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Early foraging settlement of the Tibetan Plateau highlands

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ABSTRACT

We identified and dated 18 occupational events at eight sites dating to ~14.7–10.8 kiloannum before present (ka BP) during a decade of archaeological survey and excavation on the northeastern high Tibetan Plateau (TP) > 3200 m. The ephemeral nature of the earliest sites suggests they were created by small foraging groups during very short stays. By ~12 ka BP, larger foraging groups began to occupy sites > 4000 m leading to a more intensive occupation of the high TP after ~9.5 ka BP. This archaeologically-based chronology closely matches genetically-based Tibetan population histories showing an early growth in population size and initial split with Han populations ~15–9 ka BP, and a second spike in population growth during the early-mid Holocene. We found no evidence for occupation of the high TP prior to or during the Last Glacial Maximum (LGM), suggesting the initial separation of Tibetan and Han populations may have occurred at lower elevations in the TP margins or after the LGM in the high TP.

1. Introduction

The upper Tibetan Plateau (TP) was one of the last major landforms successfully colonized by late Pleistocene human foragers. Populations surrounded the TP for > 30 kiloannum before present (ka BP) prior to that colonization (Madsen et al., 2014), but living at high altitude was constrained by low biological productivity, high ultraviolet radiation, and especially pervasive hypoxia potentially resulting in cerebral or pulmonary edema, low birth weights, and a host of related biological issues caused by living in oxygen starved areas above ~2500 m (Beall, 2014). Tibetan populations now exhibit genetic adaptations which allow them to live at high altitude and which distinguish them from nearby lower elevation populations (Xiang et al., 2013; Petousi and Robbins, 2014; Simonsen et al., 2015; Yang et al., 2017), but where and when the mutations associated with these genetic shifts first occurred remains a topic of debate. Here we report on Late Upper Paleolithic (LUP) sites on the northeastern TP dating to ~15–9.5 ka BP which provide an archaeological framework for this debate.

The TP consists of two major geomorphological regions: the high, relatively flat plateau above ~4000 m and the heavily dissected plateau margins between ~1500–4000 m cut by the tributaries of many major Asian rivers (Fig. 1) (Madsen, 2016). Since much of these marginal areas are near or below the > 2500 m danger zone for high altitude sickness, the important question, both archaeologically and biologically, is not when did early foragers first occupy the TP, but when did they first occupy the higher plateau regions? In this regard, changing late Pleistocene climatic conditions may have played an important role. After ~30 ka BP, during the Upper Paleolithic period and later, conditions roughly similar to those of today began to shift towards dryer/colder conditions (Herzschuh, 2006; Morrill et al., 2006; Opgenoorth et al., 2010). During the Last Glacial Maximum (LGM) this drying trend reached an extreme as many lakes became completely desiccated, upper plateau plant communities shifted from alpine meadows to alpine-steppe desert and the population size and distribution of many large mammals was reduced. By ~16 ka BP, a significant warming trend and an extension of the annual monsoon to the north resulted in rapid glacial melting, refilling of lakes, recovery of upper TP vegetation, initiation of loess deposition, and a return of large animal populations. This trend continued into the Holocene, with a brief interruption during the Younger Dryas ~12.9–11.7 ka BP.

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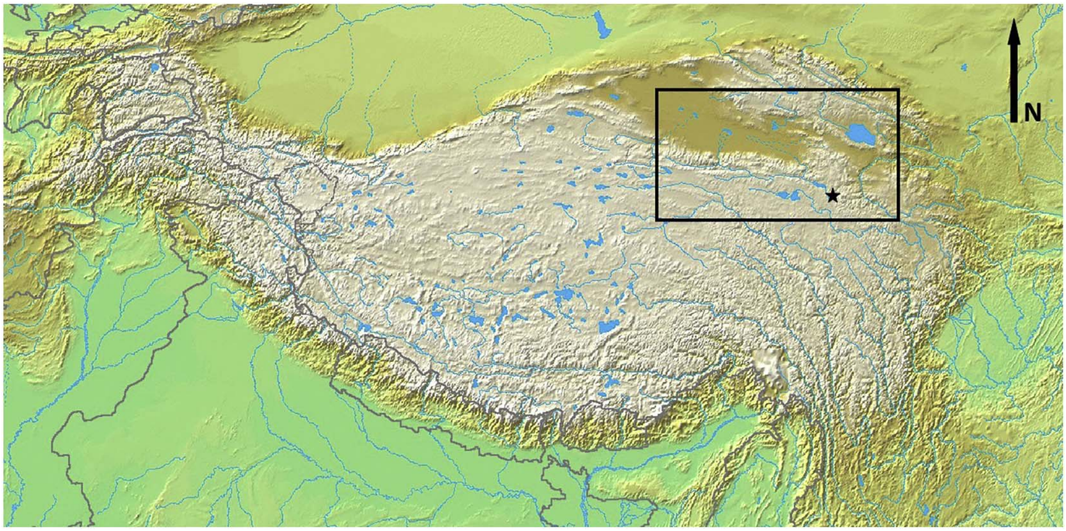

