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History and possible mechanisms of prehistoric human migration to the Tibetan Plateau

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Abstract Prehistoric human history on the Tibetan Plateau is a hotly debated topic. Archaeological research on the plateau during the past few decades has enormously improved our understanding of the topic and makes it possible for us to consider the processes and mechanisms of prehistoric human migration to the region. By reviewing the published archaeological research on the Tibetan Plateau, we propose that the first people on the plateau initially spread into the He-Huang region from the Chinese Loess Plateau, and then moved to the low elevation Northeastern Tibetan Plateau and perhaps subsequently to the entire plateau. This process consisted of four stages. (1) During the climatic amelioration of the Last Deglacial period (15–11.6 ka BP), Upper Paleolithic hunter-gatherers with a developed microlithic technology first spread into the Northeastern Tibetan Plateau. (2) In the early-mid Holocene (11.6–6 ka BP), Epipaleolithic microlithic hunter-gatherers were widely distributed on the northeastern plateau and spread southwards to the interior plateau, possibly with millet agriculture developed in the neighboring low elevation regions. (3) In the mid-late Holocene (6–4 ka BP), Neolithic millet farmers spread into low elevation river valleys in the northeastern and southeastern plateau areas. (4) In the late Holocene (4–2.3 ka BP), Bronze Age barley and wheat farmers further settled on the high elevation regions of the Tibetan Plateau, especially after 3.6 ka BP. Finally, we suggest that all of the reported Paleolithic sites earlier than the LGM on the Tibetan Plateau need further examination.

Keywords Tibetan Plateau, Prehistoric archaeology, Human migration, Driving mechanisms

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1. Introduction

The Tibetan Plateau, with an average elevation above 4000 masl (meters above sea level) and an area of over 250×10^4 km^2 (Zhang et al., 2002), is the highest and largest plateau in the world and has been called the Third Pole (Yao and Greenwood, 2009; Yao et al., 2012). The Tibetan Plateau is surrounded by a series of high mountains, which not only separate it from neighboring low elevation regions, but which also acted as a barrier to prehistoric human migration up to the plateau. The Tibetan Plateau has diverse landforms, including mountains, basins, lakes, and river valleys. The vegetation is usually low-growing and scattered, mainly tundra, steppe and desert steppe, and forest only occurs on the surrounding mountains (Zheng, 1996). Overall, the

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plateau has low biodiversity and productivity and there are only a few species of animals (Zhang, 2004). Above all, the Tibetan Plateau is an extremely harsh environment for both wildlife and humans, because of the lack of floral and faunal resources, strong ultraviolet radiation, and relatively low atmospheric oxygen levels (Beall, 2001). Consequently, the plateau has become one of the most important places for biologists, anthropologists, archaeologists and geneticists to study the evolution and environmental adaptation of plants, animals and humans (Aldenderfer and Zhang, 2004; Moore et al., 1998; Qiu et al., 2012; Yi et al., 2010).

Previous work suggests that humans first arrived on the Tibetan Plateau during the Last Glacial and began to adapt to the high elevation environment both biologically (Moore et al., 1998; Yi et al., 2010) and behaviorally (Aldenderfer and Zhang, 2004; Brantingham et al., 2010; Gao et al., 2008). Later, in the mid-late Holocene, they occupied the high elevation regions (>3000 masl) (Chen et al., 2015b). In the course of this process, humans would have had to adjust their respiratory and blood systems to deal with the problem of the low atmospheric oxygen level (Lenfant and Sullivan, 1971), reinforce the use of wild food resources (Rhode et al., 2007b), introduce domesticated plants and animals, burn animal dung, and build houses (Baker, 1969) in order to cope with the harsh conditions on the plateau. Thus, the processes and mechanisms by which prehistoric humans migrated to the Tibetan Plateau are of significant interest not only to archaeologists but also to anthropologists and geneticists. Although the history of late Holocene permanent human occupation of the Tibetan Plateau has recently been reported in depth (Chen et al., 2015b), the early human history and mechanisms of human migration to the plateau have not been adequately addressed. In this paper we review all of the archaeological and related paleoenvironmental studies of the Tibetan Plateau, in order try to attempt to understand the history and possible mechanisms of prehistoric human migration to the region.

2. Archaeological remains on the Tibetan Plateau

2.1 Upper Paleolithic in the Last Glacial (35–11.6 ka BP)

No Paleolithic site earlier than the Last Glacial has been reported. Quesang (Figure 1), close to Lhasa, with preserved human hand and foot prints, is probably one of the earliest archaeological sites reported on the plateau, with three OSL dates centered on 21 ka (Zhang and Li, 2002). Unfortunately, the prints and an additional hearth were all found on the surface and there is no reliable stratigraphy; in addition, no reliable associated cultural remains have been found and the Paleolithic archaeological nature of Quesang is still under discussion (Brantingham et al., 2007). Xiao Qaidam in the Qaidam Basin has long been considered to be a classic example of a Paleolithic site on the Tibetan Plateau. It is dated to around 30 ka BP based on the lithic industry (Huang et al., 1987); however, new OSL dates from the site indicate that it is not older than 11 ka (Sun et al., 2010). Blade artifacts were found on the surface at Lenghu site, in the northeastern part of the Qaidam Basin (Brantingham et al., 2007) (Figure 1), and the age of the lake terrace suggests that human occupation was no later than 30 ka BP; however, the date is indirect and it needs to be scrutinized carefully. Human occupation of Selincuo site, in the center of the plateau, may be as old as 40 ka BP, based on the age of relevant lake terraces (Yuan et al., 2007); however, the age of the terraces needs to be further assessed based on new evidence.

Jiangxigou 1 and Heimahe 1 in the southern Qinghai Lake Basin are the earliest reliably-dated Paleolithic sites on the Tibetan Plateau, with AMS ^{14}C and OSL ages from 15–12 ka BP (Madsen et al., 2006) (Figure 1). In addition, there are several other sites of the same age in the Qinghai Lake basin, including HZYC 1, 10HTHS 1 and 93-13 (destroyed) (Madsen et al., 2006; Rhode et al., 2014; Yi et al., 2011) (Figure 1). The stone artifacts collected from these sites are mainly products of the small-flake-tool industry of North China and microblade technology; they include cores, flakes, microblade cores, microblades, scrapers, shatters and debris. Hearths and the bones of middle- to small-sized animals have been found at most of those sites, indicating that they may have been short-term campsites (Madsen et al., 2006; Yi et al., 2011). There are no reports of other Paleolithic sites in the southeastern Tibetan Plateau, although there are several sites in Sichuan and Yunnan, including Ziyang, Liyuqiao, Lijiang, Yushuiping (Figure 1).

