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The History and Driving Force for Prehistoric Human Expansion Upward to the Hinterland of the Tibetan Plateau Post–Last Glacial Maximum

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Citation: Hou, G.; Dong, W.; Cai, L.; Wang, Q.; Qiu, M. The History and Driving Force for Prehistoric Human Expansion Upward to the Hinterland of the Tibetan Plateau Post–Last Glacial Maximum. *Sustainability* **2021**, *13*, 7065. https://doi.org/10.3390/su13137065

Academic Editor: Harry F. Lee

Received: 22 March 2021
Accepted: 18 June 2021
Published: 23 June 2021

Abstract: The timing and motivation of prehistoric human expansion into the hinterland of the Tibetan Plateau (TP) is a widely debated scientific issue. Recent archaeological studies have brought forward predictions of the earliest human occupation of the TP to the late–Middle Pleistocene. However, massive human occupation of the TP did not appear until the termination of the Last Glacial Maximum (LGM). The spatio-temporal distribution of prehistoric hunter-gatherers on the TP varies significantly before the permanent occupation after 3600 BP (before present). Here, we report on environmental-archaeological evidence from the Canxionggashuo (CXGS) site in Yushu Prefecture, which provides information that is key to understanding the dynamics of post-LGM human occupation on the TP. Radiocarbon dating has revealed two occupation periods of the CXGS site at 8600–7100 cal (calibrated years) BP and 2400–2100 cal BP. The charcoal concentration in cultural layers correlates well with paleo–human activities. Hunter-gatherers expanded westwards from the northeastern margin of the TP to the hinterland of the TP during the warming period of the early–middle Holocene (~11,500–6000 BP). However, these groups retreated during the middle–late Holocene (~6000–3600 BP) under a cooling-drying climate. Prehistoric humans finally occupied the hinterland of the TP permanently after 3600 BP, with an enhanced cold-adaptive lifestyle, although the climate was still deteriorating.

Keywords: the Holocene; Tibetan Plateau; late Paleolithic; climate change; human occupation; subsistence strategy

1. Introduction

Areas of high altitude present a major challenge for human occupation given the extreme cold, scarce food resources, and physiological stress caused by a low oxygen concentration. The Tibetan Plateau (TP), as the largest and highest plateau on Earth, also called the Third Pole, was one of the most challenging areas for prehistoric humans to conquer. For the hinterland of the TP in particular, where the altitude is above 4000 m, the severe environment makes it one of the harshest areas for human occupation [1]. As such, the TP has become a key area for studying the history of human migration from lowlands to highlands [2–4]. According to the National Archaeological Survey in China, thousands of prehistoric archaeological sites have been found on the TP [5,6], distributed across a wide altitudinal range (~1700–5000 m a.s.l.) [7], and this has laid the foundation for further research. The initial timing, dynamic, and motivation for prehistoric human exploration and occupation of the TP has become a hot scientific issue in recent decades, drawing the attention of multiple disciplines.

Archaeological and genetic studies provide valuable clues for exploring the trajectory of prehistoric human migration to the TP from surrounding areas [8–14]. However, the history of prehistoric human occupation on the TP is still highly debated, especially as regards the timing of the initial human exploration and their permanent settlement on the TP [15–17], as well as the routes of early human expansion to the hinterlands of the TP [18,19]. Recent studies have traced the initial prehistoric human exploration of the TP back to pre–Last Glacial Maximum (LGM, ~26,500–18,000 BP, BP stands for before present). Ancient humans began to explore the marginal zone and high-altitude hinterlands of the TP no later than 160,000 BP and during 40,000–30,000 BP, respectively, according to the excavations and studies of the Baishiya Karst Cave site (3280 m a.s.l.) [20,21] and the Nwya Devu site (4600 m a.s.l.) [22]. Confirmed by genetic studies [11,13], these could be the periods in which the first ancient humans explored the TP. However, these studies provide isolated evidence for early human activity on the TP, raising more questions about the patterns and driving forces of prehistoric human expansion into the TP, which thus requires further case studies. Nevertheless, prehistoric humans expanded extensively into the TP post-LGM and occupied the hinterland of the TP during the warming Holocene.

The spatial distribution of Paleolithic, Neolithic and Bronze Age sites on the TP provides valuable archives from which to derive the patterns of prehistoric human expansion into the high plateau during the prehistoric period. However, most prehistoric sites on the TP lack definitive dating. The estimation of age based on the features of artefacts, such as stone tools, pottery fragments and bronze vessels, has recently attracted more attention [23–25]. Therefore, the dating of cultural sediment that contains archaeological remains provides more reliable and higher-resolution chronology, which gives a more accurate timing of these human settlements on the TP, especially for the high-altitude hinterland [19,25].

Besides the issues of reliable chronology, the motivation for prehistoric humans to expand into the hinterland of the TP is also unknown. Favorable climatic conditions have been cited as the most important factor, promoting the occupation of the TP by hunting-gathering groups during the Late Paleolithic [26,27], as well as the settlement of the upper Yellow River valley during the Neolithic period [28,29]. In contrast, prehistoric groups extensively and permanently settled the areas above 2500 m a.s.l. on the TP after 3600 BP under a cooling climate, which was thought to be primarily facilitated by the adoption of a cold-tolerant agro-pastoral livelihood [15]. The extent to which prehistoric human occupation of the hinterland of the TP was facilitated by climatic conditions or changing subsistence strategies has not yet been clearly established.

To resolve the problems above, we refined the chronology and analyzed archaeological remains, as well as charcoal concentrations, in sediments of Canxionggashuo (CXGS, also known as Tshem Gzhung Kha Thog (TGKT) according to its Tibetan pronunciation), an early–middle Holocene Paleolithic site where plenty of microblade lithic tools and animal bone fragments were unearthed during the archaeological excavation [30]. On the basis of this, we reviewed the archaeological discoveries from the TP and compared them to the paleoclimatic records to reveal the history and possible driving forces for prehistoric human occupation of the hinterland of the TP. This work provides valuable data and insights for improving the models of prehistoric human expansion into the TP and understanding the dynamics for different groups (hunter-gatherers, farmers, and nomads) expanding upward into the hinterland of the TP.