Fig. 1. Location of our study area on the northeastern Tibetan Plateau (inset box). Qinghai Lake, where most of the early sites are located (see Fig. 2), is in the upper right of the inset box. Star shows the location of the site of Xiadawu #1 (XDW1).

2. Methods

All our investigations were carried out with the cooperation and under the supervision of personnel from the Qinghai Institute of Salt Lakes (QISL), Chinese Academy of Science, in Xining, and the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Science, in Beijing. These scholars participated fully in both fieldwork and laboratory analyses. Surveys throughout our research region (Fig. 1) were limited to areas generally accessible to vehicular traffic and conducted through what we call "directed wandering;" that is, areas around lakes and springs, along stream margins, at canyon mouths, and the toes of alluvial fans were examined on foot by a team of up to six surveyors spread at ~10 m intervals. Wherever possible we examined the margins of disturbed or exposed areas such as road cuts, gravel quarries, deflating loess, erosional channels, house and stable excavations, etc. Due to the heavy vegetative cover in the region, most of the sites we discovered, and all of the buried sites we excavated, were found in these exposed situations. As a result, all the sites we investigated were in the process of being destroyed, usually by modern human developments, but in a few instances by erosional forces. Where possible, hearths were sectioned, with the remaining portion of the hearths left undisturbed for possible future research. Where water was locally available all excavated materials were water screened through ~4 mm mesh screen. At other locations all material was dry screened through ~6 mm mesh screen. Flotation samples were collected from the sectioned portions of the hearths, floated in a water bath with the light fraction sieved through 0.5 mm mesh screens and the heavy fraction sieved through 2 mm screen. These fractions were then examined and analyzed in the QISL laboratories for the presence of seeds, charcoal, and smaller artifacts. Charcoal identification methods, detailed in Rhode (2016), involved segregation of all variants using a 10–80 × Nikon stereozoom microscope, more detailed anatomical imaging of each charcoal variant using a tabletop scanning electron microscope (Hitachi TM-1000), and comparison with reference charcoals obtained from woods collected in the northeast TP. Artifacts were collected from the sectioned fill and from use surfaces surrounding each hearth. These surface artifacts were generally collected within 1 m of each hearth, but varied depending on the size of the exposure. With rare exceptions, artifacts were restricted to within these 2 m diameter areas. These artifacts were also analyzed in the QISL laboratories and are now being curated at its facility in Xining. Approximate calendar year ages of all ^{14}C age estimates were calibrated using Calib 7.1 (IntCal13) (Reimer et al., 2013). Generalized calendar ages are presented in ka BP; specific calendar ages are described as "cal yr BP."

3. Site descriptions

We provide descriptive excavation data for six of eight LUP campsites related to the earliest occupation of the northeastern TP > 3200 m (Figs. 1, 2). See Madsen et al. (2006) for descriptions of Heimahe #1 and Jiangxigou 93-13.