Paleolithics found on the Tibetan Plateau exhibit cultural consistency with contemporary Paleolithics in North China (Gao et al., 2008). In the Late Upper Pleistocene, the Paleolithic across the Eurasian continent experienced numerous revolutions, probably stimulated by the large-scale appearance of Modern Humans. Blade technology, representing modern human behavior, appeared at around 48 ka BP in Europe (Hoffecker, 2009) and at 41 ka BP in southern Siberia (Goebel et al., 1993) and Northwest China (Li et al., 2013). A more delicate microblade technology arose in Siberia (Kuzmin and Orlova, 1998) and North China (Lu, 1998) at about 23 ka BP, and was prevalent from 20 to 10 ka BP; it is also seen on the western Loess Plateau (Ji et al., 2005; Zhang et al., 2010). The small-flake-tool industry, lasting for more than one million years in China, still dominated the Upper Paleolithic industries in North China (Zhang, 1999), even at the classic blade technology site of Shuidonggou (Institute of Archaeology and Relics, Ningxia, 2003; Institute of Archaeology and Relics, Ningxia et al., 2013) and at several important microlithic sites (Shi and Song, 2010). However, the small-flake-tool industry underwent significant changes in the late Upper Pleistocene: there was an increase in the use of exotic high quality raw

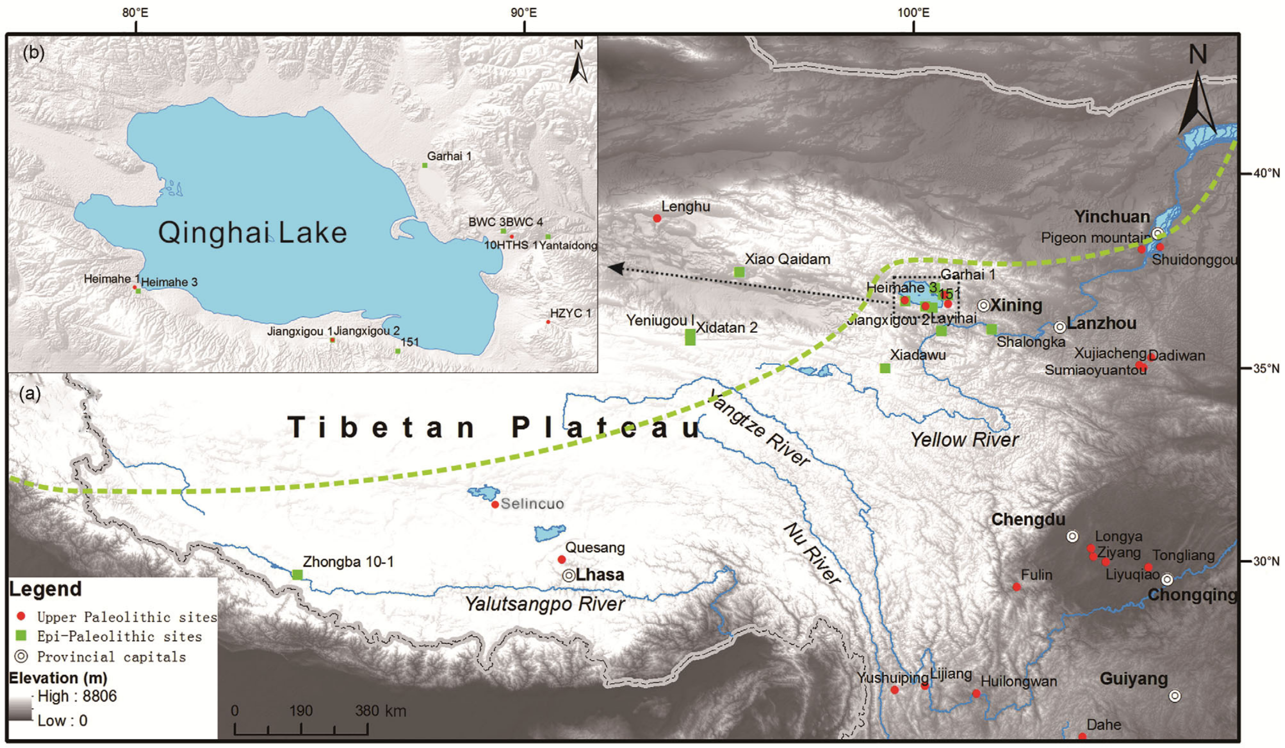

Figure 1 The Tibetan Plateau and Paleolithic (red circles), Epipaleolithic (green squares) sites on the plateau and surrounding regions. (a) The Tibetan Plateau and surrounding regions; (b) Qinghai Lake Basin. The green dashed line indicates the limits of the East Asian Summer Monsoon (Chen et al., 2010, 2008).

materials; an increase in the numbers of stone artifact numbers and in tool types; an increased modification and elaboration of stone tools; and the emergence of organic tools and decoration artifacts (Qu et al., 2013). All of these changes may reflect technological improvements and environmental adaptation innovations, which promoted the population increase indicated by an increased number of archaeological sites, with a wider distribution, and with richer archaeological remains. The appearance of similar archaeological cultures on the Tibetan Plateau therefore resulted from the expansion of the Upper Paleolithic in North China.

2.2 Epipaleolithic in the early-mid Holocene (11.6–6 ka BP)

In the Early-mid Holocene, Neolithic cultures emerged and developed on the Chinese Loess Plateau and the North China Plain, while a Paleolithic culture still persisted on the Tibetan Plateau; this Paleolitthic culture is hereafter termed "Epipaleolithic" according to Prof. Zhang Senshui's proposal that "Epipaleolithic cultures are Paleolithics in the Holocene" (Zhang, 2000). 14 of those Epipaleolithic sites have been reliably dated and are located mainly in Qinghai Lake Basin at an elevation of 3200 masl, and more rarely in the central plateau (>4000 masl) and the Yellow River Valley (2000–3000 masl) (Figure 2). Most of the sites preserve very thin cultural deposits and yield very few artifacts and faunal remains and single hearths, such as BWC3, Heimahe 3 and Yeniugou I (Rhode et al., 2007a; Tang et al., 2013; Yi et al., 2011). A few sites, such as Jiangxigou 2 (Hou et al., 2015) and Layihai (Gai and Wang, 1983), have thick cultural deposits and rich archaeological remains. Microlithics of silicalites and chalcedony are common during this period. Microblade cores include wedge-shaped and pencil-shaped examples. Tools are dominated by scrapers, especially thumb-nail scrapers, which are all delicately modified (Rhode et al., 2007a; Tang, 1999). Numerous wild animal bones, many hearths and several pottery shards of 7000 years old (Hou et al., 2015; Rhode et al., 2007a), were found in Jiangxigou 2, indicating a close relationship with low elevation Neolithic cultures. Chert artifacts similar to those from Jiangxigou 2 have also been found in the Xidatan 2 and Qiangtang collections, suggesting population connections between Qinghai Lake Basin and the central Plateau (Brantingham et al., 2007). A new excavation at site 151 in the southern Qinghai Lake Basin revealed an 8500 years' old occupation (Rhode et al., 2014) with thick cultural deposits and numerous charcoal fragments, artifacts and faunal remains in addition to an earlier short-term Last Deglacial occupation. ^{14}C dates from Zhongba 10-1 in the Yalutsangpo River valley, suggest that microlithics in the central Tibetan Plateau could be as old as 6600 BP (Hudson et al., 2014), while finds from other Paleolithic sites are all surface finds with no chronological references (Tang, 1999;

Li, 1992). There are several Epipaleolithic sites in the southeastern Tibetan Plateau (Li, 1996), but few have reliable dates.