2. Study Area

Yushu Autonomous Prefecture is located in Qinghai Province, east-central TP, and lies at an average altitude of ~4500 m, as shown in Figure 1a. Except for some valleys in the east, most of Yushu is above 4000 m a.s.l., making this area a key station along the Tang–Tibet Ancient Road, also known as the Tang–Tubo Passage, which was one of the most important passageways of human migration from the lowland to the high-altitude hinterland of the TP. Dozens of prehistoric sites have been discovered in this area [5]. According to the features of pottery shards exposed at the surface, a group of archaeological sites have been identified as belonging to the Late Neolithic or Bronze Age [5]. However, a recent chronological study indicated that most of these sites were settled within the common era, while only the Gala site beside the Tongtian River was dated to ~2700 cal (calibrated years) BP [25]. In some sites of the Yushu area, only portable microblade lithic artefacts were found, suggesting highly mobile hunting-gathering people might have occupied the area much earlier [30].

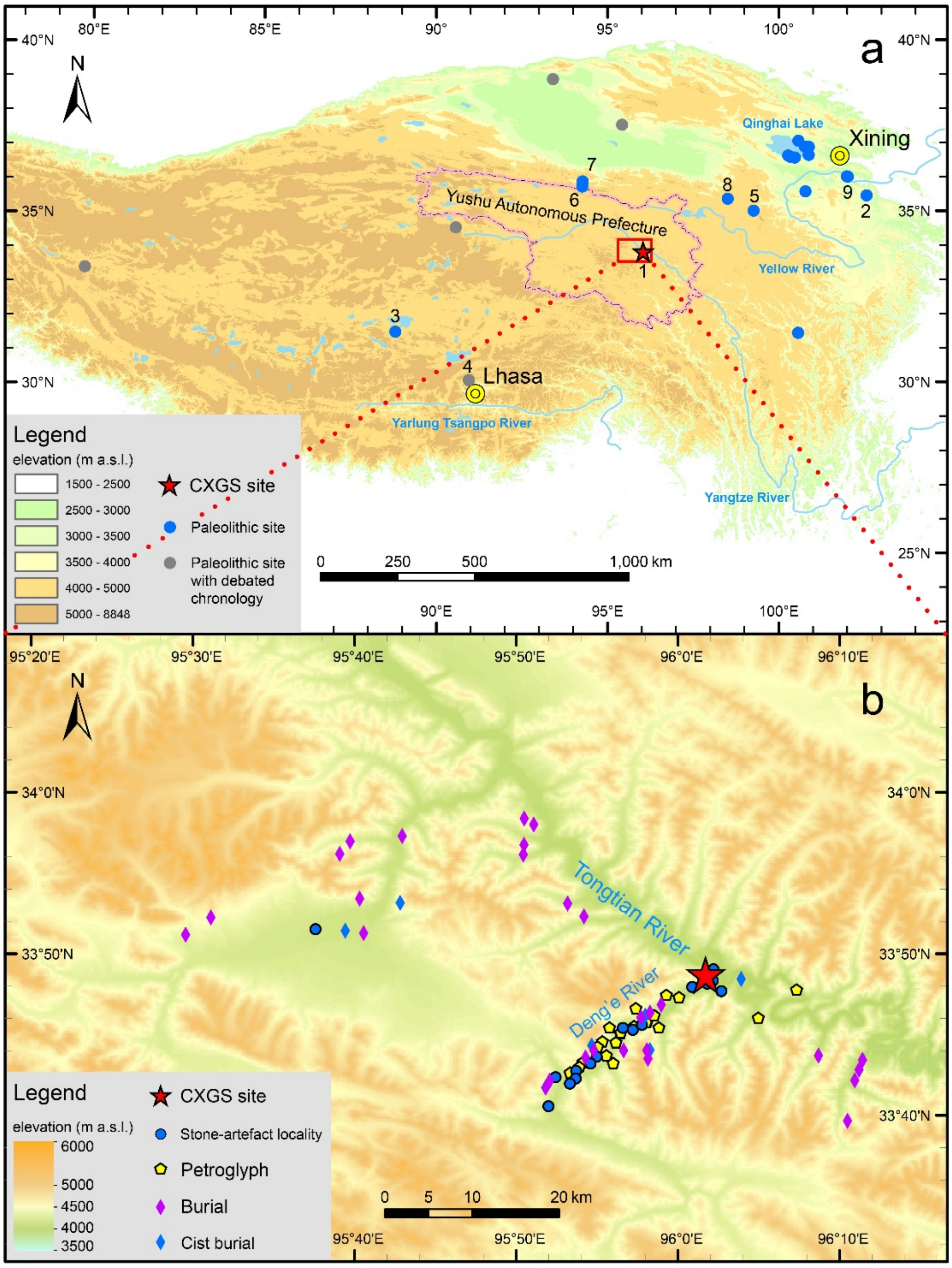

Figure 1. (**a**) Canxionggashuo (CXGS) site and other Paleolithic sites of chronological study on the Tibetan Plateau (TP). The sites mentioned in this paper are labeled as follows: 1. CXGS, 2. Baishiya Cave, 3. Nwya Devu, 4. Qiusang, 5. Xiadawu, 6. Xidatan, 7. Yeniugou, 8. Donggi Cona, 9. Shalongka. (**b**) archaeological remains around the CXGS site according to the archaeological investigations.

Tongtian River is another name for the upper reaches of the Yangtze River in Yushu Prefecture. The drainage basin of Tongtian River lies at an average altitude of ~4200 m, resulting in a low oxygen content (the atmospheric pressure at 4500 m a.s.l. is usually half the pressure at sea level), severe cold, and poor natural productivity. The annual mean temperature in this area is below 0 °C, while annual precipitation ranges from 270 to 410 mm. Glaciers and lakes are prevalent in the upper reaches. The most common vegetation types in this area are subalpine steppe and alpine steppe (Type "ET" in Köppen-Geiger's classification) [31]. The modern population density in the Tongtian River basin is extremely low (less than one person per km^2), a result of the harsh living environment. The Tongtian River valley has thus been described as one of the most difficult areas of the TP for humans to settle [32]. Modern people in Yushu primarily raise sheep and yak, while the cultivation of crops (especially naked barley) is auxiliary to their livelihood [33].

