge as solutions to similar environmental conditions (Steward, 1937; Steward, 1938; Bettinger and Baumhoff, 1982; Bettinger and Baumhoff, 1983). In this sense, climate is not a direct determinant of cultural change. However, human groups do organize their settlement–subsistence strategies around environmental limitations, and research suggests that changes in the organization of mobility strongly affect sociopolitical organization, trade, territoriality, demography, intergroup dynamics, identity, and enculturative processes (Kelly, 1992). From a theoretical standpoint then, variation in human mobility provides the foundation for human evolutionary change, and our understanding of Paleolithic cultural evolution is dependent upon understanding hunter-gatherer mobility.

For many animals, relocation is a regular and recurrent response to local resource depression. The adaptive logic of this solution is based on the economic predictions of models drawn from optimal foraging theory (Winterhalder and Smith, 1981; Bettinger, 1991; Smith and Winterhalder, 1992) and includes deterministic and stochastic solutions, both of which are built upon the principle of marginal utility (Charnov *et al.*, 1976; Charnov, 1976). The deterministic "patch choice" model generates predictions for relocation given the declining value of a current resource patch, the expected value of an alternative patch, and the cost of travel between patches. A generalized prediction of the patch choice model suggests that costs associated with relocation in a relatively unpopulated landscape are low when compared to the costs associated with extracting enough energy to survive from a dwindling resource base. The stochastic model opens the deterministic model to the issue of "risk" (Stephens, 1981; Stephens and Charnov, 1982). In optimal foraging parlance, risk is narrowly defined as the variance around the expected mean value of the foraging budget; the greater the variance, the greater the risk associated with acquiring the expected value of the total foraging effort. In a perfect world (i.e., the deterministic model), the expected value is always achieved and there is no risk. In a more realistically variable or unpredictable environment, the variance around the mean expected payoff may be so great that the probability of acquiring the minimum amount of resources required for survival is dangerously low.

Historical and ethnographic examples of resource acquisition demonstrate that optimal solutions to variable environments may be reached through acquiring resources from multiple sources. By combining the expected returns (with known means and standard deviations) of multiple sources, an individual or a small integrated group reduces the net hazards of subsistence shortfall (McCloskey, 1975; Winterhalder, 1990; Goland, 1991). In the absence of other strategies for averaging risk, human foragers move frequently to increase the number of places they acquire resources. In so doing, foragers average the risk of subsistence shortfall spatially and temporally by incorporating more foraging patches over a given period of time. This "residential mobility" is therefore a simple, effective strategy for human foragers to manage the risks and hazards of resource depression and does not require the additional costs or selective pressures associated with complex tool technology, diet breadth expansion, or the evolution of group-functional behavior.

Essentially, mobility enables human foragers in an open, relatively unpopulated landscape to escape local resource depression simply by moving camp. Mobility and relocation may therefore be considered "first-order" responses to environmental variability. Alternative solutions to risk management, such as storage, diet-breadth expansion, sharing, and other group-functional means of averaging the risks of resource shortfall may evolve under a variety of conditions, but only when mobility is constrained by the limitations of the social or ecological environment.

3. Late Pleistocene Human Biogeography in Northern China

3.1 Recent Ideas about Environmentally Mediated Culture Change

Researchers working primarily in Siberia and the Russian Far East propose that the Early Upper Paleolithic (EUP) – the cultural and behavioral techno-complex that accompanied and perhaps enabled widespread occupation of northeast Asia during marine isotope stage 3 (MIS3) – met an abrupt end with the onset of the LGM (Goebel, 1999; Goebel, 2002; Goebel, 2004). They argue that extreme environmental deterioration during the LGM reduced regional human populations to unsustainable levels and suggest that the cultural traditions that define the EUP disappeared with their makers (e.g., Brantingham *et al*., 2004b). Furthermore, they suggest that with post-glacial environmental amelioration, a completely different adaptive strategy characterized by the use of microblades, composite inset weaponry, and high foraging mobility, emerged and expanded rapidly into regions left vacant by the regional population bottlenecks of the LGM. For these researchers, a gap in the radiocarbon record of Siberia between 22.8 and 21.5 ka[1] confirms the role of environmental change in the culture-history of northeast Asia, implying that punctuated bursts of cultural evolution result from either regional extirpation or (re)colonization of virgin landscapes (Goebel, 1999; Goebel, 2002; Goebel, 2004; Brantingham *et al*., 2004b). A similar story is extended to explain the end of the EUP and the onset of the Late Upper Paleolithic (LUP) in northern China (Brantingham, 1999) and on the Qinghai–Tibet Plateau (Brantingham *et al*., 2003) (but see Brantingham *et al*., this volume, and Madsen *et al*., 2006). If true, these examples provide strong support for the deterministic role of environmental change in cultural evolution.

In 2002, archeological survey in the western Loess Plateau recorded and sampled two sites (ZL05 and PY03) with radiometric age estimates within the boundaries of the LGM (Ji *et al*., 2005; Bettinger *et al*., n.d.). However, the stone tool assemblages from these and other sites in the western Loess Plateau are distinct from the prepared, flat-faced core-and-blade technology evident at Shuidonggou, Locality 1 – the type-site for the EUP expression in northern China. The LGM sites discovered in 2002 provide temporal anchors for the modified settlement–subsistence pattern that succeeds the EUP in the western Loess Plateau and further suggest that the region was not abandoned during the LGM. While it seems clear that the classic *markers* of the EUP disappeared from north China during the LGM, it seems equally clear that *people* did not. What role, if any, did the comparatively extreme environmental change during the LGM play in the culture history of the northeast Asian Upper Paleolithic?

3.2 Regional Climate Change and Human Biogeography

Paleolithic deposits throughout the old world are typically defined on the basis of lithic assemblages comprised of recurrent tool forms and, more frequently, the remains of tool manufacturing debris. In China, hundreds of Paleolithic sites have been identified on the basis of stone tool typology (Gao and Norton, 2002; Cohen, 2003). However, because tool use and evolution are subject to local variation, migration, and differential rates of innovation, tool typology is an ineffective time marker at the resolution necessary to evaluate correlation between climate change and cultural evolution. For this reason, our analysis of human settlement dynamics in northern China during the Late Pleistocene includes only those Paleolithic sites with radiocarbon age estimates from culture-bearing deposits. Other methods for dating archeological deposits are excluded from this analysis for the sake of consistency and because they are either methodologically equivocal or insufficiently standardized. Table 1 provides the known range of radiocarbon estimates from cultural deposits in north China between 45 and 10 ka.

Radiocarbon data sets are widely employed to identify both synchronic and diachronic trends in human activity, including spatial distributions of contemporaneous cultural patterns as well as prehistoric population dynamics (see Rick, 1987). In northern China (north of 34° latitude), the spatial distribution of radiocarbon data demonstrates that regions below 41° latitude were continuously occupied from the MIS3, through the LGM, and into the post-glacial Late Pleistocene (Figures 1 and 2A–C). However, north of 41° latitude, northeast China appears uninhabited during the LGM, 24–18 ka[2] (Figure 2B). This pattern is attributed to a southward migration of human groups in response to the expansion of northern deserts and the concomitant retreat of temperate grasslands (Ji *et al*., 2005). While this may account for the depopulation of northeast China, the radiocarbon data suggest that the arid landscape occupied by the EUP hunter-gatherers at Shuidonggou was not completely abandoned during the LGM. Furthermore, despite the southward expansion of desert vegetation (Zheng *et al*., 1998; Xie *et al*., 2002) synchronous with the southward expansion of the Gobi (Feng *et al*., 1998) and Mu Us deserts (Zhou *et al*., 2002), the Loess Plateau was also occupied during the LGM. Desertification, in itself, is insufficient to explain the dramatic cultural evolution apparent during the late Pleistocene.

Beyond the general pattern of southward human migration, we ask how the environmental changes characteristic of the LGM might have forced human groups to modify their foraging behavior and therefore their settlement patterns. To do this, we look to the cumulative probability distribution of calibrated radiocarbon dates from north China for correlations with regional environmental change.

A 2D dispersion calibration (Weninger, 1986), such as that generated by CalPal calibration software (Weninger *et al*., 2005), incorporates radiocarbon age estimates and their

[1] Ages reported as 'ka' are calendar years before present.

[2] Regional variations in global environmental patterns confound absolute definition of the LGM, broadly classified as a period of maximum global ice volume. For the sake of clarity and comparison, we follow Bard (1999) in defining the LGM not by ice volume, but as an interval bracketed by two marked temperature minima, classified as Heinrich Events (HE), identified in both Greenland ice-core records and North Atlantic sediment cores. Based on radiometric dating of the sea core evidence for the end of the HE2 and the abrupt onset of HE1, the LGM dates to between 20,400 and 15,000 ^{14}C yr BP (24,500–18,300 Cal yr BP) (Elliot *et al*., 1998).

Table 1. Radiocarbon data from Paleolithic north China. Uncalibrated dates (^{14}C yr BP) are based on the Libby half-life of 5568. The 2-σcalibrated midpoints (Cal yr BP) and range (+/−) are generated using CalPal software v. CalPal_ 2005_SFCP (Weninger et al., 2005).

site	lab.#	lon.DD	lat.DD	material	^{14}C yr BP	+/−	Cal yr BP	+/−	reference
Nanzhuangtou	BK87083	115.600	39.000	Silt	9,266	100	10,450	260	RDL-BD, 1994
Nanzhuangtou	BK86121	115.600	39.000	charcoal	9,416	95	10,720	360	RDL-BD, 1994
Nanzhuangtou	BK87084	115.600	39.000	Silt	9,446	120	10,780	440	RDL-BD, 1994
Daxingtun	PV0368	123.883	47.033	Bone	9,460	80	10,800	380	Lu, 1998
Nanzhuangtou	BK97093	115.600	39.000	charcoal	9,533	100	10,880	360	RDL-BD, 1994
Nanzhuangtou	BK86120	115.600	39.000	charcoal	9,596	160	10,920	440	RDL-BD, 1994
Nanzhuangtou	BK89064	115.600	39.000	charcoal	9,572	90	10,930	320	RDL-BD, 1994
Nanzhuangtou	BK87086	115.600	39.000	Silt	9,698	100	11,020	340	RDL-BD, 1994
Pigeon Mtn (QG3)	Beta 086732	105.852	38.044	charcoal	10,060	60	11,600	320	Elston *et al.*, 1997
Pigeon Mtn (QG3)	Beta 094119	105.852	38.044	charcoal	10,120	60	11,740	360	Madsen *et al.*, 1998
Shizitan	BA93186	110.067	36.000	burned bone	10,194	540	11,790	1,480	Yuan *et al.*, 1998
Zhangjiabo	BK85031	124.700	40.050	charcoal	10,190	120	11,860	520	IA-CASS, 1991
Nanzhuangtou	BK87075	115.600	39.000	charcoal	10,213	110	11,920	500	Lu, 1999: Table 4(7)
Pigeon Mtn (QG3)	Beta 097241	105.852	38.044	charcoal	10,230	50	11,950	220	Elston *et al.*, 1997
Huangjiaweizi	ZK2078	124.050	46.017	shell	10,290	140	12,100	620	IA-CASS, 1991
Zhoukoudian (Upper Cave)	ZK136-0(1)	115.917	39.683	bone	10,466	360	12,150	1,020	Lu, 1999: Table 4(1)
Xiaonanhai	ZK665-0(665)	114.117	36.117	bone & charcoal	10,689	500	12,360	1,320	Lu, 1999: Table 4(1)
Nanzhuangtou	BK87088	115.600	39.000	wood	10,509	140	12,400	440	Lu, 1999: Table 4(7)
Hutouliang	PV0156	114.150	40.017	bone	10,689	210	12,530	560	Lu, 1999: Table 4(1)
PY04	CAMS 94202	106.646	35.835	charcoal	10,670	40	12,690	80	*reported here*
Qingtoushan	ZK1374	124.308	45.287	fossil bone	10,940	170	12,900	280	Fu, 2003
Shizitan	BA93190	110.067	36.000	bone	11,166	110	13,070	260	Yuan *et al.*, 1998
Zalainuoer	PV0171	117.583	49.350	charcoal	11,330	130	13,230	260	IA-CASS, 1991
Nanmo	ZK2888	112.400	39.300	charcoal	11,331	166	13,240	340	IA-CASS, 1997
Zalainuoer	PV0015	117.583	49.350	charcoal	11,440	230	13,340	440	IA-CASS, 1991
Daxingtun	PV0369	123.883	47.033	bone	11,470	150	13,370	300	Lu, 1998
Pigeon Mtn (QG3)	Beta 086731	105.852	38.044	charcoal	11,620	70	13,500	160	Elston *et al.*, 1997
Shizitan	BA93187	110.067	36.000	burned bone	12,303	190	14,440	720	Yuan *et al.*, 1998
Anzhangzi	ZK3076	119.717	41.017	bone	12,482	157	14,710	600	IA-CASS, 2001
Pigeon Mtn (QG3)	Beta 097242	105.852	38.044	charcoal	12,710	70	15,140	240	Elston *et al.*, 1997
Xiaonanhai	ZK170-0	114.117	36.117	bone	12,705	220	15,320	1,160	Lu, 1999: Table 4(1)
Mingyuegou	WB78-44	128.917	43.117	tooth	12,940	550	15,680	1,980	IA-CASS, 1991
Xiaonanshan	PV0719	134.033	46.783	fossil bone	12,910	410	15,720	1,720	IA-CASS, 1991
Xueguan	BK81016	111.000	36.450	charcoal	13,167	150	16,220	960	Lu, 1999: Table 4(1)
Shizitan	BA93188	110.067	36.000	burned bone	13,207	220	16,250	1,120	Yuan *et al.*, 1998
Zhoukoudian (Upper Cave)	OXA391	115.917	39.683	bone	13,200	160	16,270	1,000	Lu, 1999: Table 4(1)