There is a sharp contrast between the early-mid Holocene Epipaleolithic on the Tibetan Plateau and the Neolithic in North China. A Microlithic culture prevailed across North China during the early Holocene, coexisting with the use of ground stones and pottery (Elston et al., 2011) at the Lijiagou, Zhuannian, Donghulin sites, and showing signs of a transition from the Paleolithic to the Neolithic and the beginnings of a complex society (Chen and Qu, 2012). Accordingly, hunter-gathering was also transitioning to agriculture, with the appearance of domesticated millet in North China and domesticated rice in South China (Liu et al., 2009; Lu et al., 2009; Zhao, 2011b). The Yangshao Culture and millet agriculture developed rapidly in the middle Yellow River Region from 7 ka BP (Barton et al. 2009) and expanded to the edge of the Northeastern Tibetan Plateau of the upper Yellow River Region (Wang, 2012). Ground stones, pottery and domesticated plants and animals become the main cultural representations of the Neolithic archaeological sites in North China in the early-mid Holocene. However, at the same time a microblade industry dominated on the Tibetan Plateau, with no or few ground stones, pottery and domesticated plant and animals, and possibly trading or communicating with agricultural populations in the adjacent low elevation regions.

2.3 Neolithic millet agriculture in the late mid-Holocene (6–4 ka BP)

Neolithic sites arose and were widely distributed in the Northeastern, Northern and Southeastern Tibetan Plateau in the late mid-Holocene (Figure 2). The He-Huang river valleys in the Northeastern Tibetan Plateau have the highest density. The Majiayao Culture first arose in the middle Wei River, possibly stimulated by the Yangshao Culture (SCCAS, 2010) and gradually moved westwards to the He-Huang region and even spread to the Gonghe Basin on the plateau and to southern Gansu and western Sichuan. The Majiayao Culture had a deep influence on the Tibetan Plateau, and its classic painted pottery and millet agriculture were well-represented in Western Sichuan (D'Alpoim Guedes and Butler, 2014; Hung et al., 2011; Zhao and Chen, 2011) and even at the Karuo site in the Southern Tibetan Plateau (D'Alpoim Guedes and Butler, 2014; Tibetan Relics Bureau, 1985). Karuo is the oldest Neolithic site in Tibet with several direct dates from millet grains which are centered on the range from 4650–4250 a BP (D'Alpoim Guedes et al., 2014), theoretically about 1000 years younger than the previously reported charcoal dates (Dong et al., 2014). Other reported Neolithic sites, including Changguogou (D'Alpoim Guedes et al., 2014; Fu, 2001), Qugong (SCCAS, 1999) and Jiaritang (Tibetan Cultural Relics Management Committee and History Department of Sichuan University, 2005), are all dated to between 4 and 3 ka BP. More surface finds have been reported as Neolithic sites on the Tibetan Plateau, consisting of microlithics, chip stones, ground stones, pottery, and bone artifacts (Archaeological Institute of Chinese Social Academy and Tibetan Cultural Relics Bureau, 2010; Li, 1992). Neolithic sites in Yunnan are generally younger than 4 ka BP and exhibit connections with contemporary cultures in the Gan-Qing regions (Min, 2009). Overall, houses, storage pits, cemeteries, pottery, copper, domesticated plants and animals first appeared on the Tibetan Plateau， indicating well-developed millet agriculture societies with an advanced pottery industry (Aldenderfer, 2011; SCCAS, 2010).

Neolithics on the Tibetan Plateau originate from the well-developed Neolithic cultures in the middle Yellow River regions. The Late mid-Holocene Yangshao and Longshan Cultures were prevalent on the Loess Plateau (An, 1960), with developed millet agriculture, an hierarchicical society and with primary state politics (Liu, 2007; SCCAS, 2010). The Majiayao Culture arose and developed independently in the Gan-Qing Region under the influence of the Yangshao Culture from Shaanxi and Henan (Wang, 2012), and spread further to the Southeastern Tibetan Plateau.

2.4 Bronze Age barley and wheat agriculture in the late Holocene (4–2.3 ka BP)

In the Late Holocene, Bronze Age cultures and an agro-pastoral economic system emerged and began to flourish on the Tibetan Plateau. The Qijia Culture arose in the Gan-Qing Region, after the Majiayao Culture, at around 4000 BP, and further split into several local cultures, including the Xindian, Siwa, Kayue, Siba and Nuomuhhong (Xie, 2002). The Qijia Culture, mainly distributed in the He-Huang valleys, expanded westwards to Qinghai Lake Basin (Figure 2). Subsequently, the Kayue culture spread over a large area from the He-Huang valley to the Qinghai Lake Basin, the Qilian Mountains, the Gonghe Basin and to the 4000 masl high Guoluo region. The Nuomuhong culture was principally distributed in the Qaidam Basin and the surrounding mountains (Figure 2). Domesticated barley and wheat first arrived in this region at about 4 ka BP and were grown on the edge of the Northeastern Tibetan Plateau (Dodson et al., 2013; Flad et al., 2010). The Qijia people lived sedentary lives, depending mainly on agriculture and partly on livestock rearing, and also conducting hunting and gathering (SCCAS, 2010). They built sophisticated houses, constructed large cemeteries, produced diverse tools, grew foxtail millet, broomcorn millet, barley and wheat (Chen et al., 2015b), raised pigs, dogs and sheep, and hunted deer. Subsequently, the Xindian Culture in the He-Huang valleys developed agriculture, while the Kayue and Nuomuchong Cultures in high-elevation regions relied more on pastoralism.