The CXGS site (33°48′16″ N, 96°02′35″ E, 4016 m a.s.l.) is located in Zhiduo County, Yushu Prefecture. As shown in Figure 1b, the archaeological site sits on a small tableland near the confluence of Tongtian River and its first tributary, the Deng'e River in the east. The site was discovered during a regional archaeological investigation in 2013–2015. Plenty of archaeological remains, including burials, petroglyphs, and stone artefact localities, were discovered during the investigation, indicating prosperous regional human activity in prehistoric times. The CXGS site was then systematically excavated by archaeologists, and revealed to be an 8200–7100 cal BP Paleolithic hunter-gatherer's workshop. Details of the process of excavation, the layering of deposition, and the features of the stone artefacts have been well reported [30]. Moreover, a study of the typology and technology of the lithic artefacts revealed the CXGS site to be a lithic workshop organized by a group living in a high-altitude region nearby, given the logistical mobility and the distance to other reported Paleolithic sites [30].

3. Materials and Methods

To investigate the history of human activity at the CXGS site and its impact on the environment, a 1.5 m × 0.5 m trench was chosen according to its high concentration of stone artefacts. Afterwards, a 103 cm depth profile was obtained for sampling. The profile was divided into five layers, with layer 4 assigned three sublayers according to the texture of the sediment and the cultural remains buried (see Table 1 and Figure 2a for detail). The 0–18 cm layer is topsoil, disturbed by modern human activities and surface vegetation. A sandy clay layer was found at 18–25 cm under the topsoil. The soil found at a 25–58 cm depth consists of silty clay and contains a few cultural remains. The silty clay layer at 58–103 cm can itself be divided into three sublayers. These sublayers contain abundant stone artefacts and a few animal bone fragments. Layer 5, beneath 103 cm, consists of uninterrupted red clay, and human remains could not be seen in this layer, where our excavation and sampling terminated.

Table 1. Profile layer delamination, description of sediment texture and cultural remains.

Layer	Depth (cm)	Texture	Properties	Cultural Remains
I	0–18	Topsoil	Brown gray, loose, granulated	None
II	18–25	Sandy clay	Gray, poor cohesion, rough	None
III	25–58	Silty clay	Dark gray, weak cohesion, with fine particles	A few stone artefacts and animal bone fragments
IV-1	58–74	Silty clay	Yellowish, weak cohesion	Abundant stone artefacts and a few animal bone fragments
IV-2	74–89	Silty clay	Gray	Same as IV1
IV-3	89–103	Silty clay	Blackish, uniform	Same as IV1
V	>103	Clay	Red, uniform	None

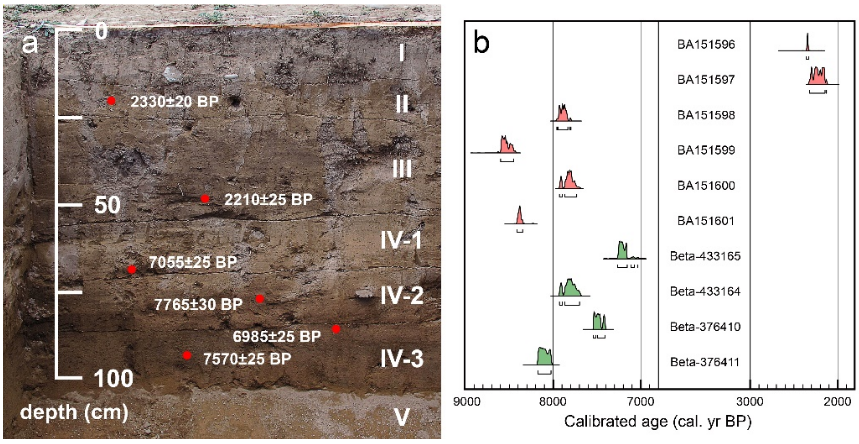

Figure 2. Profile and radiocarbon dating results for the CXGS site. (**a**) Profile of CXGS site labeled with sedimental layers and radiocarbon dating samples. Note that Layer V was not fully exposed due to the termination of our excavation. (**b**) Calibrated radiocarbon dating results of the CXGS site, with frequency curves in red representing data from this study, and curves in green representing data of a previous study [30].

Charcoal samples from different layers (see Figure 2) were sent to the Peking University Radiocarbon Laboratory for radiocarbon dating so as to determine the chronology of the profile. These charcoal samples consist of charred wood debris, but the species of wood have not been identified. The samples were pretreated with a standard acid–alkali–acid pretreatment and sent for accelerator mass spectrometry (AMS) for ^{14}C measurement. The raw dating results were calibrated with OxCal 4.4 software [34] with an up-to-date IntCal20 curve [35].

Sediments of the profile were sampled at 5 cm intervals, starting from 20 cm for water sieving, thus excluding the topsoil. Bone fragments and stone artefacts that had sunk to the bottom were collected for statistical analysis. Since animal bones and various stone artefacts are some of the most common cultural relics found at hunting-gathering Paleolithic sites, the remains found at different depths were calculated, with the intension of revealing the variation in intensity of human activity at the CXGS site. Another sequence taken at 2 cm intervals from the profile was sampled for environmental analysis—specifically, charcoal concentration.

Charcoal concentration is a good indicator of the intensity of paleofire events, including both natural fires and human activities [36–38]. The transmission distance of charcoal is strongly associated with its particle size. For instance, the vast majority of charcoal particles >125 µm were found to have settled within a 7 km range [39], and this is typical for local fire events [38,40]. Charcoal of 50–125 µm particle size is conventionally regarded as an indicator of regional (tens–hundreds of kilometers) fire events, whilst charcoal <50 µm is an indicator of larger-scale (usually >10^3 km) fire events [39]. Charcoals used for concentration measurement were acquired via heavy liquid flotation and were assessed via sampling statistics to acquire the charcoal concentration index [41]. Charcoals were floated in a zinc diiodide (ZnI_2) liquid and separated. A lower limit of 20 µm for charcoal particle size was adopted during the calculation.