Xiachuan (Shunwangping)	ZK762	112.033	35.450	charcoal	13,507	300	16,500	1,220	Chen and Wang, 1989
Shizitan	BA93189	110.067	36.000	burned bone	13,935	250	17,330	360	Yuan *et al.*, 1998
Xiawangjia	?	103.379	35.645	?	14,081	150	17,400	200	Xie, 1991
Shizitan	BA93191	110.067	36.000	bone	14,305	160	17,620	360	Yuan *et al.*, 1998
Xiachuan (Locality 1)	ZK385	112.033	35.450	charcoal	15,936	900	19,280	1,900	Chen and Wang, 1989
TX04	CAMS 94204	105.790	36.778	charcoal	16,460	45	19,670	260	Ji *et al.*, 2005
Xujiayao	ZK0670	113.733	40.367	fossil bone	16,440	2,000	19,830	4,620	IA-CASS, 1991
Shuidonggou (Locality 1)	PV0331	106.333	38.100	bone	16,762	210	19,980	580	IA-CASS, 1991
ZL05	Beta 197631	106.097	35.281	charcoal	16,750	70	20,070	360	*reported here*
Mengjiaquan	?	117.783	39.867	?	17,005	205	20,190	480	Lu, 1999: 35
Gulongshan	PV0225	122.167	39.517	fossil bone	17,090	240	20,390	780	IA-CASS, 1991
Yuhonghe	PV862	109.817	34.917	bone	17,730	500	21,230	1,280	Gao, 1990
Xiachuan (Shanshanyan)	ZK494	112.033	35.450	soil	17,855	480	21,350	1,300	Chen and Wang, 1989
Xiachuan (Shanshanyan)	ZK497	112.033	35.450	peat	18,035	480	21,520	1,320	Lu, 1999: Table 4(1)
Qiangyangdong	BK82067	124.100	39.800	charcoal	18,090	320	21,620	1,100	IA-CASS, 1991
Zhoukoudian (Upper Cave)	ZK136-0(2)	115.917	39.683	bone	18,340	420	21,890	1,020	Lu, 1999: Table 4(1)
PY03	CAMS 94203	106.645	35.835	charcoal	18,350	70	22,080	400	Ji *et al.*, 2005
ZL05	CAMS 95088	106.097	35.281	charcoal	18,920	520	22,700	1,300	Ji *et al.*, 2005
Xiachuan (Shunwangping)	ZK634	112.033	35.450	charcoal	19,046	600	22,820	1,400	Chen and Wang, 1989
Xiachuan (Locality 2)	ZK393	112.033	35.450	charcoal	20,115	600	24,030	1,540	Chen and Wang, 1989
ZL05	Beta 197633	106.097	35.281	charcoal	20,220	90	24,140	240	*reported here*
ZL05	Beta 197632	106.097	35.281	charcoal	21,180	100	25,370	520	*reported here*
Xiachuan (Locality 1)	ZK384	112.033	35.450	charcoal	21,086	1,000	25,430	2,640	Chen and Wang, 1989
Yanjiagang	?	126.300	45.600	?	21,737	300	26,250	1,200	Wu and Poirier, 1995
Heilongtan	ZK2129	118.300	34.517	clay & charcoal	21,820	520	26,260	1,560	IA-CASS, 1991
Beijing (Wangfujing)	?	116.417	39.917	?	22,670	300	27,370	900	Li *et al.*, 1998
Xiachuan (Locality 1)	ZK417	112.033	35.450	charcoal	23,224	1,000	27,860	2,600	Chen and Wang, 1989
Zhoukoudian (Upper Cave)	OXA1248	115.917	39.683	bone	23,150	330	27,940	680	Lu, 1999: Table 4(1)
Xiaonanhai	ZK654	114.117	36.117	charcoal	23,419	500	28,310	1,200	Lu, 1999: Table 4(1)
Zhoukoudian (Upper Cave)	OXA1247	115.917	39.683	bone	23,700	350	28,630	900	Lu, 1999: Table 4(1)
Shuidonggou (Locality 2)	Beta 146358	106.504	38.297	charcoal	23,790	180	28,700	580	Madsen *et al.*, 2001
Miaohoushan	PV0363	124.167	41.233	fossil bone	23,880	570	28,820	1,300	IA-CASS, 1991
Xuetian	LZU-?	127.550	44.783	?	24,500	400	29,430	1,080	Fu, 2003
Shuangbuzi	?	105.957	35.307	clay	24,538	290	29,520	900	Xie, 1997
TX08	CAMS 93169	105.249	36.685	charcoal	24,760	220	29,820	560	Ji *et al.*, 2005
GY03	CAMS 93161&2	106.640	35.831	charcoal	25,228	766	29,960	1,480	Ji *et al.*, 2005
Tashuihe	ZK2599	113.200	35.700	bone	25,425	1,005	30,010	1,820	IA-CASS, 1992
TX03	CAMS 93167&8	105.675	36.656	charcoal	25,030	80	30,040	380	Ji *et al.*, 2005
Shuidonggou (Locality 1)	PV0317	106.333	38.100	carbonate	25,450	800	30,140	1,400	IA-CASS, 1991
Caisi	ZK0635	111.417	35.833	shell	25,650	800	30,290	1,340	IA-CASS, 1991
Yangsigouwan	PV0185	108.617	37.833	fossil bone	25,620	710	30,310	1,200	IA-CASS, 1991

(Continued)

Table 1. (Continued)

Shuidonggou (Locality 2)	Beta 134825	106.504	38.297	charcoal	25,650	160	30,580	360	Madsen *et al.*, 2001
Shuidonggou (Locality 2)	Beta 132983	106.504	38.297	charcoal	25,670	140	30,590	340	Madsen *et al.*, 2001
Mingyuegou	WB78-41	128.917	43.117	fossil bone	25,810	550	30,590	760	IA-CASS, 1991
Zhoukoudian (Upper Cave)	OXA2275	115.917	39.683	bone	25,700	360	30,600	540	Lu, 1999: Table 4(1)
Zhoujiayoufang	WB78-05	126.533	44.767	fossil wood	25,980	735	30,600	1,040	IA-CASS, 1991
Zalainuoer	PV0175	117.588	49.350	coprolite	25,940	1,300	30,710	2,740	IA-CASS, 1991
Zalainuoer	PV0220	117.583	49.350	fossil bone	26,240	800	30,860	1,140	IA-CASS, 1991
Changweigou	?	105.938	35.123	?	26,336	600	30,890	760	Xie, 1997
Dingcun	PV1064	111.417	35.933	shell	26,450	590	30,970	740	Lu, 1998
Shuidonggou (Locality 2)	Beta 146355	106.504	38.297	charcoal	26,310	170	30,990	260	Madsen *et al.*, 2001
Shuidonggou (Locality 2)	Beta 132982	106.504	38.297	charcoal	26,350	190	31,000	280	Madsen *et al.*, 2001
Zhoukoudian (Upper Cave)	OXA1246	115.917	39.683	bone	26,500	460	31,000	540	Lu, 1999: Table 4(1)
Shuidonggou (Locality 2)	Beta 134824	106.504	38.297	charcoal	26,830	200	31,230	200	Madsen *et al.*, 2001
Shuidonggou (Locality 2)	Beta 132984	106.504	38.297	ostrich shell	26,930	120	31,270	160	Madsen *et al.*, 2001
Zhoukoudian (Upper Cave)	OXA2274	115.917	39.683	bone	27,370	410	32,000	1,260	Lu, 1999: Table 4(1)
ZS08	Beta 210740	35.329		106.119	charcoal		27,730	150	32,074
976	reported here								
Zhoukoudian (Upper Cave)	OXA2272	115.917	39.683	bone	27,500	380	32,090	1,280	Lu, 1999: Table 4(1)
Miaohoushan	PV0366	124.167	41.233	fossil bone	27,240	680	32,120	1,720	IA-CASS, 1991
Mingyuegou	WB78-43	128.917	43.117	fossil tooth	27,910	750	32,730	2,060	IA-CASS, 1991
Shidie	ZK2100	113.817	37.233	charred bone	27,920	1,175	32,930	2,700	IA-CASS, 1991
Zalainuoer	PV0172	117.583	49.350	charcoal	28,120	1,300	33,090	2,900	IA-CASS, 1991
Shiyu	ZK109-0	112.283	39.350	fossil bone	28,135	1,330	33,110	2,940	IA-CASS, 1991
Zhoukoudian (Upper Cave)	OXA2271	115.917	39.683	bone	28,680	460	33,450	1,900	Lu, 1999: Table 4(1)
Zhoujiayoufang	WB78-45	126.533	44.767	coprolite	28,910	1,220	33,630	2,940	IA-CASS, 1991
Guxiangtun	BK77022	126.517	45.700	charcoal	29,150	700	33,920	2,120	IA-CASS, 1991
Zhoukoudian (Upper Cave)	OXA2276	115.917	39.683	bone	29,100	520	34,040	1,680	Lu, 1999: Table 4(1)
Shuidonggou (Locality 2)	Beta 146357	106.504	38.297	charcoal	29,520	230	34,760	740	Madsen *et al.*, 2001
Shidie	ZK2006	113.817	37.233	bone	30,600	1,570	35,660	4,040	IA-CASS, 1991
Zhoujiayoufang	WB78-46	126.533	44.767	fossil bone	30,900	910	36,070	1,740	IA-CASS, 1991
Gutougou	LZU-??	104.750	34.783	clay	32,844	500	38,090	1,560	Xie *et al.*, 1987
Zhoukoudian (Upper Cave)	OXA190	115.917	39.683	bone	32,600	2,000	38,130	4,520	Lu, 1999: Table 4(1)
Zalainuoer	PV0170	117.583	49.350	coprolite	32,810	1,700	38,440	3,980	IA-CASS, 1991
Zhoukoudian (Upper Cave)	OXA2277	115.917	39.683	bone	33,200	820	38,810	2,760	Lu, 1999: Table 4(1)
Zhoukoudian (Upper Cave)	OXA2773	115.917	39.683	bone	33,460	850	39,080	3,000	Lu, 1999: Table 4(1)
Mingyuegou	WB78-42	128.917	43.117	fossil tooth	34,370	1,850	39,430	3,800	IA-CASS, 1991
Xiachuan (Fuyuhe)	ZK638	112.033	35.450	charcoal	35,177	3,500	39,540	6,200	Chen and Wang, 1989
Fajiagouwan	PV0177(2)	108.617	37.833	charcoal	35,340	1,900	40,060	3,740	IA-CASS, 1991
Temple Canyon 1	Beta 161632	105.800	38.700	carbonate	41,070	890	44,690	1,660	Bettinger *et al.*, 2003