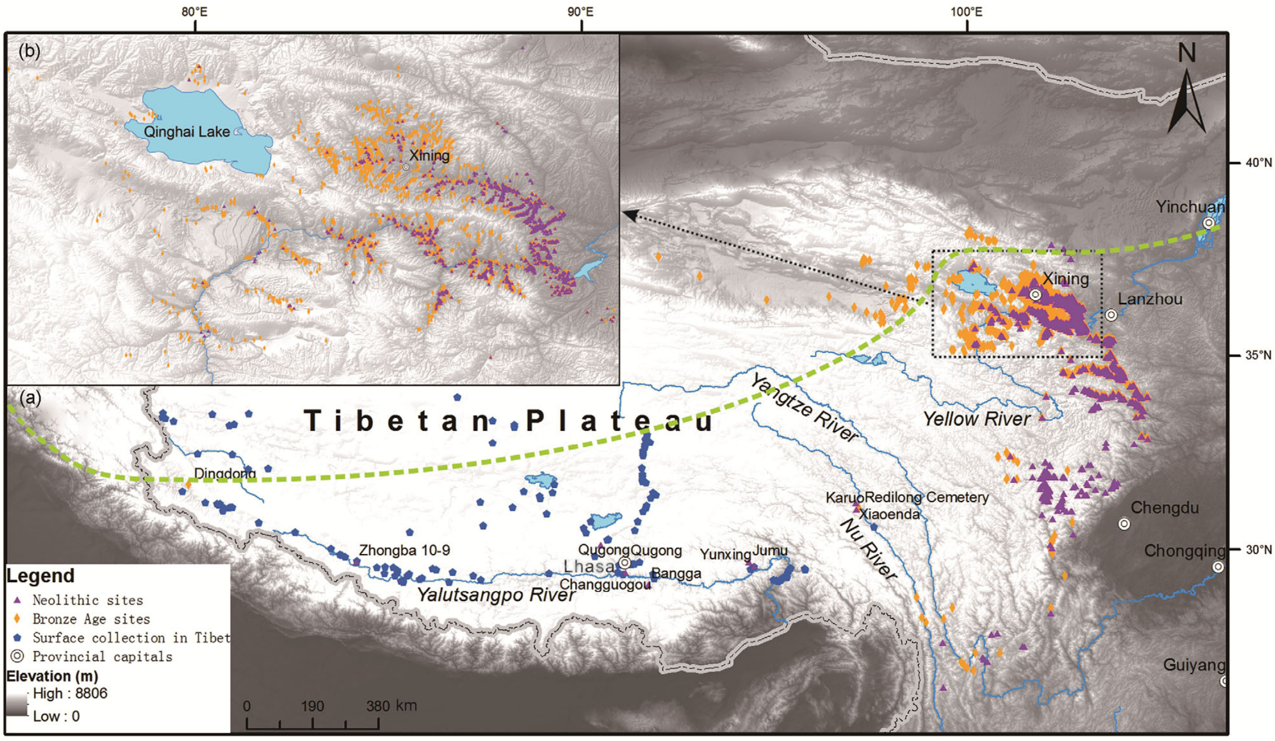

Figure 2 Neolithic (purple triangles) and Bronze Age (Yellow Diamonds) sites on the Tibetan Plateau (Chen et al. 2015b; State Administration of Cultural Heritage, 1996, 2001, 2009, 2010, 2011). (a) Tibetan Plateau; (b) He-Huang Valley and Qinghai Lake Basin. Green dashed line: limit of the East Asian Summer Monsoon (Chen et al., 2010, 2008).

There are far fewer Bronze Age sites in the Southeastern Tibetan Plateau (Aldenderfer and Zhang, 2004). Bronze Age cultures in Western Sichuan had been deeply influenced by the Sanxingdui Culture on the Chengdu Plain. Bronze Age cultures in Western Yunnan had very distinctive characteristics, but were influenced both by the local Dianchi and Erhai Bronze cultures and the Xia Shang Zhou cultures from Central China (SCCAS, 2003). Tibetan Bronze cultures exhibit a close relationship with Bronze cultures in Yunnan, but very few absolute dates are available (Huo, 1990; Lu, 2012). Studies suggest that wheat and barley became the staple food in the Southwestern Tibetan Plateau in the Bronze Age (D'Alpoim Guedes and Butler, 2014; D'Alpoim Guedes et al., 2015).

The Bronze Age in China started in the Early late-Holocene (Chang, 2014), with copper implements appearing in the Qijia and Lower Xiajiadian cultures. Ritual bronze vessels and bronze weapons appeared in the Erlitou Culture in the Middle Yellow River region, indicating more complex societies. It has been proposed that state civilization first emerged in Central China with the Xia and Shang as the first two states (Liu, 2007); the state civilization was supported by highly developed agricultural systems (Lee et al., 2007; Zhao, 2011a). Foxtail millets and broomcorn millets remained the dominant crops in North China, but wheat, barley and rice became increasingly common (Jin, 2007; Zhao, 2005). The Qijia and later Bronze Age cultures in the Gan-Qing region increasingly exhibited local characteristics, but were still influenced by contemporary cultures on the Loess Plateau (Wang, 2012). Livestock production may have played an increasingly important role in people's lives in addition to the developed millet, wheat and barley agricultures (Zhao, 2004).

3. Prehistoric human migration routes to the Tibetan Plateau

The Tibetan Plateau is separated from the surrounding regions by high mountain ranges, including the Pamir-Kunlun-Qilian Mountains to the north, the Himalayas to the south and the Longmen and Hengduan Mountains to the east; and these ranges constitute natural barriers to human migration. The Northeastern Tibetan Plateau is relatively low and flat, and is connected to the Loess Plateau by the He-Huang Valleys and with the central plateau by the Qinghai Lake Basin and the Gonghe Basin. This routeway, known as Tang-Bo old road, was historically the easiest means for people to move to the Tibetan Plateau (Chen, 1987). The Northeastern Tibetan Plateau may have played the same important role in the prehistoric period, as indicated by a continuity of archaeological cultures from the Paleolithic to Bronze Age, and by spectacular archaeological sites and well-developed agricultural systems (Chen et al, 2015b; Figure 3a, 3b). Archaeological studies show that prehistoric populations on the Northeastern Tibetan Plateau, from the Paleolithic to the Bronze Age, either came directly from the Loess Plateau or were deeply influenced by coeval cultures on the Loess Plateau. While prehistoric cultures on the Southern and Southeastern Tibetan Plateau were significantly influenced by prehistoric cultures in the Gan-Qing region, especially the millet agricultures found in the Southern Tibetan Plateau.

The foregoing suggests that prehistoric populations on the Tibetan Plateau may have originated in North China and the Northeastern Tibetan Plateau which may have been the main pathway for prehistoric human dispersal events. However, this does not rule out other possible routes, such as possible southern and western routes (Lu, 2011, 2014; Qiu, 2015). However, it is difficult to evaluate these routes since the numerous surface finds, reported as Neolithic or Bronze Age sites, currently lack any reliable chronological information. Neolithic and Bronze Age human activity in the Southern Tibetan Plateau is clearly evidenced by the Karuo, Qugong and Changguogou sites (Liu et al., 1999; Tibetan Relics Bureau, 1985). The rich archaeological, millet, barley and wheat remains from these sites undoubtedly indicate a cultural influence from North China or even direct population migration.

In addition to archaeological studies, genetic studies provide more direct evidence regarding the origin of prehistoric humans on the Tibetan Plateau. Modern settlers on the Tibetan Plateau are mainly Tibetan-Burman groups (Wang, 1994). mtDNA studies show that Tibetan-Burman groups have an early common ancestor with Asian Mongolians (Torroni et al., 1994), but split out around 6 ka BP (Qin et al., 2010; Zhao et al., 2009), or even split from the Han Chinese at about 2750 (Yi et al., 2010). Y chromosome studies yield a similar conclusion (Gayden et al., 2007; Su et al., 2000) and even suggest that prehistoric humans on the Tibetan Plateau