4. Results

4.1. Chronology

The AMS ^{14}C dating results for the CXGS site are listed in Table 2 and Figure 2, including data from both the excavation [30] and the profile of this study. Age inversion occurs at the 45–50 cm and 75–80 cm depths, which may result from the disturbance of the stratum. However, these AMS ^{14}C ages can still be taken to indicate two distinct periods of human activity during the early–middle Holocene and the late Holocene, 8600–7700 cal BP (BA151598–151601), and 2400–2100 cal BP (BA151596–151597), respectively. Combined with the dating results from the excavation [30], we can infer the early period of the CXGS site to extend to 8600–7100 cal BP.

Table 2. Accelerator mass spectrometry (AMS) ^{14}C dates from the profile of this study and during the excavation [30] of the CXGS (or Tshem Gzhung Kha Thog, TGKT) site.

Lab Code	Depth (cm)	Material	AMS ^{14}C Age (Before Present, BP)	Calibrated Age 2σ (cal BP)	Reference
BA151596	21	Charcoal	2330 ± 20	2360–2330	This study
BA151597	45–50	Charcoal	2210 ± 25	2330–2120	This study
BA151598	65–70	Charcoal	7055 ± 25	7960–7790	This study
BA151599	75–80	Charcoal	7765 ± 30	8600–8450	This study
BA151600	85–90	Charcoal	6985 ± 25	7930–7730	This study
BA151601	95	Charcoal	7570 ± 25	8420–8340	This study
Beta-433165	Layer 2	Bone	6270 ± 30	7270–7030	[30]
Beta-433164	Layer 3	Bone	6980 ± 40	7930–7690	[30]
Beta-376410	Layer 5	Charcoal	6590 ± 30	7570–7420	[30]
Beta-376411	Layer 5	Charcoal	7290 ± 30	8180–8020	[30]

4.2. Indicators of Human Activity

Relics closely related to human activities, including stone artefacts and animal bones, were extracted from the sediment samples (see Figure 3). Animal bones were abundant at depths of 35–55 cm and 85–95 cm. In particular, six pieces of animal bone fragment were found in the 45–50 cm layer, as shown in Figure 3b. Stone artefacts were present at all depths of the cultural layer (20–95 cm), but were most abundant between 65 and 75 cm, with 19 flake debitages and 15 microblades deposits at the 65–70 cm depth, and 33 flake debitages and 15 microblades deposits at the 70–75 cm (Figure 3c–e). Flake debitages were consistently distributed at 20–95 cm, while microblades only appeared at 40–80 cm (Figure 3c,e). The features of the stone artefacts at the CXGS site were systematically studied after the excavation [30], and found to be closely related to the discoveries in other Paleolithic sites on the northeastern Tibetan Plateau (NETP) such as Xidatan [42], Shalongka [43], Xiadawu [44], and Donggi Cona [45,46].

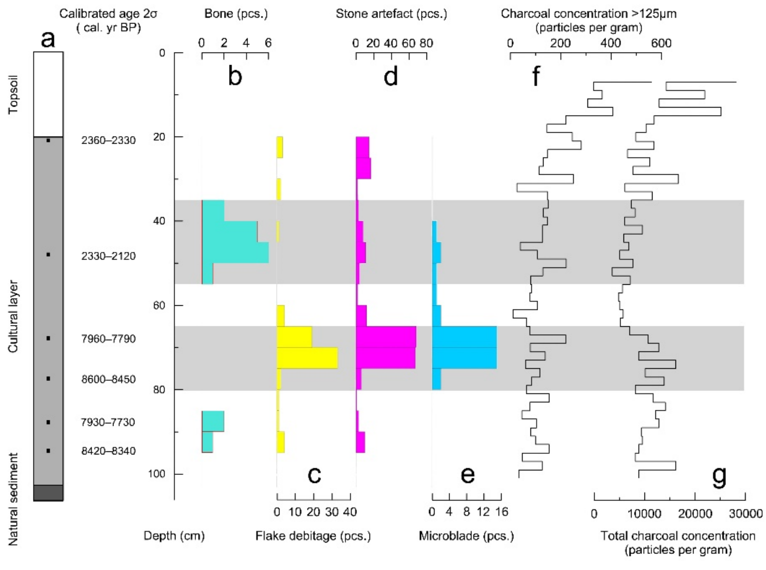

Figure 3. Cultural remains and charcoal concentrations of the CXGS profile. (**a**) Stratigraphic column with radiocarbon dates; (**b**) count of animal bone fragments; (**c**) count of flake debitages; (**d**) total count of stone artefacts; (**e**) count of lithic microblades; (**f**) concentration of charcoal >125 µm; (**g**) total charcoal concentration.

4.3. Variation of Charcoal Concentration

The variation of charcoal concentration in the CXGS profile shows a similar tendency between the all-sized particles and particles >125 μm (Figure 3f,g). There are two areas of high charcoal concentration, at 10–55 cm and 65–100 cm, separated by a gap at 55–65 cm. This indicates that fire events occurred frequently around the CXGS site during 8600–7700 cal BP and 2400–2100 cal BP, which correlated well with the distribution of cultural remains. As for the continuous increase in charcoal concentration in the upper part (10–30 cm) of the profile, this may have been influenced by modern human activities.

5. Discussion

5.1. History for Prehistoric Human Expansion upward to the Hinterland of Tibetan Plateau

Humans definitely occupied the margin of the high-altitude hinterland of the east-central TP in Yushu during ~8600–7100 cal BP and ~2400–2100 cal BP (Figure 2 and Table 2), as indicated by the AMS ^{14}C dates from the strata at the CXGS site, where archaeological remains, including animal bones and stone artefacts, were unearthed (Figure 3). Charcoal concentration in sediment is an effective index for the extent of paleofire as related to climate change or human activities [37,47], wherein charcoals >125 μm in particle size are suggested to be mainly produced by local paleofire events [40]. The concentrations of both all-sized and >125 μm charcoals in the two cultural layers (20–55 cm and 65–100 cm) of the CXGS site are obviously higher than in the 55–65 cm layer, corresponding with the distribution of archaeological remains. Thus, the high concentration of charcoal is more likely to be anthropogenic, originating from such sources as campfires, which further suggests that prehistoric humans inhabited the region around the CXGS site in these two periods.