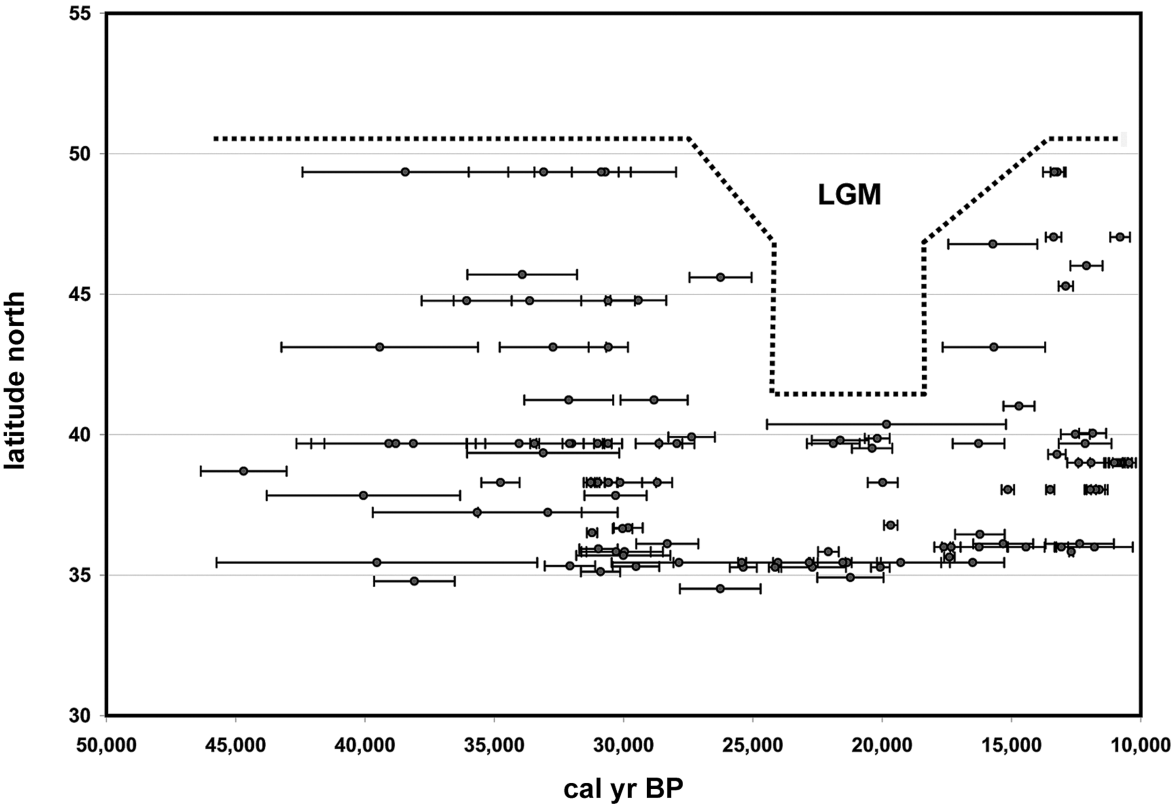


Fig. 1. Radiocarbon data from Paleolithic north China (n = 116) plotted as a function of latitude. This illustrates that north China was depopulated above 41° north during the last glacial maximum (24.0–18.0 ka). Diamonds represent the 2σ mid-point of each calibrated estimate, while the circles represent the 2σ range.

associated errors in a graphic representation of archeological occupation in calendar years. Peaks in the calibrated radiocarbon probability distribution represent clusters of calibrated age estimates. Following the general logic outlined by Rick (1987), other researchers have used cumulative probability distributions of calibrated radiocarbon dates as proxies for human population dynamics (e.g., Gamble *et al*., 2004; Surovell *et al*., 2005). Here, we prefer to use the probability distribution as a measure of archeological visibility and suggest this visibility is a result of occupation intensity (Figure 3). Essentially, more sites are sampled and more dates collected from periods when hunter-gatherers occupy fewer places for longer periods of time. Conversely, when human foragers are highly mobile, occupation intensity should be low, as population aggregation is limited and human activity more evenly distributed across the landscape. Therefore, peaks in the probability distribution of calibrated radiocarbon dates represent periods of reduced mobility, and we expect this reduction in mobility to reflect declining access to increasingly limited resources.

Assuming that generalized resource abundance is a function of regional humidity and temperature, we look to continuous, high-resolution paleoenvironmental records from East Asia, such as the Hulu Cave speleothem sequence, as a proxy for terrestrial productivity.

Fluctuations in the oxygen isotope composition of speleothem calcite at Hulu Cave in southeast China record tradeoffs between the relative contributions of summer and winter precipitation and therefore constitute an integrated record of monsoon intensity over the East Asian landmass (Wang *et al*., 2001; Yuan *et al*., 2004). When the East Asian Pacific monsoon is dominant, summer rains are strong and $\delta^{18}O$ values lower, indicating heavy precipitation transport from a proximate tropical source. Higher $\delta^{18}O$ values suggest long-distance transport of water vapor from the northwest, indicative of a stronger winter monsoon and perhaps reduced annual precipitation. Comparative studies suggest that warmer hemispheric temperature, as shown in Greenland ice core records, corresponds to greater summer monsoon intensity (Wang *et al*., 2001) and that precipitation from tropical sources is low during glacial periods, even in southeast China (Yuan *et al*., 2004).

Visual comparison of the radiocarbon probability distribution and the Hulu Cave record suggests that occupation intensity is highest, and therefore human mobility is reduced, during periods dominated by the cold/dry winter monsoon (Figure 3). However, a basic linear regression of Hulu Cave speleothem $\delta^{18}O$ values against the CalPal cumulative probability distribution shows very weak correlation between climate and occupation intensity

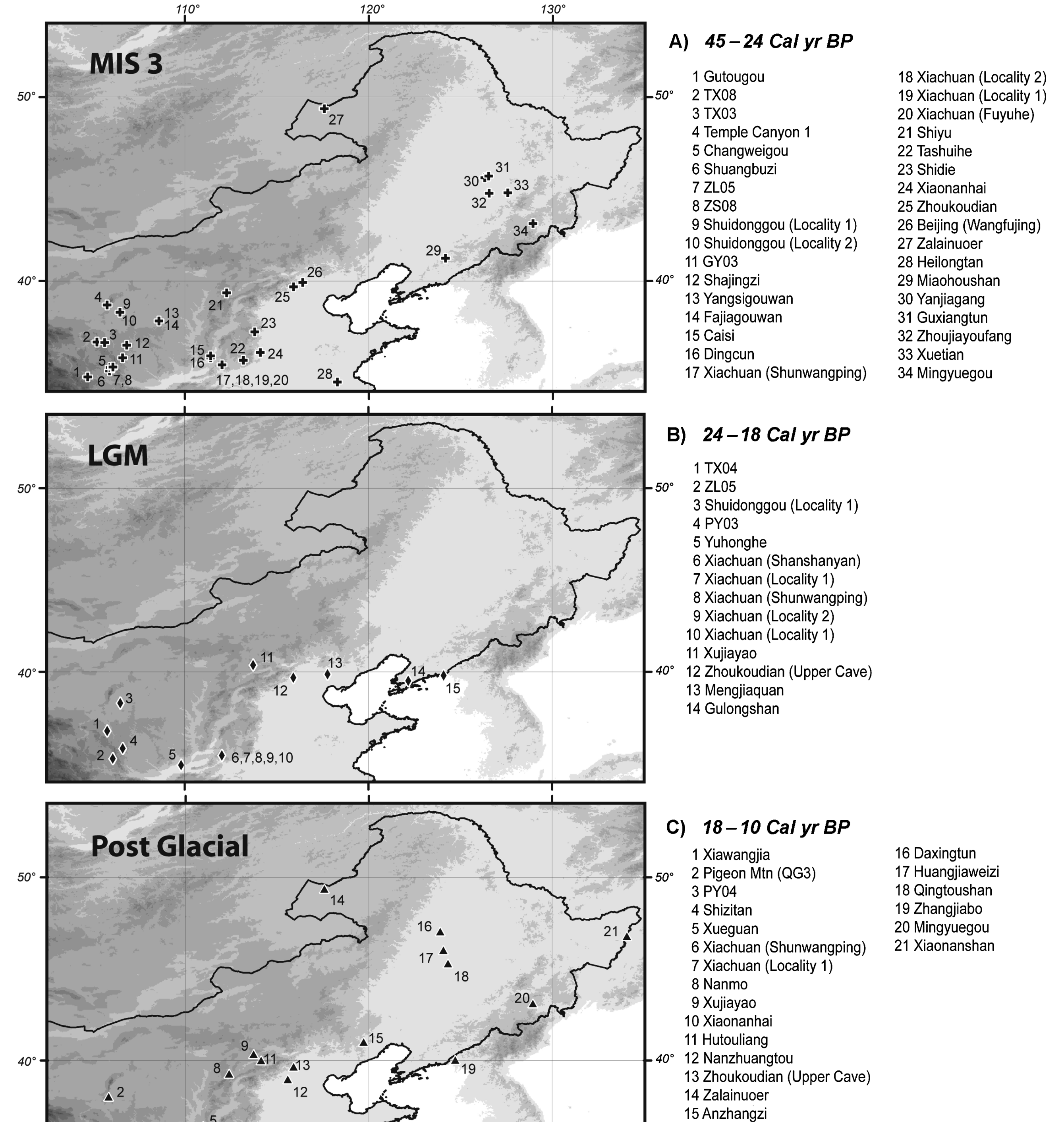


Fig. 2. Late Pleistocene archeological sites in northern China. Sites are assigned to one of the three periods on the basis of calibrated radiocarbon age ranges (Table 1): (A) MIS3 45.0–24.0 ka; (B) LGM 24.0–18.0 ka; (C) post-glacial 18.0–10.0 ka. Most of northeast China is depopulated during the LGM.