Jiangxigou #1 (JXG1) is at ~3318 m in the mouth of a small Qinghai Nanshan canyon (36.5903° N, 100.2956° E) (Madsen et al., 2006). Hearth #4, located ~2.5 m south of Hearth #3 (the "lower hearth" as reported in Madsen et al. [2006]; Fig. 3), consists of a dense concentration of charcoal, ash, and fire-cracked stream cobbles near the base of surface loess (it was reported as the "lower loess hearth" in Rhode et al. (2014).) It is 145 cm below the modern surface and 15 cm above dune sand (Fig. 4). A 125 cm long elongated triangular area tapering from 93 to 0 cm west-east, was excavated. Charcoal- and ash-stained sediments in a 90 × 60 cm area average ~4 cm thick. Whole and fire-cracked stream cobbles are densely packed within this concentration and extend on an apron 60 cm from its margin. Many cobbles are large, 35–68 cm in maximum width, but smaller, fire-cracked cobble fragments averaging 5–20 cm diameter dominate within the hearth proper. Charcoal fragments from Hearth #4 are identified as willow (*Salix* sp.). One such charcoal fragment dated to 12,190 ± 50 ^{14}C BP or a median age estimate of ~14,080 cal yr BP (~13,912–14,250 @ 2 s.d.). A technologically non-diagnostic flake was found adjacent to the hearth.

Together our investigations indicate that the LUP occupational phase at JXG1 consists of three isolated hearths apparently representing brief visits by small groups of LUP foragers. Two occupational events, represented by hearths dating to ~14.5 and ~14.6 ka BP (Madsen et al., 2006), took place while the basal dune was active, while hearth #4, dating to ~14.1 ka BP, was created after the dune surface stabilized and loess began to be deposited ~14.5 ka BP. All three hearths consist of small fires laid on unmodified surface sediments. Whole and fire-cracked stream cobbles are in and around 60–80 cm diameter areas of charcoal and ash stained sediments. The underlying surfaces are not heat oxidized. The simple hearths, together with a limited number and diversity of lithic and faunal remains, suggest very brief occupations.

Hudong Zhongyangchang #1 (HZYC1) lies at ~3404 m in the mouth of a narrow Riyueshan canyon, 12.3 km from Qinghai Lake (36.6390° N, 100.8781° E). Surface loess is 1.0–1.5 m thick and overlies ~25 cm of reworked sediments covering basal eolian sand. There is an active

Fig. 2. Satellite view of Qinghai Lake showing the locations of dated late Upper Paleolithic sites around the lake: (1) Heimahe #1 (HMH1); (2) Jiangxigou #1 (JXG1) and Jiangxigou 93-13 (JXG93-13); (3) Hudong Zhongyangchang #1 (HZYC1); (4) Yantaidon #1 (YTD1); (5) Xiatongbao #3 (XTB3); (6) Garhai #1 (GH1).

dune system to the west of a small stream flowing from the canyon (Fig. 5). Vegetation cover consists primarily of low grasses, bunchgrasses, and forbs, with willow along the stream.

We identified and excavated three hearths at HZYC1. Hearth #1 consists of a ~60 cm diameter concentration of stream cobbles and charcoal covering a pit hearth that is roughly conical in cross-section and ~30 cm deep (Fig. 6). Small burned well-rounded stream cobbles occur throughout the pit fill. The cobbles are ~2–10 cm in maximum width and many are heat fractured. Unidentified charcoal dates to 11,720 ± 70 ^{14}C BP or a median estimate of ~13,541 cal yr BP (~13,428–13,729 @ 2 s.d.). An apron of lithic debris including numerous microblades and small unidentified bone fragments feathers outward ~4–5 m around the hearth, with a maximum density of 14 artifacts/m^2 adjacent to the hearth. In addition to the hearth cobbles, broken, fire-cracked cobbles are scattered around the periphery.

Hearth #2 is a well-formed oval cobble-filled pit hearth that originates in the base of the loess and extends down into underlying sand (Fig. 6). The exposed upper portion of the pit feature is 125 × 80 cm. Small stream cobbles averaging ~8 cm in diameter fill a prepared bowl-shaped pit reaching 20 cm below the disturbed surface. Many of the cobbles are heat fractured and charcoal stained, and all the cobbles rest in a matrix of charcoal and ash stained soil. A layer of charcoal underlies the cobbles within the pit. The hearth is surrounded by a ~3 m diameter surface on which there were small unidentified calcined bone fragments, an unidentifiable tooth fragment, and a lithic assemblage (n = 148) that includes numerous microblades. Charcoal is identified as willow and dates to 11,010 ± 60 ^{14}C BP or a median estimate of ~12,877 cal yr BP (~12,732–13,025 @ 2 s.d.).