Our study is consistent with recent archaeological investigations and dating work carried out in the Yushu area [25,30], indicating that humans permanently occupied this marginal zone of the high-altitude hinterland of the TP in the third millennium BP. The dating results of the CXGS site (Table 2) suggest initial human occupation in the Yushu area as early as ~8600 BP. Dozens of Late Neolithic and Bronze Age sites have been reported in this area [5]. However, whether human occupation of the Yushu area in ~7100–2700 BP actually occurred needs to be further examined via excavation and dating work. Preliminary dating work has suggested most sites were occupied after the initiation of the common era [14,25]. At the same time, the existence of low-intensity human settlements in Yushu and other high-altitude hinterlands during the middle–late Holocene (~6000–3600 BP) cannot be denied, especially considering the insufficiency and inaccuracy of chronological data in many archaeological sites.

Nevertheless, massive human expansion into and occupation of the TP occurred after the LGM, which is much later than the pioneers such as the Denisovans and the Nwya Devu group [20–22]. Previous archaeological studies on the TP indicated that prehistoric humans undoubtedly occupied the marginal zone of the hinterland of the TP since the middle Holocene [42,48]. Although some scholars argue that hunter-gatherers might have expanded into the high-altitude hinterland much earlier, the chronology of these key Paleolithic sites is still debatable. For example, some scholars propose that foragers occupied the Qiusang site (4270 m a.s.l.) near Lhasa in Tibet at ~21,000 BP [49], while some others refute this and argue that humans probably occupied the site during the early Holocene (~8400–7400 cal BP) [16]. However, these dating results have been questioned due to either the method [50] or the absence of reliable cultural layers [51]. Restricted by reliable stratigraphic information, the oldest Paleolithic sites post-LGM near or above 4000 m a.s.l. on the TP are Xiadawu (~11,200 cal BP, 3988 m a.s.l.) [44] and Xidatan (~7200 cal BP, 4300 m a.s.l.) [42], while other well dated prehistoric sites above 4000 m a.s.l. include Donggi Cona (5800–5000 cal BP, 4136 m a.s.l.) [45,46], Jiaritang (3200–2900 cal BP, 4311 m a.s.l.) [52] and Piyang-Donggar (2725–2170 cal BP, 4139 m a.s.l.) [53].

To understand the trajectory of prehistoric human extension into the hinterland of the TP, a clarification of the history of stepwise expansion from low-altitude to high-altitude areas of the TP is essential. Some models of prehistoric human colonization on the TP have been proposed basing on archaeological evidence [8,10,15,19]. However, archaeological studies have been updated in recent years, and this study provides more valuable clues to understanding the pattern of prehistoric occupation of Tibet in prehistoric times, as shown in Figures 4 and 5.

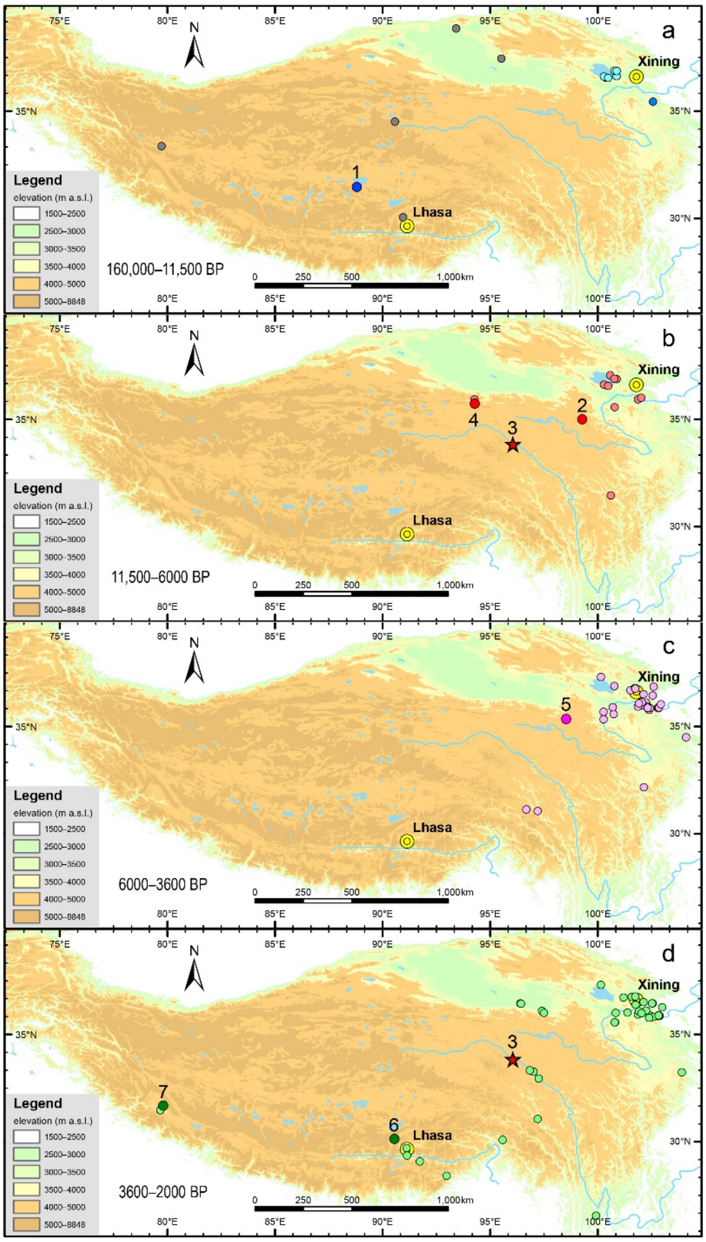

Figure 4. Spatial and temporal distribution of prehistoric archaeological sites on the TP, divided into four stages: (**a**) 160,000–11,500 BP, with blue dots representing sites before the Last Glacial Maximum (LGM), cyan dots representing sites post-LGM but before 11,500 BP, and gray dots representing Paleolithic sites with debated chronology; (**b**) 11,500–6000 BP, where red dots represent sites of this period, and the CXGS site is marked with a red star; (**c**) 6000–3600 BP, where pink dots represent sites of this period; (**d**) 3600–2000 BP, where green dots represent sites of this period, while the CXGS site is marked with a red star. Archaeological sites with reliable chronology near or above 4000 m a.s.l. are labeled as follows: 1. Nwya Devu (4600 m a.s.l.), 2. Xiadawu (3988 m a.s.l.), 3. CXGS (4016 m a.s.l.), 4. Xidatan (4300 m a.s.l.), 5. Donggi Cona (4136 m a.s.l.), 6. Jiaritang (4311 m a.s.l.), 7. Piyang-Donggar (4139 m a.s.l.).