($R^2 = 0.0913$), suggesting that most variations around the environmental mean are insufficient to effect significant changes in human behavior. There is, however, a very strong correlation between occupation intensity and extreme environmental change, defined as $\delta^{18}O$ values 1.5 standard deviations above and below the mean $\delta^{18}O$ value between 45 and 10 ka. Figure 4 illustrates this relationship. Hulu Cave isotopic values greater than 1.5 standard deviations

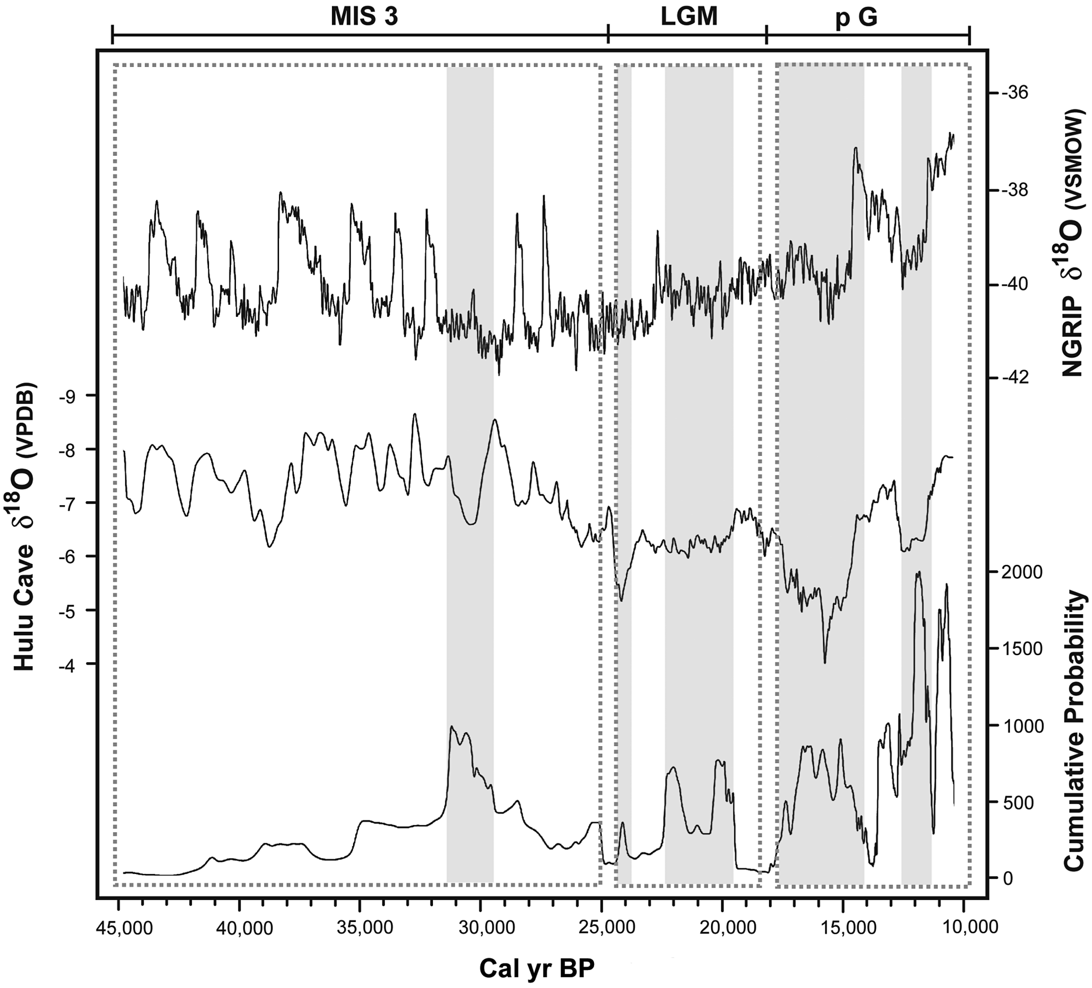


Fig. 3. Graphic comparison of human occupation intensity against climate. The bottom curve represents occupation intensity across northern China as a function of the cumulative probability of radiocarbon age estimates. The middle curve is a proxy for monsoon intensity in south China (Wang et al., 2004). Higher $\delta^{18}O$ values indicate strong winter monsoons (cold/dry); lower values indicate stronger summer monsoons (warm/wet). The upper curve represents hemispheric changes in precipitation and temperature recorded in Greenland ice (NGRIP, 2004). Higher $\delta^{18}O$ values indicate warmer temperatures and higher humidity. Shaded bars identify visual correlations between occupation intensity and climate.

from the mean correspond with high occupation intensity while isotopic values 1.5 standard deviations below the mean correspond with low occupation intensity. One-way analysis of variance confirms that occupation intensity is consistently higher during cold/dry periods dominated by the winter monsoon than during periods dominated by the warm/wet summer monsoon ($F = 167.4$; $P = 0.000$). This suggests that the range of Paleolithic human foraging behaviors adapted to marginal environments like those of Pleistocene northeast Asia are stable in all but the most extreme of climatic anomalies. During such extremes, we see significant modifications to human settlement–subsistence patterns reflected in the distribution of calibrated radiocarbon probabilities from northern China.

Explanation of this pattern rests on understanding the interplay between resource distribution and human mobility. Recurrent dominance of the high-precipitation summer monsoon system during the MIS3 interstadials kept lake levels high (Chen and Bowler, 1986; Pachur *et al*., 1995; Komatsu *et al*., 2001) and stabilized the expansive steppe and grasslands that supported large-bodied terrestrial mammal populations across northeast Asia. The relative ubiquity of subsistence resources during these warm/wet intervals enabled Paleolithic hunter-gatherers to move freely between lake margins, grasslands, and animal migration routes to intercept the seasonal movements of large, seasonally mobile ungulate herds. As subsistence productivity declined in one area, human hunters moved easily into adjoining areas to capitalize on the rich biomass of the previously undisturbed local environment. The combination of high environmental productivity and low human population density during the warm/wet intervals of MIS3 meant that subsistence risks associated with movement into adjacent areas were relatively low. This enabled small foraging groups to relocate both

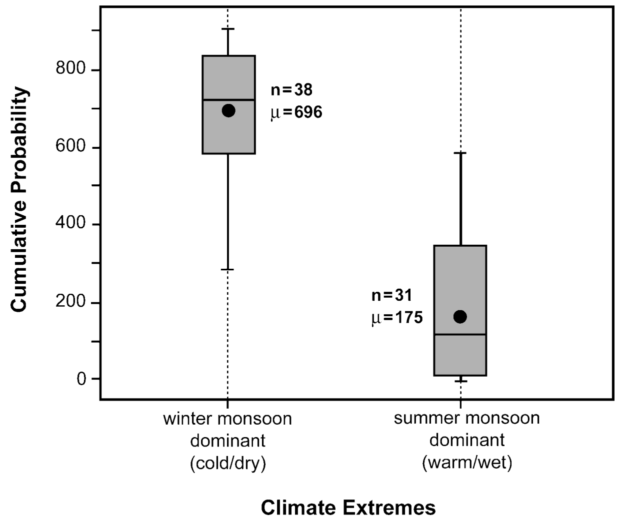


Fig. 4. Occupation intensity by environmental extreme. Analysis of variance demonstrates that two environmental extremes (as determined by the Hulu Cave $\delta^{18}O$ monsoon intensity record) correspond to significantly different human settlement patterns: Occupation intensity, a measure of population concentration, is more pronounced during cold/dry intervals, whereas warm/wet intervals correspond to high mobility.

their foraging range and their residential base opportunistically, creating an irregular "random walk" pattern of movement about the landscape (see Brantingham *et al*., 2003; Brantingham, 2003; Brantingham, 2006).

Simulation studies suggest this "random walk" pattern becomes increasingly difficult for human foragers to sustain as the total productivity of the landscape declines and resources become increasingly concentrated in fewer locations separated by greater distances (Brantingham *et al*., 2003). With the onset of the LGM, freshwater bodies in northeast Asia retreat, become saline, or disappear completely (Pachur *et al*., 1995; Owen *et al*., 1997; Zheng *et al*., 1998; Yang *et al*., 2004), while sand and gravel deserts expand dramatically at the expense of grasslands and steppic vegetation (Feng *et al*., 1998; Sun *et al*., 1998; Yu *et al*., 2000; Xie *et al*., 2002; Zhou *et al*., 2002). The resulting "patchy" distribution of freshwater resources effectively constrains the distribution of plants and animals dependent upon them. Here, the implications for human foraging groups are profound: long-distance movement between rare and perhaps unpredictable fresh water sources becomes increasingly hazardous. Long-distance movements are unlikely because the risks of resource shortfall are high and the costs of movement are great.

In this situation, foraging groups become increasingly tethered to the few remaining areas capable of supporting consistent plant and animal survival. While high residential mobility was the easiest solution to local resource depression during the recurrent warm/wet intervals of the MIS3, survival during cold/dry intervals required reduced residential mobility and alternative methods of reducing the risks of subsistence shortfall. Ultimately, human foragers were forced to develop novel adaptive strategies to contend with the unprecedented, extreme, and prolonged environmental restrictions of the LGM.

4. Cultural Evolution and the LGM

4.1 The Archeological Record of Northeast Asia

Our analysis of radiocarbon data from across northern China suggests that while human settlement patterns did change in response to environmental deterioration, the region was not abandoned entirely. Similarly, radiocarbon data from Siberia and the Russian Far East demonstrate that other regions of northeast Asia were not abandoned during the LGM (Kuzmin and Keates, 2005). Furthermore, it seems that neither the Korean Peninsula nor the Japanese archipelago were abandoned outright during the LGM (Bae and Kim, 2003; Ikawa-Smith, 2004; Nakazawa *et al*., 2005).

It is clear, however, that following the LGM a new adaptive technology built around the production of microblades spread rapidly in China, Siberia, Korea, and Japan. The seemingly instantaneous appearance of microblades across the whole of northeast Asia has been attributed to the recolonization of landscapes left vacant by regional population extirpations brought on by the LGM (Goebel, 1999; Goebel, 2002; Goebel, 2004; Brantingham *et al*., 2004b).

Despite considerable attention (e.g., Chard, 1974; Chen, 1984; Gai, 1985; Tang and Gai, 1986), the origins of northeast Asian microblade technology remain unclear (Lu, 1998; Cohen, 2003). The most liberal interpretations of the archeological evidence for microblade technology suggest that they were an uncommon but recurrent feature of Late Pleistocene adaptations during the MIS3, often overlapping with the EUP or even the Early Paleolithic in northern China, between 31 and 25 ka (Chen and Wang, 1989; Lu, 1998), and in Siberia between 30 and 25 ka (Derevianko *et al*., 1998). The emergence of microblade industries in Japanese Hokkaido (Nakazawa *et al*., 2005) and southern Korea (Bae and Kim, 2003; Ikawa-Smith, 2004) by 24 ka, further suggests that a single origin and subsequent diffusion of this technology is unlikely (cf. Chen, 1984; cf. Chen and Wang, 1989). Rather than searching for single origins, archeologists should be looking to each of these early cases for similarities that might underscore the adaptive benefits of microblade technology (Elston and Brantingham, 2002). For each of these early cases, microblade technology should be considered an outgrowth of Paleolithic industries in existence prior to the LGM (see Brantingham *et al*., this volume).