Hearth #3 is an irregular ~250 × 80 cm area of charcoal and ash stained sand with discontinuous and vague margins resulting from deflation and modern disturbance. The 1–4 cm thick stained sediment overlies culturally sterile sand. A single 8 cm diameter stream cobble occurs near the center of the staining. The associated lithic assemblage (n = 553) includes whole and fragmentary microblades, as well as abundant generalized flakes. The lithic debris is denser immediately surrounding the charcoal staining, reaching 15–16 flakes/m^2. Unidentified charcoal dates to 11,020 ± 60 ^{14}C BP or ~12,887 cal yr BP (~12,738–13,034 @ 2 s.d.).

The ^{14}C age estimates suggest that HZYC1 was occupied at ~13.5 ka BP and again about ~12.9 ka BP. While the ~12.9 ka BP dates from hearths #2 and #3 are statistically indistinguishable, stratigraphic differences suggest they represent separate occupations. Hearth #2 originates at the base of surface loess, while hearth #3 is in the underlying eolian sand, suggesting the initiation of post-glacial loess deposition began ~12,880 cal yr BP in this location. The sediments between the hearths were disturbed, but they appear to be the result of small forager groups occupying the site for short periods. Given the basin-shaped, cobble-filled construction of the hearths and the wide array of lithic debris, these stays may have been somewhat

Fig. 3. View of the JXG1 road cut exposure showing the position of hearth #1 (left figure), hearth #3 (right figure), and the approximate location of hearth #4 reported here (arrow).

Fig. 4. Profile (A) and plan (B) views of Hearth #4 at JXG1. In (B) note the charcoal and ash concentration on west (right) side of the exposed hearth.

Fig. 5. View of HZYC1 looking north towards an active dune field. The figures show the approximate positions of the three hearths.

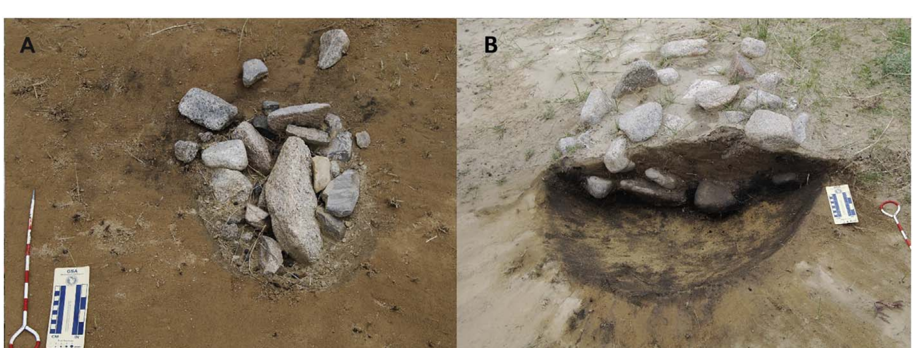

Fig. 6. Views of hearth #1 at HZYC1, prior to excavation (A), and hearth #2 after it was partially excavated (B).

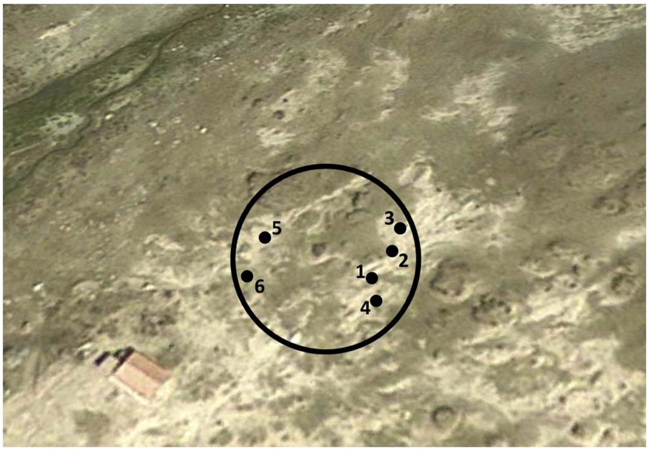

Fig. 7. Satellite view of Yantaidong #1, showing the relative positions of the early prehistoric hearths at the site.

prolonged.