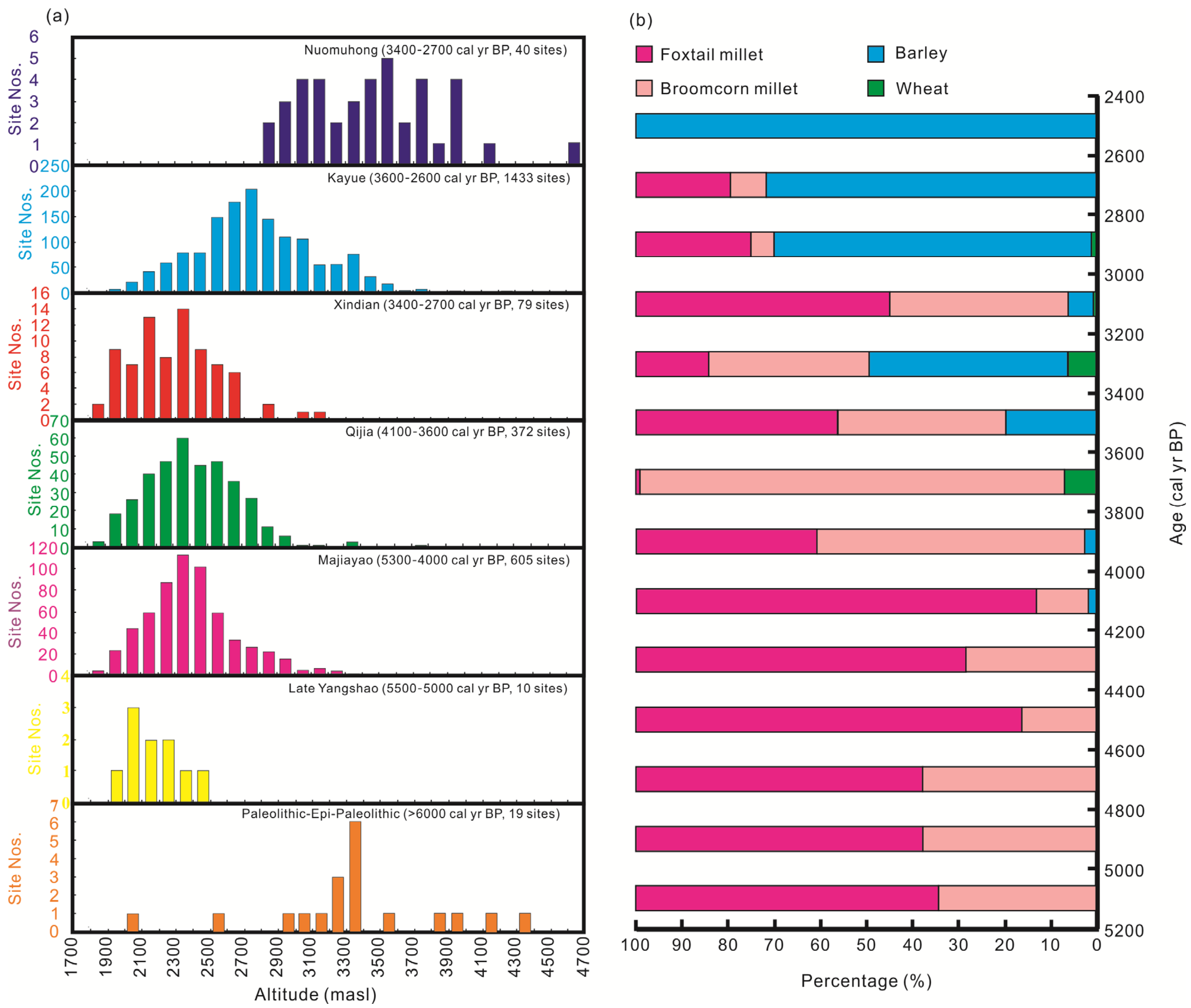

Figure 3 Archaeological cultural evolution and associated changes in crops (revised from S1 and S6 from Chen et al., 2015b). (a) Changes in site number with altitude; (b) changes in crop composition through time.

originated from the Yangshao Culture populations in the Middle Yellow River region (Qi et al., 2013; Su et al., 2000). Autosome studies also confirm the close relationship between Tibetan-Burman groups and East Asian populations (Gayden et al., 2009; Kang et al., 2010). In addition, an older maternal ancestral signal, possibly with a LGM age, has been traced by different studies (Wen et al., 2004; Zhao et al., 2009; Qin et al., 2010; Qi et al., 2013). Two population exploration events on the Tibetan Plateau found in genetic studies are consistent with archaeological studies (Figure 4g), while the earlier one needs further scrutiny.

4. The possible mechanisms of prehistoric human dispersal to the Tibetan Plateau

4.1 Role of the relatively warm and humid Last Deglacial climate on the Tibetan Plateau in attracting the first prehistoric humans

During the Last Glacial period, Modern Humans spread rapidly around the globe, arriving in Australia at about 50 ka BP (Roberts et al., 1990), reaching the North Arctic in Siberia at around 27 ka BP (Pitulko et al., 2004), reaching America via the Bering Bridge at 15 ka BP (Goebel et al., 2008), and appearing in the high elevation Andes at 12 ka BP (Rademaker et al., 2014). A series of Paleolithic archaeological changes in North China at around 35 ka BP (Qu et al., 2013), and the undoubted occurrence of Modern Human fossils dated to 42 ka BP at Zhoukoudian (Shang et al., 2007), constitute the oldest evidence for Modern Humans in China. The unprecedented diversity and prosperous development of archaeological cultures in the late Last Glacial period in China imply the distinct ability to adapt to different environments together with a strong trend of spatial expansion. These characteristics may have resulted in the first appearance of humans on the Tibetan Plateau. Early archaeological evidence on the Tibetan Plateau can be divided into two groups. One group includes three sites supposedly older than 20 ka BP with disputed dates; and the other group comprises two sites dated to 15–12 ka BP in the Qinghai Lake Basin with both reliable stratigraphy and reliable dates (Figures 1 and 4f).

The Tibetan Plateau was an extremely harsh environment for humans in the Last Glacial (72–18 ka BP) period prior to the deglaciation. In addition, all of the reported older sites (>20 ka BP) on the plateau are under debate. Thus, the possibility of human activity on the plateau before 18 ka BP is very low. One of the older sites on the plateau, Selincuo, dates to 40 ka BP, a difficult time for human survival on the plateau given that climate was cold and with millennial-scale fluctuations (Figure 4a), aeolian activity was common (Lai et al., 2009; Qiang et al., 2013), and vegetation in Qinghai Lake Basin and Zoige Basin had degraded to desert steppe or even desert (Shen et al., 2005; Yan et al., 1999). In addition, the low population pressure in the surrounding low elevation regions, indicated by the small number of archaeological sites, provided little impetus for human migration to the Tibetan Plateau. Therefore, the existence of the Selincuo site on the high plateau (4600 masl) is highly disputed. There were four millennial-scale climatic fluctuation events during 40–30 ka BP (Figure 4a). Modern humans may have briefly visited the Tibetan Plateau, as indicated by the Lenghu site (2800 masl) in the Qaidam Basin, during several warm events during which the climate was as favorable as the Holocene (Thompson et al., 1997; Yao et al., 1997). During the cold LGM (24–18 ka BP) (Clark et al., 2009), the environment on the Tibetan Plateau was more severe, with less plant and animal resources and human activity, even on the Western Tibetan Plateau, clearly decreased (Morgan et al., 2011; Zhang et al., 2010; Ji et al., 2005). Thus, human appearance on the Tibetan Plateau during the LGM, as indicated by the Quesang sites, needs further scrutiny. Considering the distinctive environment of the Tibetan Plateau and Paleolithic human activity in surrounding regions, we should treat the reality these reported Paleolithic sites very carefully. The few sites with reliable dates may be represent the traces left by early explorers whose DNA signal has been traced by genetic studies (Qi et al., 2013; Qin et al., 2010; Zhao et al., 2009) (Figure 4g).