In northern China, the presence of small microblade-like, bipolar bladelets at Shuidonggou-2 suggests a potential technological substrate from which a classic microblade industry may have emerged (Madsen *et al*., 2001; Brantingham *et al*., 2004a; Brantingham *et al*., 2004b). Numerous archeological examples from other parts of northeast Asia confirm the use of microblades as inserts in composite tools (Chard, 1974; Lu, 1998; Derevianko *et al*., 1998), therefore, the critical innovation required for the emergence of microblade technology is a tool form in which small, replaceable, sharp stone flakes may be inserted in hafts or fore-shafts made of wood or bone. If the EUP blade forms generated through prepared-core technology at Shuidonggou were used as inserts in composite tools, then perhaps other flake and blade tools might be easily incorporated as the need arose. The essential points about the assemblage at Shuidonggou-2 are first, the production of small, retouched microblade-like bipolar bladelets co-occurred with production of classic EUP tool forms, suggesting cultural continuity between the two technological adaptations, and second, composite tool technologies were in place prior to the LGM.

4.2 Archeological Investigations at Zhuang Lang 5

The undisturbed stratigraphic sequence of the ZL05 exposure provided an ideal setting for two angles of research: (1) to examine the environmental context of human occupation in the western Loess Plateau during the LGM; and (2) to assess the potential for cultural continuity between the earlier EUP complex at Shuidonggou and the later, apparently local adaptations at ZL05 in the western Loess Plateau. In 2004, we returned to collect a continuous paleoenvironmental record from the ZL05 loess profile and to excavate sufficient cultural material to characterize these local human adaptations.

The ZL05 site (originally "ZL005") was named for the nearby city of Zhuang Lang, in southern Gansu Province, west of the Liu Pan Mountains. The site has also been called "Sumiaoyuantou" (Ji *et al*., 2005) because of its proximity to a previously recorded, but unstudied site with the same name.

ZL05 was discovered on a pedestrian survey of the Shui Luo River and its tributary, the Bei Shui Luo River. High above the river, on a promontory that marks the confluence of the two rivers sits a large Late Neolithic site. Immediately below this is a broad flat terrace that planes roughly 10 m above the north side of the modern Bei Shui Luo riverbed (Figure 5). The river action that cut this terrace exposed the ZL05 site and an extensive, previously un-cut section of aeolian Pleistocene loess. While the top 2 m of the terrace section show evidence of periodic Late Neolithic and dynastic disturbance, most of the section is pristine. The dominant archeological component rests, suspended in fine-grained Malan loess, approximately 1.5 m above the surface of the Bei Shui Luo flood plain (Figure 6: Component X). That all of the artifacts are un-rolled and in-place, and no other evidence of fluvial re-deposition such as gravel stringers or sandy deposits were found in or around the cultural components, confirms that the archeological assemblage was neither disturbed nor deposited by fluvial action. By all appearances, this site was occupied briefly and buried rapidly by airborne deposition.

The site was not excavated exhaustively, but rather sampled horizontally from its southern face. All culture-bearing deposits were wet-screened with 3 mm mesh and several samples were subjected to water flotation with an Ankara-style flotation tank at Lanzhou University. With the exception of two carbonized *Chenopodiaceae* fragments in "Component X", flotation produced very little charred material indicative of in situ anthropogenic burning. At

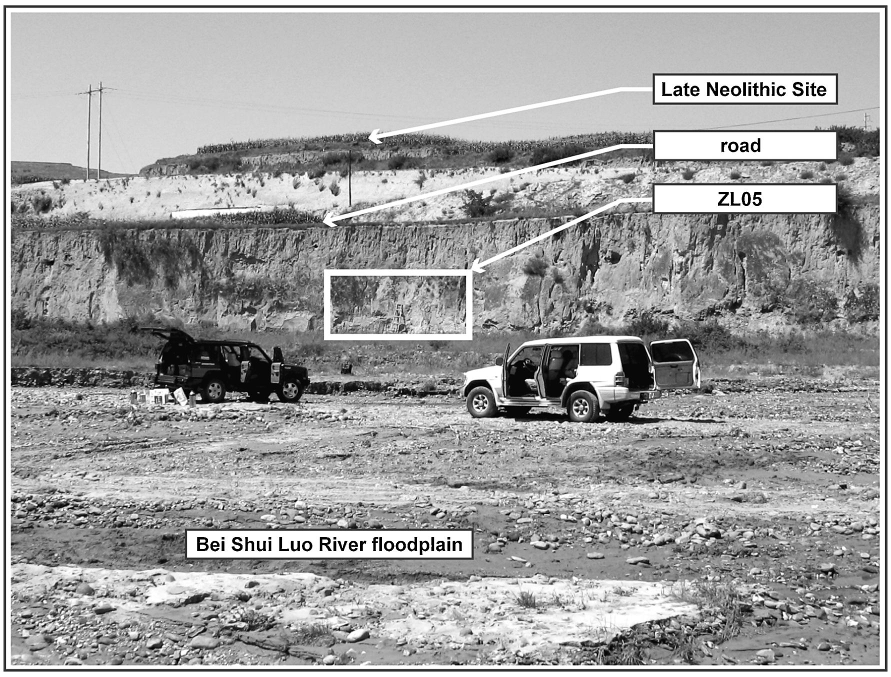
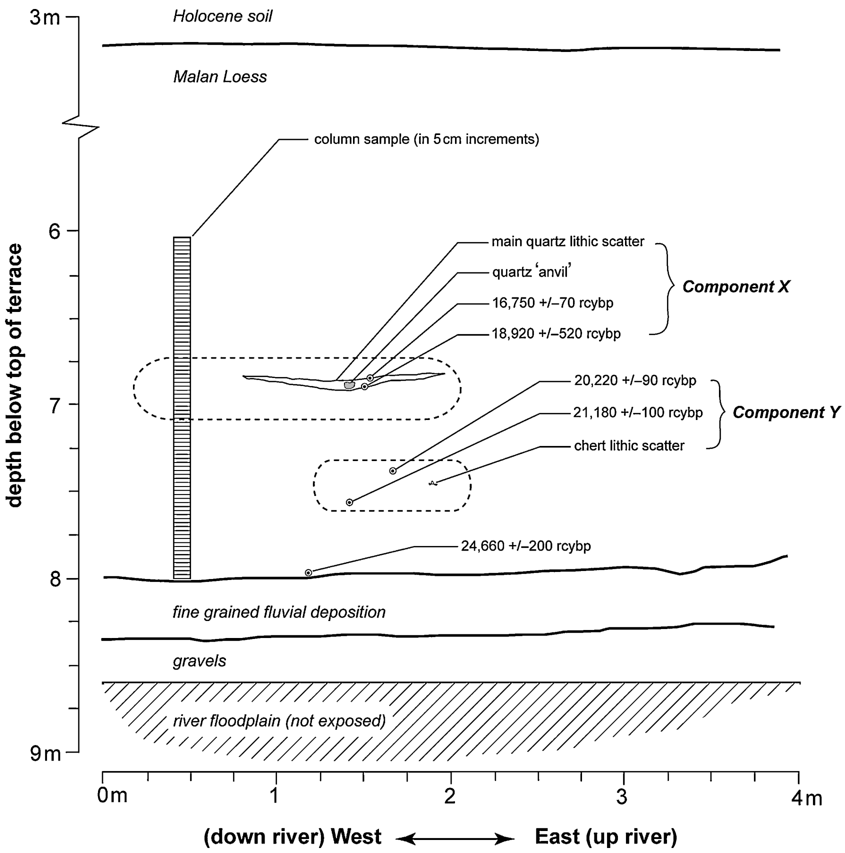


Fig. 5. Looking north to the south-facing profile at ZL05 across the Bei Shui Luo River. (Photo by D.B. Madsen.)

Fig. 6. The ZL05 excavation profile.



this point, it is impossible to know whether these seeds represent local processing and subsequent burning of small-seed bearing plants or if they are the product of local range fires. If further excavation were to corroborate the former, ZL05 would represent one of the earliest known examples of small-seed subsistence in China and, for that matter, anywhere in the world.

The dominant ZL05 cultural component represents a relatively isolated event of lithic reduction (Figure 6: Component X). The centerpiece of the component is a robust and pitted quartz slab surrounded by broken quartz core fragments, and thousands of small pieces of quartz debitage, distributed densely up to a meter away from the center of the deposit. The slab itself is an anvil upon which numerous massive crystalline quartz cobbles, presumably collected from the nearby riverbed, were battered through bipolar reduction to generate expedient flakes and small geometric lithic shards (Table 2). No retouched or classically formal tools were recovered from this assemblage, but two blade-like flakes emerged, reminiscent of the expedient bipolar blades recovered from Hearth 2 at Shuidonggou, Locality 2 (Brantingham *et al.*, 2004a). Two radiocarbon estimates anchor the upper ZL05 lithic component to the LGM, between 24.0 and 19.7 ka (Figure 6).

The appearance of additional, temporally distinct cultural material at other points in the section suggests that this location was visited repeatedly during the Late Pleistocene. Evidence for the small-scale reduction of chert, roughly 45 cm below the main lens of occupation (Figure 6: Component Y), dates between 25.9 and 23.9 ka. Additionally, several isolated but undated chipped stone implements were found scattered throughout the Malan loess.

Geologically, the section is comprised of five distinct depositional events (Figure 7). The uppermost layers are modern cultivated soils and disturbed Holocene paleosols. The layer in which the cultural deposits rest is massive, friable, Pleistocene loess, generally consistent with Malan loess deposits found in other regions of the Loess Plateau (e.g., Chen *et al.*, 1997). This deep Malan loess deposit sits atop non-compact, granular, reddish sand, interleaved by fine, yellow sand. Below this are poorly sorted, rounded gravels, indicative of high-energy alluvial deposition. The contact between the aeolian Malan loess and the preceding alluvial deposition dates between 29.3 and 27.8 ka (Ji *et al.*, 2005; Bettinger *et al.*, n.d.).

Column sampling of the Malan loess at ZL05 in 5-cm increments enabled a high-resolution paleoenvironmental sequence for the period surrounding the primary occupation of the site (Figures 6 and 7). Specifically, two proxy markers of monsoon variability, Magnetic Susceptibility and Grain Size Distribution Analysis, suggest a pattern consistent with the loess–paleosol sequence established elsewhere in the western Loess Plateau (Chen *et al.*, 1997). Likewise, the

Table 2. Lithics from ZL05. Size sorting (following Henry et al., 1976; Ahler, 1989) with a stack of nested geological test sieves yields a size distribution to define bipolar reduction of massive crystalline quartz cobbles (Component X). Component Y is too small (n = 5) to determine reduction strategy from a size distribution. "Other" represents a compilation of scattered lithics, found embedded throughout the profile, and "surface" represents surface collections directly below the ZL05 section.

	>10mm	10–5mm	5–2.5 mm	<2.5 mm	blade	core	core frag	anvil	N
component X	203	537	1,241	247	2	7	11	1	2,249
component Y	0	2	3	0	0	0	0	0	5
other	0	3	14	0	1	0	0	0	18
surface	27	8	3	1	0	0	7	0	46
total	230	550	1,261	248	3	7	18	1	2,318

ZL05 sequence is generally consistent with the Hulu Cave record which tracks summer monsoon intensity as a record of $\delta^{18}O$ fluctuations in speleothem calcite (Wang *et al*., 2001; Yuan *et al*., 2004). High-energy fluvial action at the base of the ZL05 section corresponds to a pronounced peak in the Hulu Cave speleothem record indicative of summer monsoon dominance. This peak has also been correlated with Dansgaard–Oeschger warming event number 4 (Wang *et al*., 2001: 2346), which marks the beginning of a steady decline into the Last Glacial.

Soil formation, often measured by magnetic susceptibility, implies high precipitation and is an established proxy for summer monsoon intensity in the Loess Plateau (An *et al*., 1991). The Xlf magnetic susceptibility record from the ZL05 section demonstrates pronounced soil formation for the interval between 29.0 and 24.0 ka, but declines immediately thereafter as summer monsoon precipitation decreased in concert with global patterns of environmental change characteristic of the long steady slide into the LGM.