Yantaidong #1 (YTD1) is at ~3304 m near the mouth of a short canyon in the western Riyueshan (36.8670° N, 100.7808° E). Two small springs provide perennial water. About 1.1–1.2 m of loess covers exposed bedrock and alluvium, but is extensively deflated in the 30–40 m diameter site area, leaving isolated grass/forb-covered hillocks of loess. Small charcoal- and ash-stained areas within this deflation zone are exposed in the faces of these small hillocks and on the deflated surfaces between them. Small arrays of microlithic debitage, fire-cracked rock, and some bone fragments surround these charcoal stains. Three of six possible hearths could be dated (Fig. 7).

Hearth #2 (Fig. 8) is a roughly circular (~60 cm diameter) 4–5 cm thick layer of ash and charcoal in a shallow basin. A layer of small cobbles overlies the ash and charcoal, with most in the 10–20 cm maximum diameter range. A number of similar cobbles surround the hearth. The hearth contained a small number of unidentified burned and calcined bone fragments from a gazelle-sized mammal, as well as microlithic debitage and a retouched microblade. The lithic assemblage (n = 262) from a ~2 m diameter area around the hearth includes a *lame à crête*, several microblades, one microblade core, and three thumbnail scrapers. Charcoal fragments, identified as willow, yielded a date of 10,360 ± 60 ^{14}C BP or ~12,224 cal yr BP (~11,983–12,422 @ 2 s.d.).

Hearth #3 is a roughly semicircular ~50 cm diameter area of charcoal- and ash-stained loess with a single elongate cobble on its surface. This sediment fills a shallow 8 cm deep basin. Microblades and microblade cores, along with microlithic debitage, were recovered from the hearth surface, the basin fill, and a surrounding apron extending ~1 m from the hearth margins. A piece of unidentified charcoal dates to 10,230 ± 60 ^{14}C BP or a median calendric estimate of ~11,949 cal yr BP (~11,704–12,168 @ 2 s.d.).

Hearth #4 (labelled "Hearth 11" in Rhode et al. [2014] and "F11" in Rhode [2016]) is a virtually intact roughly oval, 60 × 38 cm, hearth feature isolated in a small loess hillock (Fig. 8). Six small (< 10 cm diameter) fire-cracked stream cobbles rest on the surface of a 12 cm deep ash- and charcoal-filled basin. Artifacts in and on the hearth consist of a small number of microblades, microlithic debitage, and burned/calcined bone fragments. Some charcoal fragments identified as willow dated to 10,470 ± 60 ^{14}C BP or ~12,408 cal yr BP (~12,116–12,569 @ 2 s.d.).

Three of six probable hearths found on eroding loess surfaces at YTD1 are ^{14}C dated to between ~12.2–12.4 ka BP. They appear to represent separate, short occupational events, but extensive fire oxidation and the array of different tool types and tool production suggest they may be the product of prolonged use. However, no extended cultural midden connecting the hearths is evident in surviving loess hillocks, and artifacts on the aprons around the hearths extend out < 1 m from their peripheries. All six hearths exhibit modest preparation consisting of scooping out small basin-shaped 10–12 cm deep depressions in the loess surface.

Xiatongbao #3 (XTB3) consists of a series of isolated hearths eroding out of badly disturbed loess in the mouth of a small Riyueshan canyon at ~3340 m, ~4.6 km from Qinghai Lake (36.8819° N, 100.7577° E). The hearths occur in deflated and disturbed loess overlying fluvial terraces along a small, permanent stream (Fig. 9). The hearths are in a roughly oval ~90 × 40 m area cut by informal roads. Most of the 1.1–1.2 m thick loess cap overlying the cobbles and gravel in the terraces has eroded and only small, separate hillocks remain. We consider 6 of 21 features at XTB3 to be LUP, based on their ^{14}C age estimates.

Hearth #2 is a disturbed, 77 × 55 cm concentration of charcoal- and ash-stained loess, charcoal fragments, and whole and fire-cracked stream cobbles in the middle of a road (Fig. 10). These fill a 16 cm deep prepared basin-shaped depression. A ~5 cm thick layer of charcoal and stained loess covers the basin floor and underlies a layer of rock and stained loess in the upper part of the basin fill. The cobbles are ~5–12 cm in maximum dimension and angular breaks suggest thermal fracturing. Flakes, microblades, two thumbnail scrapers, a retouched flake and a large array of microlithic debitage are associated with the hearth. Charcoal fragments are identified as sea buckthorn (*Elaeagnus rhamnoides*) and date to 10,000 ± 60 ^{14}C BP or ~11,485 cal yr BP (~11,263–11,723 @ 2 s.d.).