Numerous archaeological sites with both secure stratigraphy and reliable dates first appeared in the Qinghai Lake Basin (Figure 1) in the Tibetan Plateau during the ameliorating Last Deglacial period, especially during the Bølling-Allerød (B/A) warm events (Figure 4). The climate at middle-high latitudes of the Northern hemisphere during the B/A may have been as warm as the Holocene, as implied by Greenland ice core records (Figure 4a); and on the Tibetan Plateau, the temperature during the B/A may have been as high as today as a result of the amplification of B/A events on the high plateau (Yao et al., 1997, 2000). During the Last Deglacial period, the East Asian Summer Monsoon was as strong as today, with substantial precipitation in the northeastern Tibetan Plateau. Low elevation regions such as Qinghai Lake Basin could have provided more food resources than the dry western Loess Plateau and deserts in Northwest China. In addition, the large elevation differences in the northeastern Tibetan Plateau result in diverse environments and large seasonal differences between small regions, which may have provided humans with a variety of habitats which enabled them to face seasonal changes and climatic fluctuations. In this scenario, the first group of highly mobile hunter-gatherers with microblade technology tools arrived in Qinghai Lake Basin from North China during 15–12 ka BP (Figures 4e, 5a). As winter would have been very cold, these people were probably on the Tibetan Plateau on a seasonal basis (Brantingham et al., 2010), advancing to Qinghai Lake Basin in summer and retreating to the western Loess Plateau via the He-Huang valley in win-

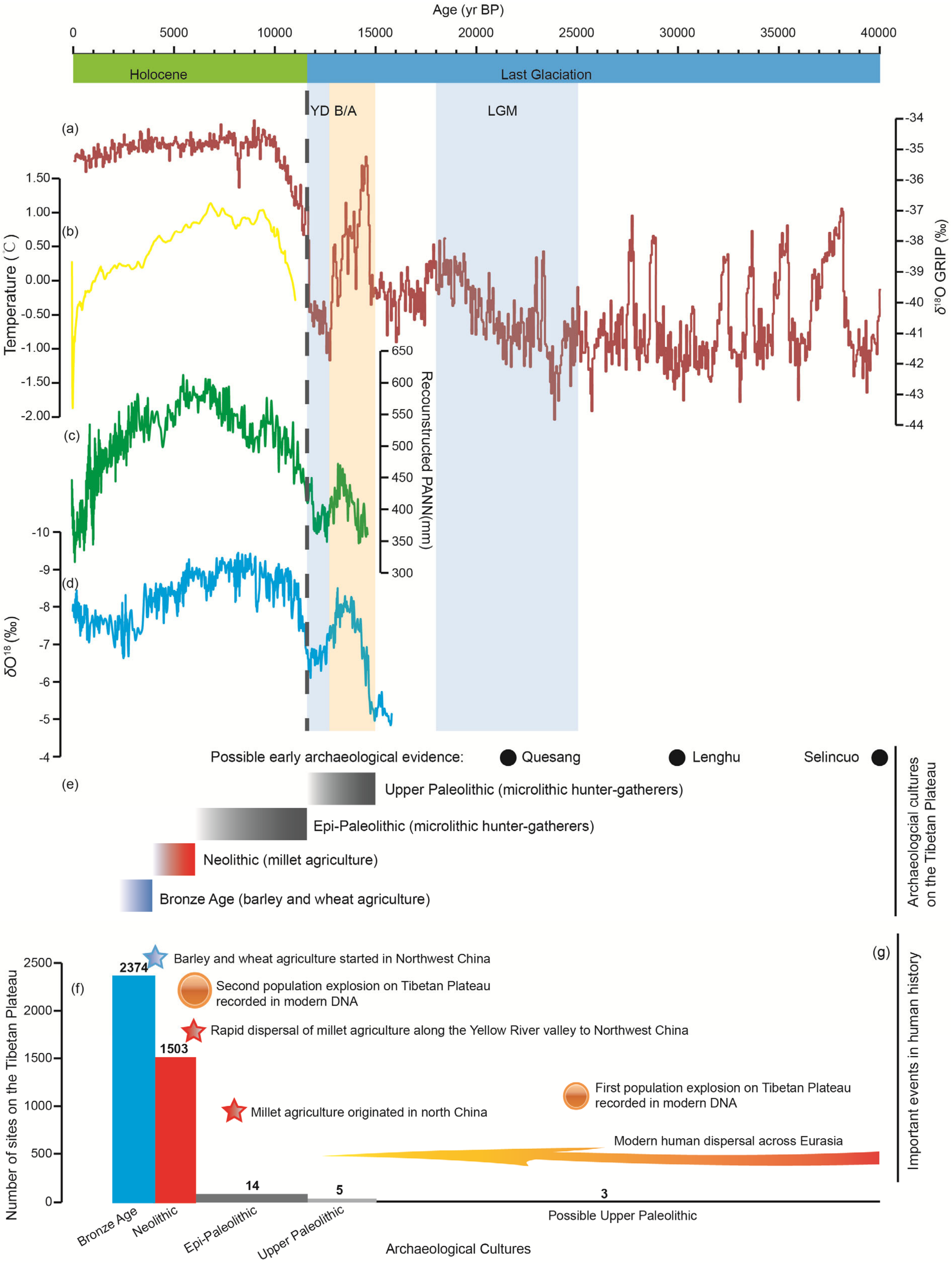

Figure 4 Climate change records over the past 40 ka BP in the Northern Hemisphere and archaeological records from the Tibetan Plateau. (a) Stable oxygen isotope record from a Greenland ice core indicating global temperature changes (Greenland Ice-core Project, 1993); (b) quantitative reconstruction of Holocene temperature change in the Northern Hemisphere (Marcott et al., 2013); (c) quantitative precipitation reconstruction from Lake Gonghai indicating East Asian summer monsoon evolution (Chen et al., 2015a); (d) speleothem stable oxygen isotope record indicating Indian Monsoon evolution (Dykoski et al., 2005); (e) archaeological records from the Tibetan Plateau; (f) changes in prehistoric archaeological site numbers on the Tibetan Plateau (Chen et al., 2015b; State Administration of Cultural Heritage, 1996, 2001, 2009, 2010, 2011); (g) important events in human history.

ter. A Broad Spectrum Revolution in the Upper Paleolithic may have enabled these first visitors to the Tibetan Plateau to adapt to the high elevation environments (Tang, 2011a, 2011b).

4.2 Role of the development of millet agriculture and a warm-humid climate in promoting the further migration of hunter-gatherers to the Tibetan Plateau during the early-mid Holocene

After the Last Deglacial Period, with its fluctuating climate with a warm B/A and cold YD, during the relatively warm and stable Holocene humans became more reliant on food production than on hunter-gathering, and there was the increased utilization of domesticated plants and animals (Diamond, 2002). Common millet and foxtail millet were domesticated in North China at around 10 ka BP (Lu et al., 2009; Zhao, 2011b) and at the same time, or even earlier, rice was domesticated in South China (Jiang and Liu, 2006). The remains of early domesticated millet found at the Cishan, Xinglongtou, Peiligang, Yuezhuang and Dadiwan sites in North China suggest that early millet farming was carried out in the foothills of the neighboring mountain chains, where drier and better drained locations suited millet cultivation (Liu et al., 2009). Millet became the staple food in the middle Yellow River regions around 7 ka BP (Liu et al., 2014) and consequently the population supported by millet agriculture, which provided a stable food source, increased dramatically and expanded westwards to the rim of northeastern Tibetan Plateau (Figure 5b).