Increases in mean and median grain-size, relocated by wind action from the expanding deserts northwest of the Loess Plateau, are characteristic of loess deposition records during the LGM (Derbyshire *et al*., 1998; Kohfeld and Harrison, 2003) and point to the increasing dominance of the winter monsoon system, perhaps governed by the interaction between the Siberian–Mongolian high pressure and Aleutian low pressure systems (Ding *et al*., 1992; Chen *et al*., 1997). At ZL05, the increased median size of the windborne dust particles confirms the strength of the winter monsoon during the LGM. Lastly, this high-resolution

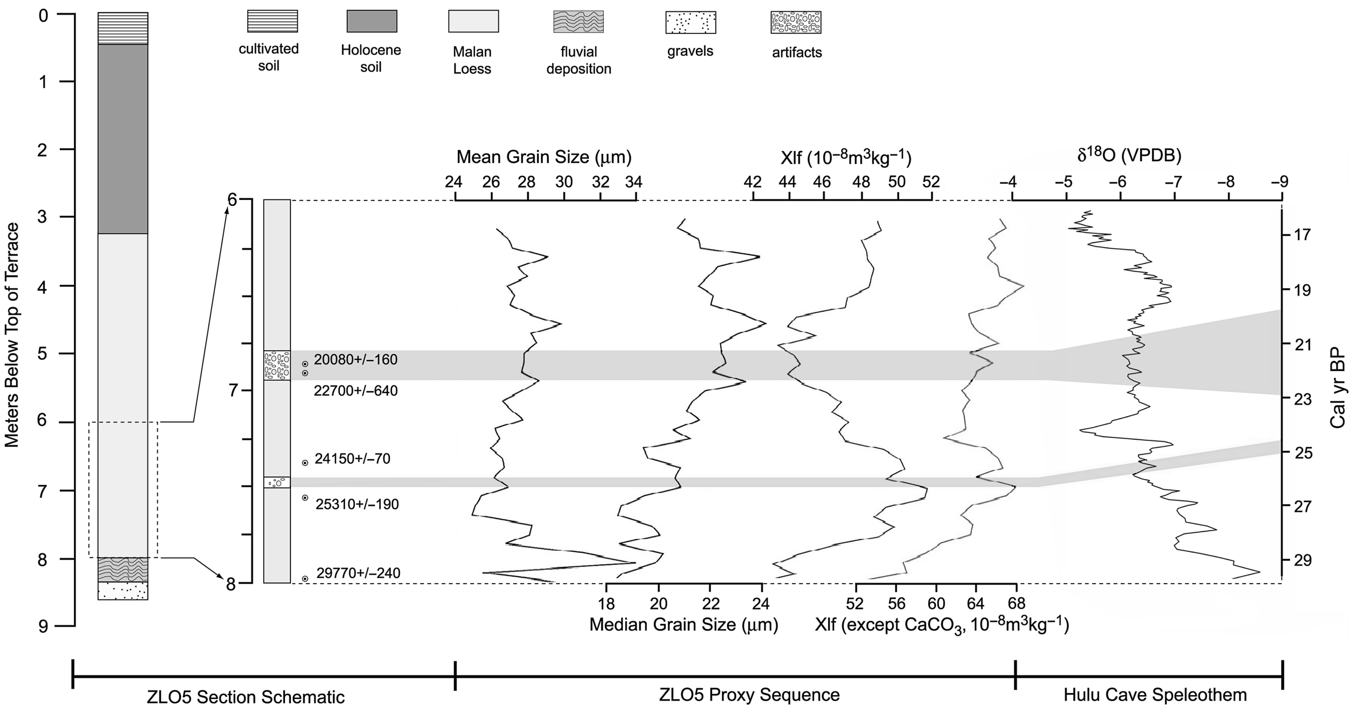


Fig. 7. Geological deposition and environmental proxies from ZL05. The Hulu Cave proxy for monsoon intensity is provided at right for rough comparison.

sampling at ZL05 illustrates the punctuated variability of the winter/summer monsoon trade-offs during the last interglacial–glacial cycle.

5. Raw Materials, Paleolithic Tool Technology, and Human Mobility

To interpret the archeological record of the western Loess Plateau we combine our analysis of hunter-gatherer mobility based on radiocarbon data, with basic archeological patterns of stone raw material use throughout the region. Essentially, the frequency of specific raw materials in archeological assemblages reveals how people acquire them.

For hunter-gatherers, stone raw materials are acquired either by trade or by direct access. Given the low population density of Pleistocene northeast Asia and the volatility of environmental change during MIS3, direct access is perhaps the best explanation for raw material acquisition for much of the Pleistocene.

One of us (Brantingham, 2003) has argued that the diversity of stone raw materials in an archeological assemblage results from: (1) how much toolstone an individual can carry; and (2) how rapidly the mobile toolkit changes as local materials are incorporated to replace exotic materials carried from greater distances. The simulations in this model are based upon a ‘‘random walk’’ foraging pattern, similar to that proposed for the EUP foragers of the MIS3 interglacial (Brantingham *et al*., 2003). In this scenario, hunter-gatherer mobility patterns are assumed to operate without regard to raw material availability. Rather, hunter-gatherer movement is determined by local subsistence productivity. Hunter-gatherers move from one foraging patch to the next in response to resource depression, generating a seemingly random pattern of movement about the landscape. If movement is determined by access to subsistence resources, and not lithic resources, then we should expect to see hunting technologies capable of incorporating a wide range of local raw materials, regardless of the limitations of the material. If this ‘‘neutral model’’ is correct, the archeological assemblages of highly mobile, random walk hunter-gatherers should always be dominated by local materials and the manner of stone tool use and manufacture should reflect the local character of the raw materials. This simple, deterministic relationship has been demonstrated with both archeological and ethnographic data (Andrefsky, 1994).

The basic implications of the neutral model, that raw material availability has little effect on the migratory patterns of human foragers, suggest that highly mobile, random walk foragers transfer exotic raw materials, perhaps over great distances, but not with any regularity. Whenever the random walk foraging pattern exists, the proportion of exotic raw materials in the archeological assemblage should be low, but potentially visible. Furthermore, as the random walk pattern is curtailed by environmental circumscription, access to exotic raw materials declines steeply and their archeological representation should be negligible.

If exotic materials carried in the mobile tool kit decline exponentially with increasing distance from the source of the materials (Brantingham, 2003), the technological adaptations underwriting random walk hunter-gatherer subsistence strategies must be flexible enough to incorporate a wide range of raw materials. Strategies built upon rigid, prepared-core technologies, such as flat-faced core and blade reduction (a defining feature of the EUP), biface technology, or microblades, will not survive the random walk pattern when hunter-gatherers move into regions bereft of suitable raw materials. Therefore, we do not expect to see much of the typical EUP technology in the western Loess Plateau where find-grained cryptocrystalline raw materials, such as those used at Shuidonggou, are rare or non-existent. For a random-walk foraging pattern geared toward the pursuit of shifting resource abundance, as was characteristic of the last interstadial, to survive and persist, it must be supported by a highly flexible technological adaptation.

The production of blades during the EUP suggests a composite tool technology wherein stone tools, including levallois-style blades and points, are set in some combination of shafts, foreshafts and other hafting elements to create implements suitable for large game hunting and butchering. These hafts and handles, presumably made from wood or bone, are thus the defining feature of the EUP and provide a flexible, technological substrate into which locally adaptive modifications might be incorporated. As hunter-gatherers moved into landscapes devoid of lithic raw materials suitable for EUP prepared-core blade, flake, and point manufacture, they developed alternative methods of stone tool production and adjusted these new, and perhaps smaller, lithic insets to suit the pre-existing composite weaponry system. This pattern is visible at ZL05 in Component X, where expedient, bipolar reduction of massive, crystalline quartz cobbles produced thousands of small lithic shards.

The ZL05 lithic data (Table 2) demonstrate that reduction of an individual cobble yields (minimally) 124 small fragments, and the predominant size of the debitage (5–2.5 mm) fits within the size range of truncated microblades. Presumably, the choice pieces of quartz were removed by the toolmaker for inserts in composite armatures. Alternatively, extensive bipolar reduction generated tool blanks that were removed for subsequent modification. The local abundance of quartz cobbles and the high volume of manufacturing debris suggest that raw material conservation was not imperative. Here, the costs of acquiring only a few suitable tool blanks by reducing a large number of locally abundant raw materials are low in comparison to acquisition and curation of higher-quality, exotic raw materials.

6. Hunter-Gatherer Occupation of the Western Loess Plateau

Radiocarbon determinations from TX08 and TX03 in the northern portion of the western Loess Plateau, ZS08 in the upper reaches of the Shui Luo River basin and GY03 in the eastern foothills of the Liu Pan Mountains are coeval with those at Shuidonggou (Table 1; Figure 8). In each of these cases, the lithic assemblages are comprised of rough stone tools, manufactured from massive, crystalline quartz cobbles with hard hammer and bipolar percussion (Ji *et al*., 2005; Bettinger *et al*., n.d.). While these sites are contemporaneous with the EUP assemblages at Shuidonggou, they do not conform to the classic expectations of the EUP techno-complex. The temporal and spatial proximity to Shuidonggou led Bettinger *et al*., (n.d.) to classify the assemblages from these sites as the *Tong Xin* facies of the north China EUP. It seems clear that the assemblages from each of these sites represent adaptations to local resources, implying that regular access to higher-quality exotic materials was exceedingly costly, or at least rare enough to be relatively invisible archeologically. This local focus coincides with a pronounced cold/dry interval centered around 30.0 ka (Figure 3), suggesting reduced mobility.

However, at this point it would be premature to rule out a shared ancestry with the classic EUP adaptations at Shuidonggou. Recent archeological survey data from Ningxia Province, east and north of the Liu Pan Mountains along the current boundary of the desert–loess transition zone, demonstrate that an EUP blade technology similar to that at Shuidonggou exists over a much greater area than previously supposed (Gao *et al*., 2004). Nevertheless, this technology does not penetrate into the higher elevation zones of the western Loess Plateau. Additional data from stratified