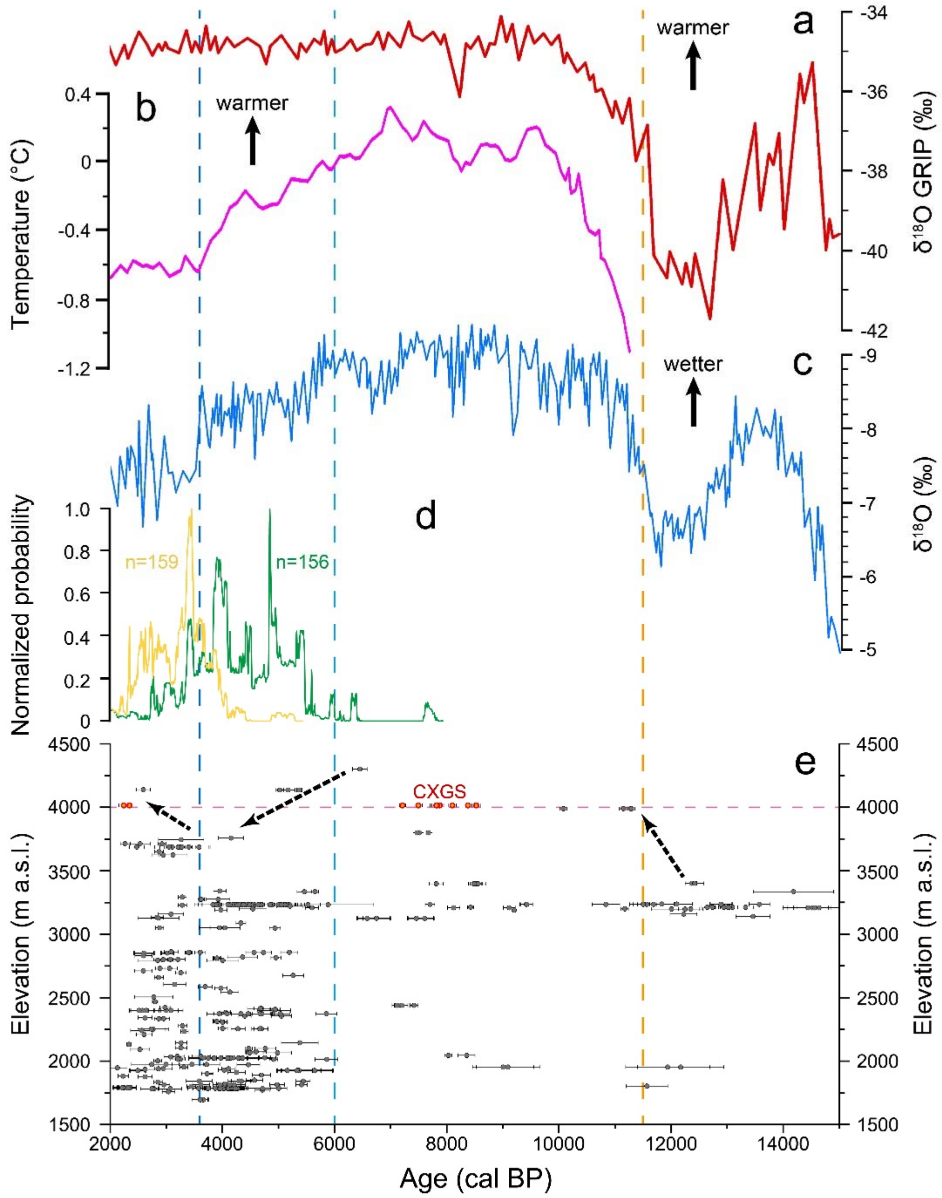

Figure 5. Comparison of paleoclimate records, crop utilization in China, and altitudinal variation in human activity on the TP during 15,000–2000 cal BP. (**a**) $\delta^{18}O$ record from Greenland ice core indicating global temperature changes [54]; (**b**) reconstruction of the temperature variation in the Northern Hemisphere during the Holocene [55]; (**c**) $\delta^{18}O$ record for the intensity of Asian monsoon derived from Dongge Cave, China [56]; (**d**) normalized summed probability density curve constructed from published radiocarbon dates of millet remains (in green) and wheat or barley remains (in yellow) from China (Table S1) [15,57–92]; (**e**) altitudinal variation in prehistoric human activity on the TP constructed from radiocarbon ages, where red dots represent the CXGS site.

Hunter-gatherers started to explore the TP before the LGM [20–22]. As regards the more massive expansion into and occupation of the TP post-LGM, foragers definitely occupied areas above 3200 m a.s.l. in the Qinghai Lake basin of the NETP from ~14,600 cal BP [2], after which they mainly engaged in hunting-gathering in the area (Figure 4a). Paleolithic groups continued to occupy the Qinghai Lake basin during the Younger Dryas (~12,900–11,600 BP), while the lower-altitude areas with elevation between 1700 and 2000 m a.s.l. in Yunnan Province in the southeastern Tibetan Plateau (SETP) and Gansu Province in the western Loess Plateau were also occupied [93–95].

The range of hunting-gathering gradually expanded towards the high-altitude hinterland of the central TP during the early–middle Holocene, reaching the Xiadawu site (3988 m a.s.l.) in Guoluo Prefecture at ~11,000 cal BP [44], the CXGS site (4016 m a.s.l.) in Yushu Prefecture in 8600–7100 cal BP [30], and the Xidatan (4300 m a.s.l.) and Yeniugou sites (3800 m a.s.l.) in the Kunlun Pass in 7500–7200 cal BP [42,48]. The living space and intensity of hunting-gathering groups on the TP increased in 11,500–6000 BP compared to previous periods, and humans colonized different altitudinal regions of the TP during this period (Figures 4b and 5e). The feature of artefacts in these sites have shown similarities to those from contemporaneous sites in the Qinghai Lake basin and the upper Yellow River valley [4,48], suggesting hunting-gathering groups might have expanded to the high-altitude hinterland of the TP from the NETP.