It can be assumed that the widespread development of millet agriculture, together with a favorable climate during the early-mid Holocene, caused relatively large-scale migration to the Tibetan Plateau, leaving Epipaleolithic remains. The rapid development of millet agriculture in the middle Yellow River regions would undoubtedly have promote the migration of hunter-gatherers in the western Loess Plateau to the adjacent expansive but almost unpopulated Tibetan Plateau (Figure 5). In addition, the precipitation in the Tibetan Plateau increased significantly in the early Holocene as a result of the strengthening East Asian Summer Monsoon (Figure 4a, 4c, 4d) and would consequently have ameliorated the physical and biological environment (Cheng et al, 2013; Herzschuh et al., 2010; Shen et al., 2005) and attracted more hunter-gatherers (Figure 4f). Human activity on the Tibetan Plateau expanded dramatically, indicated by sites in the Yarlung Tsangpo river valleys in the southern plateau and in high elevation regions in the inner Plateau (Brantingham et al., 2013; Tang et al., 2013), and by thicker cultural layers at sites such as Jiangxigou 2 and 151 (Figure 1b). Qinghai Lake Basin, on the routeway of human migration to the inner Plateau from the Loess Plateau, may have tightly connected hunter-gatherers in the high inner plateau and millet farmers in the low elevation He-Huang valleys and western Loess Plateau. Currently there is still no archaeological evidence reflecting year-round human activity on the Tibetan Plateau, and the prevailing Epipaleolithic on the plateau during the early-mid Holocene may have resulted more from the pushing effect of population pressure and the elimination of low elevation millet agriculture (Brantingham et al., 2007).

4.3 Role of the development of millet agriculture in promoting human settlement of the low elevation region of the Tibetan Plateau in the late mid-Holocene

The number of archaeological sites on the Tibetan Plateau increased rapidly in the late mid-Holocene (Figure 4), implying the widespread movement of Neolithic people to the plateau (Figure 5c), consistent with the population expansion on the Tibetan Plateau around 6 ka BP traced by genetic studies (Figure 4g). This spread of population was closely related to millet agriculture. The sustained strengthening of the East Asian Summer Monsoon during the mid-Holocene (Figure 4c, d) probably simulated the flourishing of Neolithic culture in North China (Chen et al., 2015a) and the establishment and expansion of millet agriculture (Jia et al., 2013). Millet agriculture further expanded to more marginal regions under conditions of an increasing population, expansion of settlements and the evolution of a more complex society resulting from agricultural development (Figure 5c). Associated with the Majiayao Culture, millet agriculture advanced to the Hexi Corridor (Dong et al., 2013a) and the Northeastern (Chen et al., 2015b; Dong et al., 2013b, 2014) and Southeastern Tibetan Plateau (D′Alpoim Guedes and Butler, 2014; D’Alpoim Guedes et al., 2014; Hung et al., 2011; Cultural Relics Management Committee of Tibet Autonomous Region et al., 1985; Zhao and Chen, 2011) (Figure 2). Constrained by thermal and frost conditions in high elevation regions (Chai, 1999; Wang, 1996), broomcorn and foxtail millet could only be grown in the He-Huang Valleys under 2500 masl in the Northeastern Tibetan Plateau (Chen et al., 2015b), but up to 3100 masl in the warmer and more humid Southeastern Tibetan Plateau (e.g., the Karuo site—D’Alpoim Guedes et al. (2014b)), although Neolithic Cultural remains reached 4000 masl on the plateau. However, in the mid-Holocene, humans on the inner plateau probably relied exclusively on hunting and gathering prior to the arrival of cold-adapted barley and wheat (Figure 5c). Humans started to permanently settle in the low elevation regions in the Northeastern Tibetan Plateau during the late mid-Holocene (Chen et al., 2015b), evidenced by sophisticated houses, well-organized burials and numerous domesticated animal bones—probably because of the stable food resources provided by millet agriculture. It was the development of millet agriculture which encouraged the first permanent settlement on the Northeastern Tibetan Plateau in the late mid-Holocene when the East Asian Summer Monsoon was not as strong as during the early and middle Holocene

(Chen et al., 2015b; Dong et al., 2012; Jia et al., 2013) (Figure 4).

4.4 Role of barley and wheat agriculture in facilitating widespread and permanent settlement in the high elevation regions of the Northeastern Tibetan Plateau during the late Holocene

Domesticated barley and wheat started to appear in North China at about 4 ka BP (Chen et al., 2015b; Dodson et al., 2013; Flad et al., 2010; Jin, 2007), mainly in Northwest China. It is believed that barley and wheat were first domesticated at about 10 ka BP in Western Asia (Tanno and Willcox, 2012). Barley and wheat agriculture may have been transported eastwards and southwards to Northwest China through Central Asia and Mongolia (Spengler et al., 2014), and further eastwards to the middle Yellow River region and westwards to Xinjiang (Dodson et al., 2013) (Figure 5c, d).

Because of the introduction of barley and wheat agriculture, famers were not prevented from moving up to the high elevation Tibetan Plateau during the interval of cold and dry climate after 4 ka BP (Figure 2b, c, d). The study of plant remains and AMS ^{14}C dating results from 53 sites in the Northeastern Tibetan Plateau indicate that domesticated barley and wheat first arrived in the He-Huang Region at around 4 ka BP and that their ratio within crops rapidly increased, although millets were still the principle crop (Figure 3b). After 3.6 ka BP, barley and wheat agriculture spread rapidly to regions higher than 2500 masl, and up to 3400 masl, and became the primary food crop for people living in these high elevation regions (Figure 3b). The distribution of archaeological sites during this period significantly exceeds the previous elevation limits in the He-Huang Valleys to regions higher than 3000 masl, such as Qinghai Lake Basin, Qaidam Basin, Gonghe Basin and the Guoluo region (Chen et al., 2015b) (Figure 2). Along the eastern margin of the plateau, barley and wheat cultivation may also have spread southwards to Sichuan, Yunnan and the Yarlung Tsangpo river valley in Tibet (D'Alpoim Guedes et al., 2015) (Figure 5d). Therefore, barley and wheat became the dominant crop after 3.6 ka BP on the Tibetan Plateau. It is assumed that the cold- and frost-tolerance of barley (D'Alpoim Guedes and Butler, 2014; Zhao, 2004) played an important role in enabling permanent settlement on the Tibetan Plateau. In addition, the introduction of domesticated sheep (Zhao, 2009) and the domestication of yak (Qiu et al., 2015) also facilitated year-round settlement at high elevations. It is possible that hunter-gatherers in the inner plateau were already transitioning to pastoralism at this time (Figure 5d). As demonstrated in Chen et al. (2015b), cold- and frost-adapted barley and wheat agriculture facilitated permanent settlement on the Tibetan Plateau after 3.6 ka BP when the climate became cold and dry.