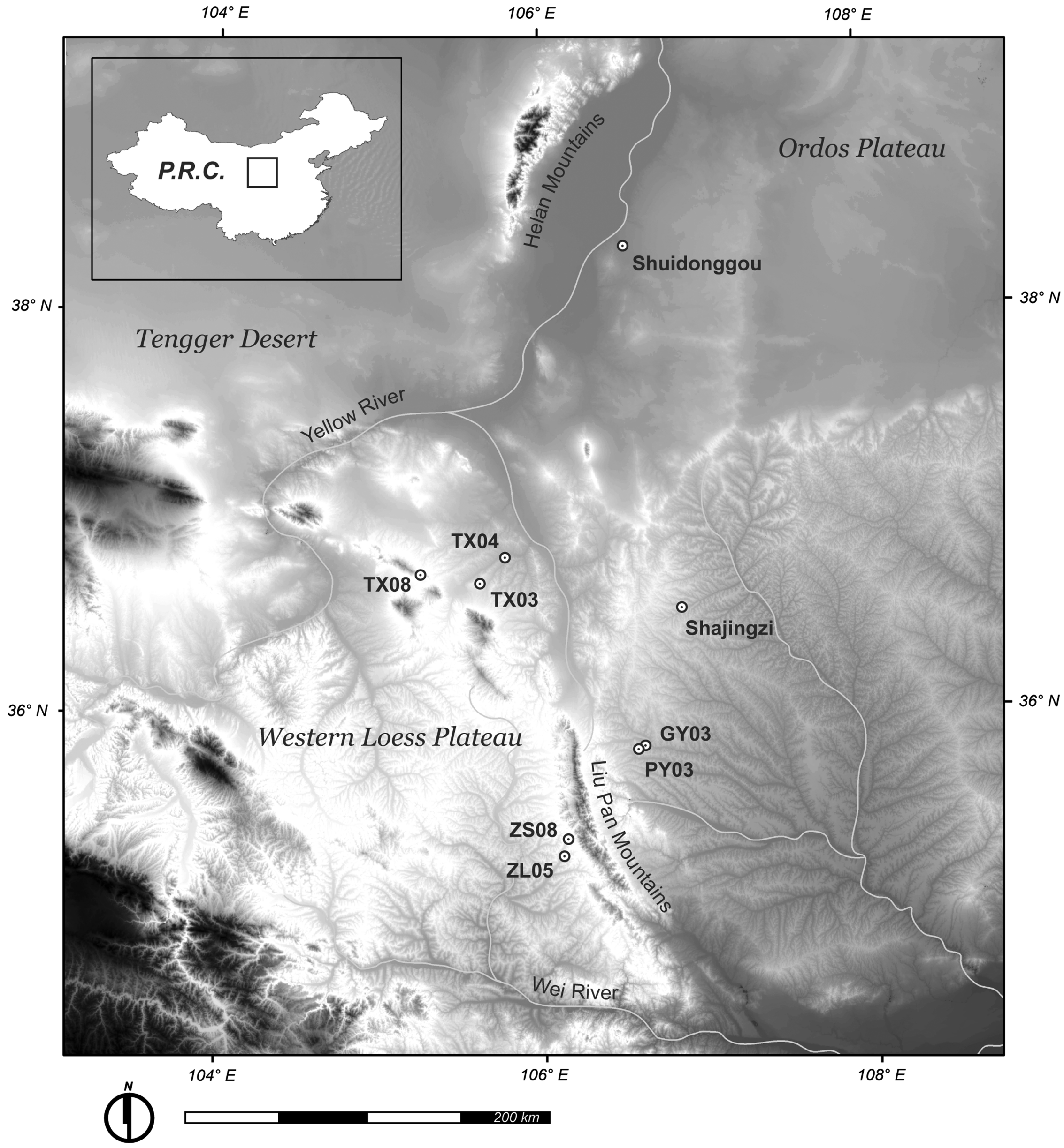


Fig. 8. Recently dated Paleolithic sites from the western Loess Plateau and surrounding regions.

archeological sites along the desert–loess boundary, specifically in Ningxia Province are necessary to clarify the nature of human mobility during this interval and to better establish the cultural connections between the *Tong Xin* EUP in the western Loess Plateau and the classic EUP adaptations further north.

At ZL05, the earliest evidence for temporary human occupation (Figure 6: Component Y) corresponds to a period dominated by the high-precipitation regime of the Pacific summer monsoon. That the cultural assemblage here is comprised of stone tool manufacturing debris made from non-local chert suggests the early inhabitants of this river margin were relatively mobile and carried their preferred toolstone with them over great distances as they went about their foraging rounds. In contrast, the proprietors of the later and much larger deposit of tool manufacturing debris (Figure 6: Component X) focused their attention on the highly abundant, but low quality, local quartz. The fracture mechanics of massive, crystalline quartz are irregular and unpredictable, making it far less optimal for prepared-core reduction technology than other raw materials such as cert, jasper, silicified limestone, or even quartzite (see Seong, 2004, for discussion and summary of vein quartz fracture mechanics). However, it is clear from the upper ZL05 component that local hunter-gatherers had little interest in raw-material conservation, choosing instead to batter the local materials intensively with hammer-and-anvil percussion until the desired flakes or shards were generated. The intensive and wasteful use of highly abundant, local raw materials suggests a pattern of reduced mobility during the cold, arid LGM.

Here, we incite the environmental parameters of range contraction put forth in the preceding sections. During MIS3 the migratory range of human foraging groups was consistently expanding and contracting in response to high-amplitude, long-term climate fluctuations characterized by the Dansgaard–Oeschger cycles. We have suggested that mild periods characterized by heavier summer rainfall and reduced winter dust storms facilitated high mobility among human foraging groups. It was during these intervals that the EUP expanded slowly by way of human migration across northeast Asia. This gradual pace is evident in the 10,000–15,000 year time lag between the initial appearance of EUP technology in Siberia and the later appearance of it at Shuidonggou in northern China (Brantingham *et al*., 2001; Madsen *et al*., 2001; Brantingham *et al*., 2004a). Conversely, during the periods dominated by the cold/dry winter monsoon, hunter-gatherers were tethered to concentrated yet disparate and unpredictable resource patches, making long-distance movement between them much less feasible. Recurrence of these punctuated cold/dry intervals during MIS3 inhibited the random walk migration pattern of human foragers thereby limiting the rate of EUP cultural expansion.

At ZL05, the later, and much larger, "Component X" appears during a pronounced cold/dry interval, generally described as the LGM. Here, the expedient use of local raw materials seems to confirm the circumscribed range of hunter-gatherer groups occupying the Shui Luo River basin in the western Loess Plateau.

While microblade technology is a recurrent feature of the north China Upper Paleolithic, it is virtually unknown in the western Loess Plateau. This is due to the absence of suitable raw materials in the area and to the circumscribed nature of Paleolithic foraging strategies in the western Loess Plateau. True microblades, however, are evident north of the Yellow River along the southern limits of the Helan Mountains at Pigeon Mountain by 15.1 ka (Elston *et al*., 1997) and at PY03 on the eastern slope of the Liu Pan Mountains by 22.1 ka (Bettinger *et al*., 2003). At Pigeon Mountain and perhaps at Shuidonggou, raw materials suitable for microblade production are locally available. At PY03, a single, heavily reduced microblade core suggests either importation from adjacent regions or thorough reduction of a rare local resource. In each of these locations, the use of small, linear blades removed from prepared wedge, prismatic, or boat-shaped cores represents the addition of a distinct lithic reduction strategy to a pre-existing composite weaponry system. Despite the absence of raw materials suitable for microblade production, the underlying technological adaptations visible at ZL05 during the LGM might be considered equivalent to those at PY03, Shuidonggou, and even Xiachuan where true microblade technology does exist during the LGM.

We echo previous suggestions (Madsen *et al*., 2001; Brantingham *et al*., 2004a; Brantingham *et al*., 2004b) that the composite tool technology of the EUP provided the substrate into which the succeeding fluorescence of microblade technology was easily incorporated. This began initially during the MIS3, but expanded rapidly and significantly following the LGM.

Clearly, microblade technology does not originate as a product of post-glacial adaptations. Furthermore, if northeast Asia was not uniformly abandoned during the LGM then simple recolonization cannot explain the rapid fluorescence of hunting adaptations based on microblade technology. Acceptance of these points warrants alternative explanations for the post-glacial explosion of microblade adaptations.

7. A Speculative Model of Cultural Evolution in Northeast Asia

7.1 The Evolution of Extended Social Networks During the LGM

Northeast Asia was not depopulated during the LGM. However, environmental deterioration did force human foragers into the narrow refugia of a marginal, northern latitude environment. During this time, increasing aridity across northeast Asia and the retreat of temperate grasslands deep into the Loess Plateau and the north China Plain gave rise to demographic packing along the margins of the expanding deserts where more people were aggregated in fewer inhabitable areas. Since most of the landscape was uninhabitable, access to limited resources in circumscribed areas became highly contested, and territorial competition for these limited resources placed additional limits on the long-established practice of managing resource depression with simple mobility. With mobility an insufficient solution to the hazards of resource shortfall, alternative adaptive strategies emerged from the pre-existing tapestry of EUP adaptations already in place across northeast Asia.

Two alternative strategies for managing the hazards of resource shortfall are storage and diet-breadth expansion (see Madsen and Elston this volume). Either or both of these organizational alternatives were likely solutions to the inevitable resource shortfalls resulting from the punctuated cold/dry intervals associated with winter monsoon dominance during the Late Pleistocene of northeast Asia. However, we suggest that the prolonged environmental deterioration of the LGM may have necessitated the evolution of institutional solutions to cope with the frequent hazards of subsistence shortfall.

Institutional, group-beneficial adaptations are abundant in the ethnographic literature of Holocene hunter-gatherers. For the !Kung of southwest Africa and for many Aboriginal hunter-gatherers of central Australia, social institutions answer the ever-present threat of resource depression in arid, marginal environments. The *Hxaro* system of mutual, reciprocal exchange enables the !Kung to average subsistence risk across a network of individuals separated by up to 200 km (Weissner, 1977; Weissner, 1982). Similarly, the elaborate section and subsection marriage systems of Aboriginal Australia establish predefined alliances between biologically unrelated individuals, providing small mobile groups with insurance against the recurrent economic hardships of a spatially and temporally variable environment (Yengoyan, 1968). Both are examples of group-beneficial, institutional solutions to resource depression, and we suggest that similar institutional adaptations emerged during the LGM in northeast Asia.

The evolution of complex, social or institutional solutions to marginal environments during the later Paleolithic is not a new idea. In particular, the Upper Paleolithic expansion of modern humans throughout Europe is seen as a triumph of social rather than technological or biological adaptation (Gamble, 1983; Gamble, 1986). For both Gamble and Whallon (1989), human occupation of extreme environments is contingent upon the existence of integrated social networks capable of transferring information, mates, and resources over great distances. While the ethnographic record bears witness to these propositions, the difficulty is in identifying the conditions under which such extended networks might evolve and then in finding the archeological evidence to confirm it. The truth of the matter is that extended, long-distance social networks do not evolve in an undifferentiated, disarticulated population of individuals spread out over vast tracks of land. Rather extended social networks and the institutions that maintain them likely evolve when individuals combine to form cohesive social groupings and when there are distinct differences between neighboring groups.

7.2 Coordinated Group-beneficial Behavior Evolves Only by Group Level Selection

While adaptive solutions such as technological innovation, mobility, and even diet-breadth expansion may evolve by natural selection acting on individual variation, elaborate social institutions shared by genetically un-related individuals distributed over vast tracks of uninhabited land do not. Instead, the evolution of coordinated group-beneficial behaviors only occurs under a narrow range of conditions where natural selection acts on the adaptive capacity of the entire group. The conditions that provide for group selection have been established with formal, mathematical models couched in the evolutionary dynamics of population genetics (Boyd and Richerson, 1985; Wilson and Sober, 1994; Soltis *et al*., 1995; Boyd and Richerson, 2002; Richerson and Boyd, 2005). We offer only a basic outline of them here.

On any level, natural selection acts on phenotypic variation. By comparison to organic evolution, cultural evolution generates phenotypic variation rapidly both within and between groups of people. Specifically, significant between-group variation allows selection to act on the level of the group whereas typical Darwinian natural selection acts on the adaptive variation between individuals. Therefore, the emergence and maintenance of between-group variation are essential components of evolution by group selection.

Theoretical modeling suggests that between-group variation will be maintained through punishment (enforcement of the social norms that maintain group-beneficial behaviors) (Hirshleifer and Martinez Coll, 1988; Boyd and Richerson, 1992), conformist social learning (where people learn by imitating the most common behavior) (Henrich and Boyd, 1998), or some combination of the two. Predispositions towards moralistic punishment and conformist social learning are thought to represent the "tribal instincts" of an evolved general psychology, itself a product of long-term environmental variation during the early Pleistocene history of modern humans (Richerson and Boyd, 1998; Richerson and Boyd, 2000; Richerson and Boyd, 2001; Richerson *et al*., 2003; Richerson *et al*., 2005). For either of these processes to give rise to group selection, the rate of migration between the groups must be low enough to prevent the erosion of the cultural differences that keep the groups distinct.