However, in 6000–3600 BP, the distribution range of prehistoric sites on the TP shrank remarkably in comparison to the former period (Figure 4b,c). Prehistoric humans mainly occupied areas below 3500 m a.s.l. in the eastern margin of the plateau, although hunter-gatherers still appeared around Donggi Cona lake (4136 m a.s.l.) in the Guoluo Prefecture in 5800–5000 cal BP (Figures 4c and 5e) [45,46]. However, the intensity of human inhabitation in low-altitude regions of the NETP markedly increased during the 5500–3600 BP period, and hundreds of Neolithic sites have been found in the valleys of the upper Yellow River and Yangtze River [5,6,96,97]. This indicates that agricultural groups extensively occupied the low-altitude NETP in this period. Meanwhile, indigenous hunting-gathering groups might also have co-existed with incoming new farming groups, such as the Zongri group in NETP [98] and the Karuo group in SETP [99].

The domain of prehistoric humans on the TP expanded unprecedentedly in 3600–2000 BP [15,100]. As shown in Figure 4d, Prehistoric humans expanded into the hinterland of the TP, and especially into areas such as the upper Yarlung Tsangpo River valley in south TP, and Yushu in east-central TP. Nevertheless, the sources of Bronze Age groups on the hinterland of TP might be complex. Plenty of cemeteries and petroglyphs have been found in the Yushu area, such as in the Deng'e River valley, as shown in Figure 1b. A special kind of burial, cist burials (stone slab tombs), were also identified in the eastern margins of the TP, including Gansu, eastern Qinghai, western Sichuan and northern Yunnan. These burials were suggested to be ~1000–2000 years older than those in the Yushu area [101]. However, pottery fragments from the Yushu area have similar features to those discovered from the Bronze Age Kayue Culture (~3600–2300 cal BP) in the NETP [25]. In particular, the grey ceramic amphoras with two big handles are extremely similar to the Tangwang Type (~2700–2500 cal BP) from the Kayue Culture [102]. This indicates that humans might have migrated to the east-central TP from different regions of the eastern margin of the TP.

5.2. The Factors Promoted Prehistoric Human Expansion upward into the Hinterland of the Tibetan Plateau Post–Last Glacial Maximum (LGM)

The severe environmental conditions during LGM seem to have been a primary factor preventing ancient humans from exploring the hinterland of the TP, although the climate conditions may have been slightly diverse in different regions of the TP [103]. The earliest evidence of human occupation in areas above 4000 m a.s.l. post-LGM comes from the Andes Mountains. Humans settled in areas above 4300 m a.s.l. in 12,800–11,500 BP under a relatively cold climate [104], but the motivation for this remains unclear. Humans carried on accessing the highlands above 4000 m a.s.l. in the Andes in 9000–6000 BP, mainly driven by favorable climatic-environmental conditions [105]. These case studies suggest that natural factors contributed significantly to humans living on highlands in the prehistoric period, which offers insight into the factors behind prehistoric human expansion towards the hinterland of the TP.

What encouraged prehistoric humans to migrate upward into the high-altitude hinterland of the TP is a scientific issue of great interest, and it has been intensively discussed in recent years [10,15,16,19,22]. Some scholars have argued that climate change was the major factor influencing human migration onto the TP [26,27,106], while others propose that technical innovation, such as agricultural evolution, allowed humans to settle year-round on a large scale in areas above 2500 m a.s.l. post–3600 BP [15]. Some scholars have also suggested that the primary factor promoting the occupation of the TP by prehistoric humans varied in different periods [19], which might also elucidate the factors influencing prehistoric human expansion into the hinterlands of the TP. However, the existing archaeological evidence remains insufficient, demanding further excavation and dating work be carried out on Paleolithic sites on the TP to clarify the spatio-temporal patterns of human occupation in the high-altitude hinterland of the TP.

We now know that human occupation of the TP in 15,000–6000 BP was primarily influenced by climatic and environmental changes, as inferred from the comparison between archaeological and paleoclimatic evidence (shown in Figure 5). Humans have occupied the Qinghai Lake basin since ~14,600 cal BP [2], which corresponds to the termination of the LGM and the onset of a wetting and warming climate [107] during the Bølling-Allerød interval (~14,600–12,900 BP). The tree pollen concentration in Qinghai Lake sediment reached ~60% during this period [108], indicating a high coverage of forest around the Qinghai Lake basin, which is significant considering that a forest–steppe transition is regarded as the optimal condition for hunting [109]. Moreover, substantial increases in temperature and precipitation during the Bølling-Allerød interval in the Northern Hemisphere might have resulted in rapid population increases in East Asia, as has been indicated by genetic evidence [110], and this also contributed to human expansion into the unpopulated habitats of the TP.

The climate evidently deteriorated during the Younger Dryas, resulting in a sharp drop in the temperature and the intensity of the Asian monsoon, as shown in Figure 5a–c. Forest coverage in Qinghai Lake basin also obviously declined [108]. Although prehistoric humans persisted in occupying middle-altitude areas, such as the Qinghai Lake basin, during the Younger Dryas [111], they also exploited lower-altitude areas such as the northern Yunnan Province and the western Loess Plateau [93–95], which would have been more beneficial to survival during winter. Humans spread upward into areas close to 4000 m a.s.l. soon after the beginning of the Holocene, at ~11,200 cal BP [44], which was related to rapid climatic amelioration and local environmental improvement [112]. Moreover, warmer-wetter conditions seem to have taken hold in the western TP during the early Holocene [113]. The warm-wet climate has also been cited as a major factor in promoting the expansion of human living space in prehistoric times [114,115]. This upward expansion seems to have been sustained until the middle Holocene, with the support of favorable climatic-environmental conditions (Figures 4 and 5).