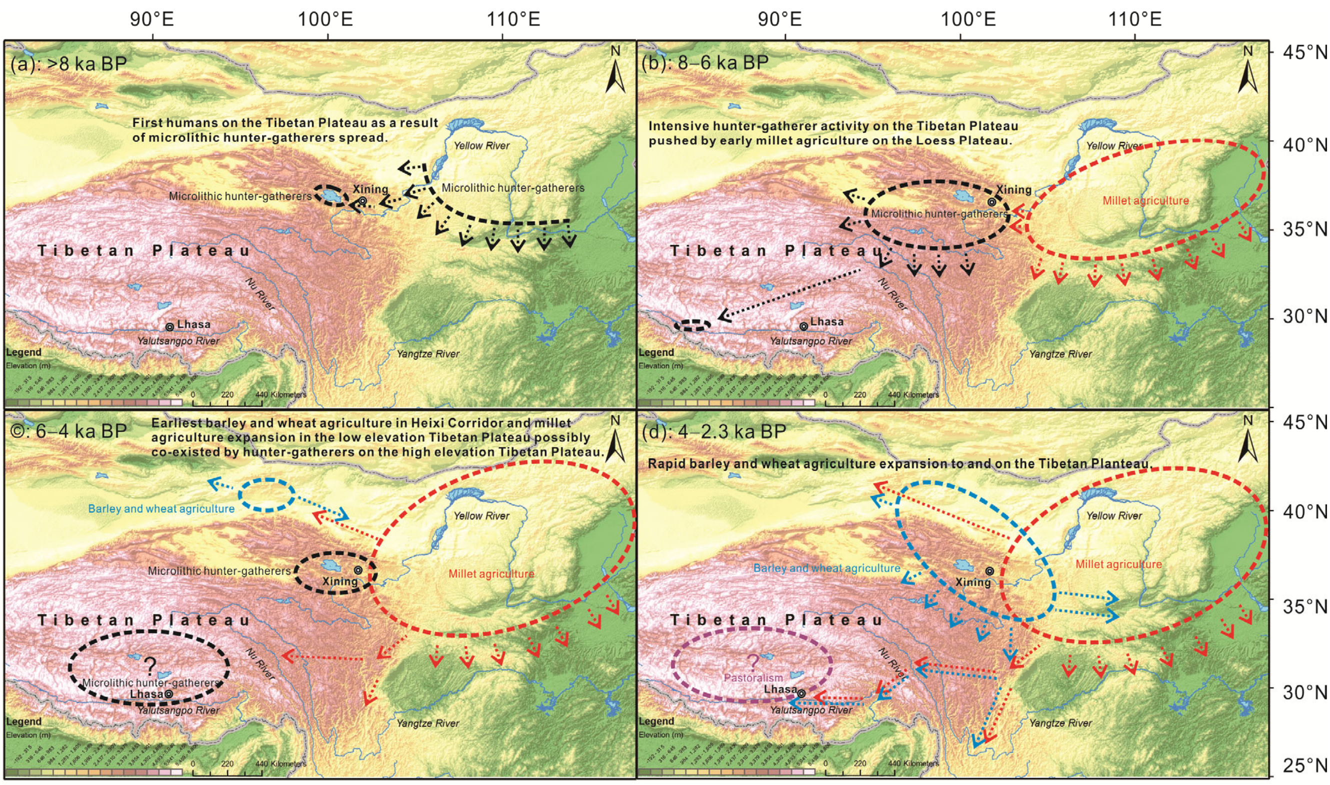

Figure 5 The four stages of human migration to the Tibetan Plateau.

5. Conclusions and prospects

Archaeological and genetic studies have already revealed the general picture of the history and mechanisms of prehistoric human migration to the Tibetan Plateau (Figures 4, 5). This process can be divided into four stages, each characterized by different factors closely related to climate change, population increase as well as agricultural development.

During the Last Glacial prior to the Deglacial (72–18 ka BP), small groups of hunter-gatherers may have engaged in brief hunting expeditions on the Tibetan Plateau. During the Deglacial period (18–11.6 ka BP), especially during the warm B/A event, highly mobile microlithic hunter-gatherers from North China first actively wandered to the Qinghai Lake Basin in the Northeastern Tibetan Plateau. During the warm and humid early and middle Holocene, hunter-gatherers were pushed by rapidly expanding millet agricultural communities from the Western Tibetan Plateau to the almost empty Tibetan Plateau. From 6–4 ka BP, the millet agricultural population expanded to the He-Huang Valley in the Northeastern Tibetan Plateau and Sichuan and Tibetan regions in the Eastern and Southeastern Tibetan Plateau below 2500 masl. From 4 to 2.3 ka BP, especially above 3600 masl, the introduction of domesticated barley, wheat and sheep, and the establishment of a cold-adapted agro-pastoral economy, finally enabled prehistoric humans to permanently settle on the high elevation plateau, under conditions of a cold climate and high food resource pressure.

Based on the foregoing review, we suggest that reconstructed history of human activity on the Tibetan Plateau and the mechanisms of population migration are still not completely understood. Consequently, we suggest that future work needs to be directed to addressing the following issues:

(1) Spatial distribution and subsistence patterns of Paleolithic people on the Tibetan Plateau. Systematic archaeological surveys and absolute dating should be carried out to search for sites older than 15 ka BP in order to test or verify the older DNA signals from genetic studies. More excavations should be done to reveal the nature of early human subsistence on the Tibetan Plateau.

(2) Seasonality of human activity on the Tibetan Plateau. Current evidence indicates that humans permanently settled on the Tibetan Plateau higher than 2500 masl only after 3.6 ka BP, when barley and wheat were widely cultivated on the plateau. However, hunter-gatherers appeared on the Tibetan Plateau much earlier than 3.6 ka BP. Therefore, how did these hunter-gatherers live and move on the Tibetan Plateau? Did they move around on the Tibetan Plateau or did they migrate seasonally between the high elevation Tibetan Plateau and the low elevation Chinese Loess Plateau? Did they permanently settle on the plateau much earlier than 3.6 ka BP in the much warmer and humid Southern Tibetan Plateau? The current archaeological evidence is currently inadequate to be able to answer these questions and future archaeological surveys and excavations should be conducted to address them.

(3) Population spread or cultural transmission? It is always difficult in archaeology to determine whether cultural change was caused by population migration or by cultural transmission. Although, based on a review of previous studies, we have defined four stages of human migration to the Tibetan Plateau, it is clear that they were only cultural shifts. We have also assumed that prehistoric humans spread from the Western Tibetan Plateau to the Northeastern Tibetan Plateau through the He-Huang Valley, and southwards to the Southeastern Plateau along the eastern margin of the plateau. However, it is almost impossible to identify the creators of archaeological cultures solely from site numbers, site ages and other physical remains. Ancient DNA studies are needed to answer these questions.

(4) Archaeological studies in the inner Tibetan Plateau need to be intensified. The lack of systematic prehistoric study of the inner plateau, mainly Tibetan, significantly hampers our understanding the human history of the entire plateau. There are very few absolutely dated prehistoric and Bronze Age sites on the Tibetan Plateau, although hundreds of surface finds have been reported. We urgently need to seek evidence of early prehistoric sites with a secure stratigraphy and rich archaeological remains.

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