In addition to heritable, stable variation between groups, intergroup competition is necessary for behavior to evolve by group selection; that is, there must be a competitive imbalance between groups. Initially, group-beneficial cultural variants (e.g., formal institutions that provide for resource-redistribution or sharing in times of need) are most likely to spread to an entire group when the group is small, and such diffusion is possible through stochastic processes analogous to genetic drift (Richerson and Boyd, 2005). Once established within a single cohesive group, group-beneficial variants can spread to other groups by two distinct processes: differential survival and differential diffusion (Boyd and Richerson, 2002). The former amounts to local extinction when one group outcompetes another leading to either complete dissolution or assimilation of the less competitive group. This slow process of group selection may require as much as 1500 years to produce widespread, group-level adaptations (Soltis *et al*., 1995). Differential diffusion, however, will allow group-level adaptations to evolve and spread much more rapidly. Here, imitation of successful neighbors, also called "prestige-biased transmission" (Henrich and Gil-White, 2001; Henrich, 2001), facilitates the rapid spread of entire packages of cultural behavior between and within spatially structured populations (Boyd and Richerson, 2002). Finally, and critically, if differential diffusion allows group selection to act on group-beneficial behaviors there must be regular interaction between groups with different adaptive strategies. Without this regular interaction, intergroup competition will be weak and natural selection will not act on the level of the group.

7.3 Archeological Signatures of Group-Level Adaptation

Unfortunately, current archeological methodology cannot provide direct, unequivocal evidence for prehistoric social institutions. However, the conditions promoting the evolution of group-beneficial adaptations via group selection do have material correlates and these may be extracted from the archeological record. Archeology must provide evidence for this evolution in the following sequence: (1) the existence of small, independent foraging groups; (2) measurable between-group cultural variation; (3) mechanisms that maintains between-group variation; (4) interaction between groups; (5) competition between groups; and (6) the rapid spread of cultural attributes to reflect the outcome of between-group competition.

Novel adaptive solutions such as group-level cooperation and resource sharing can emerge by chance in small groups of human foragers. The archeological record of Paleolithic hunter-gatherers in northern China suggests that population densities were relatively low throughout the Pleistocene. Paleolithic archeological deposits are stratigraphically thin, typically containing only a few hearths and small clusters of stone tools.

The formal modeling described above requires measurable between-group cultural variation. On a microscale, this variation will be difficult to detect given the low probability of archeological preservation. However, if we accept the dates provided for pre-LGM microblades at Dingcun and Caisi in north China (Lu, 1998), the occasional appearance of such novel technological variants suggests that cultural evolution can and will generate isolated solutions to local adaptive problems. Locally adaptive solutions will produce strong between-group variation when populations are spatially segregated. The emergence of localized, geographically isolated cultural variation is analogous to allopatric speciation in biological populations (e.g., Mayr, 1963: 278–295). Two lines of archeological evidence point to geographic cultural speciation in northern China: spatial aggregation and segregation during cold/dry periods and regional differences in toolstone use and manufacture. A third possible measure of between-group variation is symbolic or "ethnic" marking (McElreath *et al*., 2003). Though common in the Paleolithic record of other parts of the world (Conkey, 1978; White, 1993; Kuhn *et al*., 2001; Close, 2002), with a few notable exceptions symbolic representation is conspicuously absent from the Paleolithic of north China. Therefore between-group differences most likely emerged and solidified through isolation rather than through the evolution of ethnic markers.

For group selection to act on any cultural variant, including cooperative behavior, there must be competition between groups. In this case, "competition" is not limited to direct aggressive conflict between groups, merely that one group must have a competitive advantage over another for survival and reproduction. This competitive advantage must be visible to members of both competing groups and this requires interaction between groups. Group selection is therefore unlikely to act on spatially isolated populations. Rather, the initial selective pressures occur when small, previously isolated groups are forced to compete for limited, localized resources during the cold/dry intervals of MIS3, and particularly during the LGM (Figure 9). With climatic amelioration, human groups once again expand their foraging range, taking with them the group-level behaviors and identities. This expansion brought previously isolated groups into contact, and those groups with well-defined social networks were able to outcompete those groups without. This competitive process led to the rapid spread of behavior, and perhaps technology, as natural selection once again acted on the level of the group. The final archeological testament to this process is the extremely rapid spread of microblade technology across northeast Asia during the post-glacial period.

In broad strokes, the archeological record does meet the necessary conditions for the evolution of group-beneficial behavior by group selection. Additional data and directed research may crystallize the local and regional dimensions of these necessary conditions. At the moment, the most tangible evidence in support of this hypothesis – the rapid and widespread post-glacial appearance of microblade technology – is also the phenomenon we desire to explain.

7.4 Social Networks and the Diffusion of Microblades

We suspect the rapid post-glacial appearance of microblade technology, as evidenced by its "geologically instantaneous" florescence in Siberia (Brantingham *et al*., 2004b, p. 280), resembles the "S-shaped" sigmoid adoption curves identified in the diffusion of innovations literature (e.g., Rogers, 2003, p. 11). The spread of such innovations requires an interconnected population capable of transmitting detailed information between individuals within groups and between groups. While the technological identity of

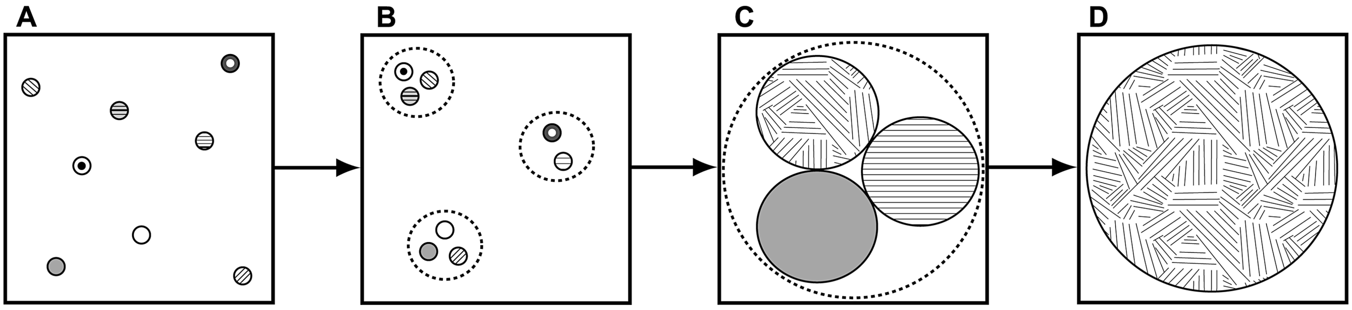


Fig. 9. A schematic of evolution by group selection and the diffusion of innovations. "A" represents small groups of random walk hunter-gatherers dispersed over the landscape during MIS3. We assume that group-functional behavior predominates in at least one of these small groups. In "B" the environmental circumscription of the LGM forces previously independent groups into competition for localized and limited resources. Ultimately, one adaptive strategy outcompetes all others and all individuals in the local area adopt the cultural markers and behaviors of the most successful group. Each group then evolves in isolation (analogous to allopatric speciation). We assume that group-functional behavior helped one of the small groups in the top-left cluster to outcompete all other groups in the cluster. During "C" post-glacial climatic amelioration facilitates expansion into previously uninhabitable landscapes bringing previously independent groups into competition once again. The group in the upper-left possesses an adaptation for group-functional behavior; the others do not. In "D" the group with the group-functional behavior outcompetes its neighbors and the cultural markers and behaviors of this group spread throughout the entire region.

the EUP spread via human migration over tens of thousands of years, the more complex technological knowledge associated with microblade production spread between people, already dispersed over a broad geographic region, in only a few thousand.

During MIS3 the primary locus of human cultural adaptation was local and individual. Adaptations emerged on the strength of local adaptive solutions and spread primarily through migration. The evolution of group-functional behavior was made possible by the range contraction and subsequent concentration of hunter-gatherer groups in narrow refugia across northeast Asia during the LGM. It was demographic packing that brought small, previously independent band-level groups into stable interaction spheres and enabled the evolution of coordinated, group-beneficial behavior. Without this recurrent and prolonged interaction, human groups might never have developed the social coordination necessary for the evolution of well-delineated ethnic memberships, nor would they have had the power to institute and enforce the social sanctions necessary to sustain group-beneficial adaptations.

Post-glacial climatic amelioration alleviated this demographic packing and saw the expansion of symbolically marked, extended social networks into extensive territorial holdings. As each of these extended social networks was exposed to new, perhaps superior adaptive strategies, such as microblade tool technology, these strategies spread rapidly throughout the territorial range of the network via conformist social transmission. When a technological adaptation well suited to the environmental uncertainty of the post-glacial period reached the borders of an initial territorial range of the network, it was picked up by members of the adjacent territory and spread rapidly to the extent of its borders. Local limitations in raw material abundance were answered through trade and exchange between members within the extended and coordinated social network. Access to high-quality raw materials was no longer contingent upon direct access to them.

We suggest that the rapid post-glacial proliferation of microblade-based adaptations across northeast Asia was facilitated by social transmission and not merely by migration or colonization. This rapid "diffusion of innovations" was made possible by the evolution of coordinated, group-functional institutions that emerged by necessity during the environmental deterioration of the LGM.

8. Conclusion

Ultimately, our understanding of the evolutionary trajectory that attends the broad-spectrum revolution and later, the agricultural revolution, hinges on our ability to reconstruct the evolution of group-level coordination and group-functional adaptation rather than the appearance or disappearance of specific and perhaps idiosyncratic artifact types.

Most research on Pleistocene cultural evolution assumes more or less individual actors, independent of group-level behavior. Given the likelihood of extremely low population densities for much of the Paleolithic, this perspective is perhaps reasonable. But when archeological data suggest concentration, demographic packing, or population aggregation, we should take note. During these times, the potential for the evolution of social institutions that fundamentally alter the ways in which human foragers manage their environment and transmit information is staggering.

We suggest that ecological conditions in northeast Asia during the LGM provided the right context for the evolution of long-distance cultural continuity and interaction. The evolution of such group-beneficial behavior between unrelated individuals enabled small corporate groups to withstand the periodic but pronounced resource shortfalls characteristic of marginal environments in northern latitudes. In concert with localized technological evolution, population growth, and climatic amelioration during the post-glacial period, group-beneficial behaviors enabled human foragers to expand rapidly into other, previously inaccessible margins such as the Siberian Arctic, the Tibetan Plateau, Beringia, and ultimately North America. This hypothesis echoes older explanations for the cultural and demographic expansions seen in the Upper Paleolithic record of Europe (Gamble, 1983; Gamble, 1986) and elsewhere (Whallon, 1989). That similar group-level adaptations evolved in other parts of the world at different times does not require cultural continuity with northeast Asia, but merely similar demographic and ecological conditions as those seen in northeast Asia during the LGM.

Finally, since well-demarcated social entities defined inwardly and outwardly on the basis of pottery, architecture, land-use practices, and settlement hierarchies are the hallmarks of Neolithic society, the evolution and persistence of Neolithic social systems during the Holocene is predicated on the existence of highly structured group-level coordination. Without it, agricultural subsistence itself would not be possible. With it, the Neolithic *culture* of agriculture spreads rapidly, at the expense of hunter-gatherers and their group-level adaptations, to all but the most intractable of landscapes.

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