Moreover, human occupation of the TP was suggested to be influenced by both climate change and social evolution after ~8000 BP [8]. Hunter-gatherers occupied the TP with greater frequency and intensity in 8700–6000 BP, and they also inhabited the margin of the hinterland of the TP, such as the Yushu area (Figures 4 and 5). Temperature and precipitation on the TP generally remained stable at a high level during this period [106,116,117], providing a favorable living environment in high-altitude areas [108,118]. Moreover, broomcorn and foxtail millets were probably domesticated in ~10,000 BP [119,120]. The earliest center for millet cultivation may be eastern Inner Mongolia during the Xinglongwa period (8200–7400 cal BP) [121,122], while millet crop remains have been identified at contemporaneous sites in northern China, such as Cishan [119], Dadiwan [123], and Yuezhuang [124]. These archaeological findings indicate that farming groups began to emerge in the Loess Plateau after the second half of the ninth millennium BP, and this might have compelled hunting-gathering groups to move westward toward the TP, thus also promoting the human occupation of the hinterland in east-central TP in ~8700–6000 BP (Figures 4b and 5e).

Humans extensively settled areas below 2500 m a.s.l. in the NETP from ~5200 BP [15], and this was mainly promoted by the intensification and expansion of rain-fed agriculture in northern China after the seventh millennium BP [122], as shown in Figure 5d. Millet cultivation became the most important subsistence strategy in the western Loess Plateau at around ~5900 BP [125], and this promoted the development and wide expansion of the late Yangshao Culture (~5500–5000 cal BP) and Majiayao Culture (~5300–4000 cal BP), as well as the spread of millet crops into the eastern TP [57,126]. Favorable climate conditions also facilitated cultural development in this period [28,29]. As millets are cold-sensitive crops, and the upper limit for their cultivation in this area has been assessed to be ~2400 m a.s.l. [127,128], farmers mainly settled below 2500 m a.s.l. during 5200–3600 BP [15]. The living space of hunter-gatherers also moved downward towards the eastern margin of the TP, into sites such as those at Zongri and Karuo, probably in order to acquire millets from nearby farming groups [99]. This resulted in the absence of human occupation in high-altitude areas during this period. A megadrought event was detected in Central Asia [129], synchronous with the drop in intensity of the Asian monsoon (shown in Figure 5c), and this may have impacted the water supply on the TP, immediately triggering the retreat of hunter-gatherers (Figure 4c). Furthermore, temperatures on the TP in 6000–3600 BP were lower than in 11,500–6000 BP [106,117], which might also be responsible for the downward human migration during this period, as shown in Figure 5.

Prehistoric humans permanently and extensively settled areas above 2500 m a.s.l. on the TP in around 3600 BP, which was mainly facilitated by the adoption of cold-tolerant crops (barley and wheat) and sheep [15], which had initially been domesticated in West Asia [130,131]. These western crops and livestock were initially introduced into China in the fifth millennium BP [132], as also shown in Figure 5d, and into the Hexi Corridor in ~4000 BP through the trans-Eurasia cultural exchange [58]. However, humans did not adopt barley as their staple food until ~3600 BP in the NETP [133]. Post–3600 BP, an agro-pastoral lifestyle, characterized by raising yak and sheep and cultivating barley, was adopted, which enabled humans to occupy areas such as the eastern Qaidam basin (2500–3500 m a.s.l.) on the NETP year-round [134,135]. Nevertheless, this kind of subsistence strategy could not support intensive human settlements in areas above 4000 m a.s.l., where nomadic production is the main component of the livelihood today. A nomadic lifestyle might have been introduced into northwest China in ~2800 BP [136], which then probably emerged in the Yushu area in ~2700 BP [25]. Domestic animal remains, petroglyphs and cist burials sites have been read as signs of the emergence of a transhumance [137,138], as had frequently been found at archaeological sites in the Yushu area [25], also shown in Figure 1b. This archaeological evidence indicates that humans might have adopted a cold-adaptive nomadic lifestyle, which finally facilitated the permanent occupation of the high-altitude hinterland of the TP during the late Bronze Age.

6. Conclusions

Environmental and archaeological studies conducted on the CXGS site reveal that prehistoric human expanded into Yushu area, the eastern margin of the high-altitude hinterland of the TP, during the periods of ~8600–7100 cal BP and ~2400–2100 cal BP, respectively. This suggests the persistent expansion towards the high-altitude hinterland of the TP by prehistoric hunter-gatherers during the warming early–middle Holocene (11,500–6000 BP).

Early expansion into the high-altitude hinterlands by hunter-gatherers appear to be strongly related to favorable climatic-environmental conditions during the early–middle Holocene. During this period, the environment in the hinterland of the TP was highly suited to hunter-gatherers' activities.

The cooling-drying climate conditions post–6000 BP, and the facilitation of cultural exchange between indigenous hunting-gathering groups and newly emerging agricultural groups in the eastern margin of the TP, are likely responsible for the lack of human occupation of the high-altitude hinterland of the TP. It was not until the fourth millennium BP that the high-altitude hinterland of the TP was reoccupied. The increase in nomadic lifestyle brought about by the prehistoric trans-Eurasia cultural exchange after 2800 BP finally facilitated the permanent settlement of the hinterland of "the roof of the world".

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13137065/s1, Table S1: published radiocarbon dates of millets and wheat-barley remains in prehistoric China.

Author Contributions: Conceptualization, G.H.; formal analysis, M.Q. and Q.W.; funding acquisition, G.H.; investigation, G.H., L.C. and Q.W.; resources, L.C.; supervision, G.H.; visualization, M.Q. and Q.W.; writing—original draft, G.H.; writing—review and editing, M.Q. and W.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Natural Science Foundation of Qinghai Province, grant number 2021-ZJ-917; Strategic Priority Research Program of the Chinese Academy of Sciences, Pan-Third Pole Environment Study for a Green Silk Road, grant number XDA2004010101; Qinghai Provincial Project for Thousand Top Innovative Talents.

Data Availability Statement: The data presented in this study are available in the corresponding references.

Acknowledgments: We thank Y. He from Sichuan University for field guidance; N. Jiangcai from Yushu Prefecture Museum for providing data and photos; L. Yang from Qinghai Normal University for fieldwork; C. Oldknow, G. Dong, and R. Li from Lanzhou University for analysis and discussion.

Conflicts of Interest: The authors declare no conflict of interest.

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