Hearth #9 is an exposed concentration of charcoal-stained loess filling a shallow 6 cm deep basin. It is roughly circular (70 × 60 cm), but is badly disturbed. Only a single small fire-cracked cobble was recovered from the sectioned fill, but a small area of rocks and charcoal-stained loess immediately adjacent to the hearth appears to represent rocks and charcoal raked from the hearth. Multiple microblades and pieces of microlithic debitage were recovered from the hearth fill. Charcoal is identified as willow, one piece of which dates to 9510 ± 50 ^{14}C BP or ~10,822 cal yr BP (~10,600–11,085 @ 2 s.d.).

Hearth #10 is a badly disturbed concentration of charcoal-stained loess and fire-cracked rock with a maximum width of 105 cm. It

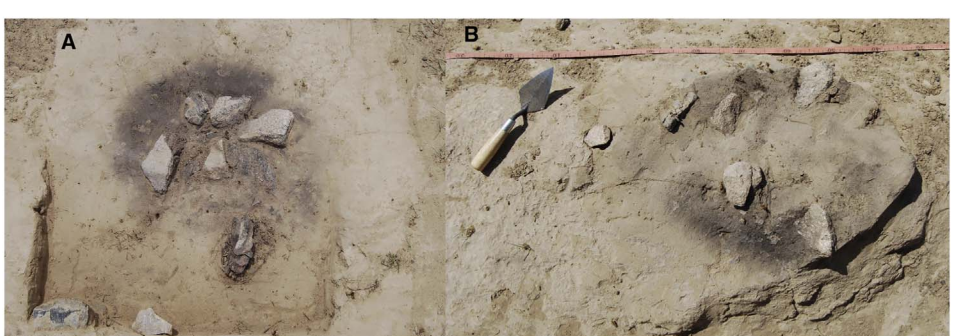

Fig. 8. Views of hearth #2 (A) and hearth #4 (B) at YDT1 exposed in plan view.

Fig. 9. (A) View of the Xiatongbao #3 site location looking upstream towards the Riyueshan, a canyon mouth setting typical of the early sites around Qinghai Lake. (B) View of the site looking south towards Qinghai Lake. The figures are standing at the locations of the investigated hearths reported here.

contains two slightly basin-shaped depressions, one roughly circular (25 cm diameter) and one roughly oval (75 × 45 cm). The area of charcoal staining varies between 5 and 10 cm thick, with the larger depression filling an 8 cm deep shallow basin. A small number of fire-cracked rocks (< 10 cm max. diameter) and a large assemblage (n = 200) of flakes, microblades, and microdebitage were recovered from a 2 × 2 m surface scrape around the hearth, and two long bone shaft fragments from a medium-to-large mammal were recovered from the hearth fill. Charcoal in this hearth is identified as willow and sea buckthorn. A piece of charcoal (taxon undetermined) is dated to 10,100 ± 50 ^{14}C BP or ~11,696 cal yr BP (~11,401–11,973 @ 2 s.d.).

Hearth #15 is a roughly circular concentration of charcoal and charcoal-stained loess filling a shallow 5 cm deep, ~80 × 50 cm, basin containing a single large 18 × 30 cm stream cobble and a small piece of fire-cracked rock. No lithic artifacts were recovered from the fill, but a small amount of lithic debitage was recovered from a surface scrape of the surrounding area. Charcoal fragments are identified as sea buckthorn and date to 10,170 ± 50 ^{14}C BP or ~11,859 cal yr BP (~11,620–12,057 @ 2 s.d.).

Hearth #17 is a roughly circular 55–60 cm diameter concentration of charcoal and charcoal-stained loess between the stream terraces in a shallow, 8 cm deep basin. A circular 12 cm deep, 32 cm diameter pit/basin, lined with 8 relatively flat stream cobbles, immediately adjacent to the hearth appears to have been in use simultaneously. The burned and fire blackened cobbles are uniformly 2–3 cm thick and 10–15 cm wide. The pit fill is black charcoal-stained loess containing a substantial amount of charcoal, some of which is sea buckthorn and some an unidentified hardwood (Rhode, 2016). A piece of undetermined charcoal dates to 10,280 ± 50 ^{14}C BP or ~12,053 cal yr BP (~11,822–12,378 @ 2 s.d.). A single microblade and several flakes of microdebitage were recovered from the pit fill.

Hearth #18 is a circular, ~70–75 cm diameter, 13 cm deep, flat bottomed basin-shaped pit feature eroding from the face of a loess hillock (Fig. 11). A very dark 3–5 cm thick layer of charcoal-stained soil, containing a large quantity of charcoal fragments, overlies an unoxidized basin floor. This charcoal layer is overlain by a layer of relatively flat stream cobbles averaging ~10 × 10 cm in width and ~2–3 cm in thickness. These fire-blackened cobbles are mostly lying flat in the center of the basin, but several lie against the sloping sides. The fill above these blackened cobbles consists of charcoal-stained loess containing a smaller quantity of charcoal fragments, some of which is identified to sea buckthorn and to the same unidentified hardwood as Hearth #17 (Rhode, 2016). A piece of undetermined charcoal from the hearth dates to 10,050 ± 50 ^{14}C BP or ~11,565 cal yr BP (~11,321–11,811 @ 2 s.d.). A number of microblades and an array of microlithic debitage were collected from around the hearth.

Six of the 21 hearths from XTB3 date to the LUP and span a period between ~12–10.8 ka BP. Although there is extensive disturbance, the spatial arrangement and different vertical placement within the surface loess suggests they are the result of separate short visits by small foraging parties. However, hearths #10, #15, and #18, dating to ~11.5–11.9 ka BP are chronologically similar and may represent a

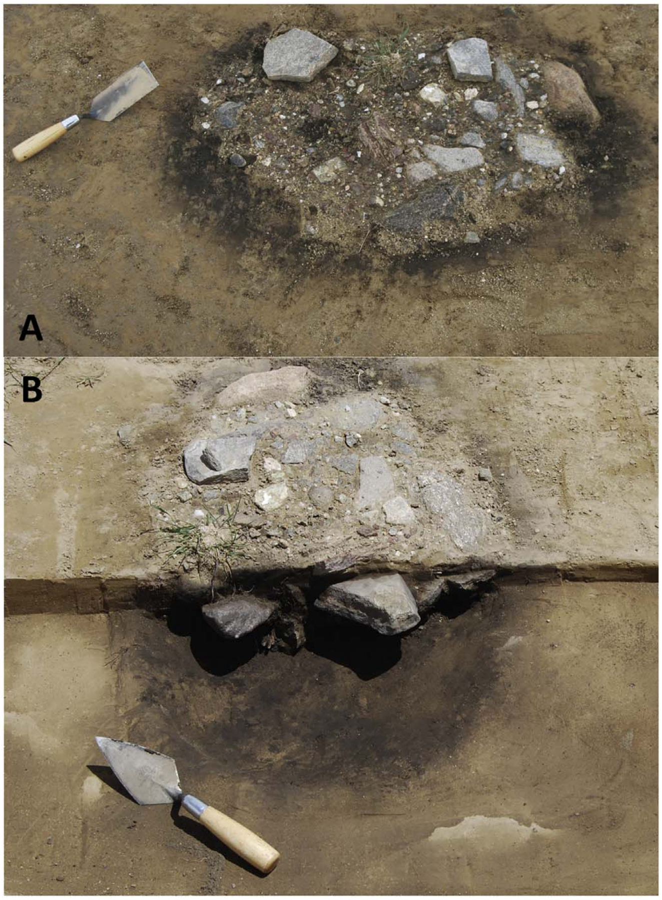

Fig. 10. View of Hearth #2 at XTB3 as discovered (A), and partially excavated (B). Trowels point north.

single occupational event by a larger party. The six dated LUP hearths take two general forms. One form consists of simple, small fires laid directly on the underlying, unmodified surface. Rocks used for heating are absent or few in number. Their simplicity suggests their intended use was limited to light, warmth, and/or modest food preparation. The other hearths are more complex, and consist of shallow basins excavated into the underlying loess. Fires were built in these basins or in adjacent basins, and then relatively flat stream cobbles were laid on top of the coals. These may have been used for baking/roasting. Faunal remains are limited to a few bone splinters from small-to-medium gazelle-sized mammals and a single medium-to-large deer-sized mammal. The limited distribution of artifacts around the hearth perimeters, the limited diversity in artifact types, and the lack of any evidence of midden formation together suggest relatively short site visits.

Garhai #1 (GH1) consists of a small, isolated, badly disturbed hearth eroding from below a small, 2.5 m high by 4 m diameter, dune at 3213 m on the northeastern margin of Garhai Lake, an extension of Qinghai Lake (37.6289° E, 100.5494° N). The GH1 hearth was deposited on the surface of the alluvial fan underlying this small dune.

The hearth is ~45 × 30 cm, but its margins are disturbed by bioturbation. It is somewhat basin-shaped in form, but the ~7 cm deep basin is also churned and mottled and there is no clear structure to the feature. Most of the fill is charcoal-stained sand and only small unidentified charcoal fragments were observed. Unidentified charcoal fragments date to 9480 ± 60 ^{14}C BP or ~10,749 cal yr BP (~10,572–11,080 @ 2 s.d.). With the exception of a unifacial 'transverse' side scraper, the lithic assemblage consists of technologically non-diagnostic debris apparently derived from the same reduction event.

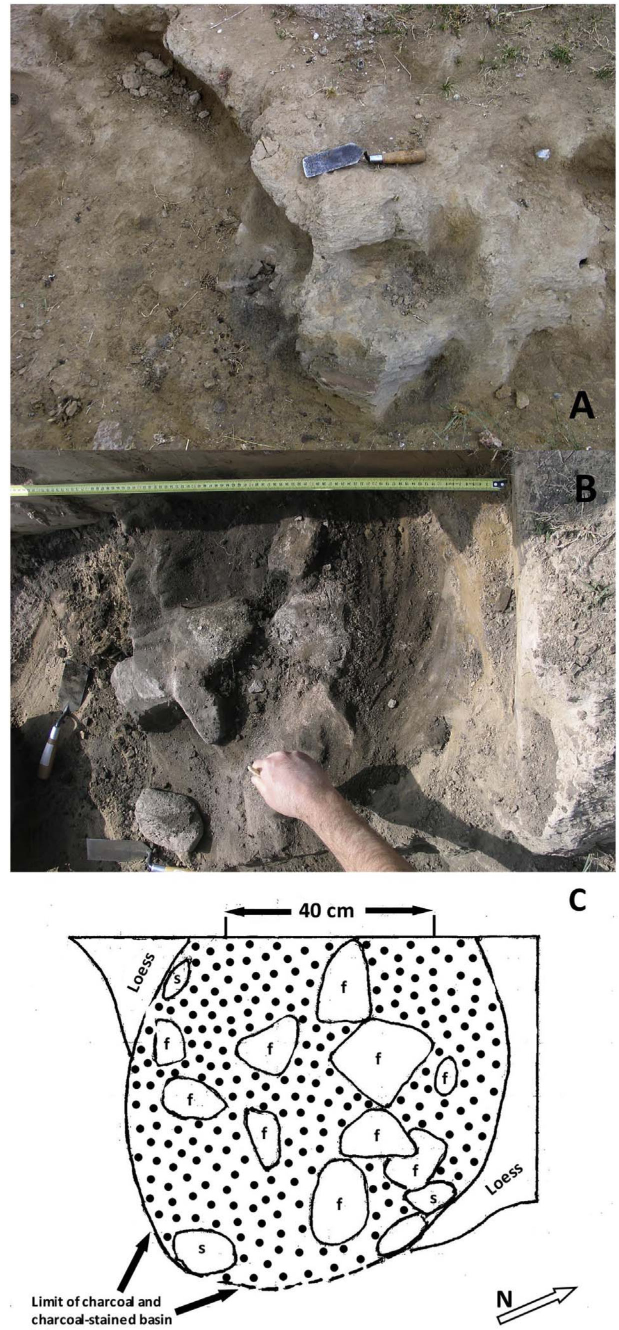

Fig. 11. Views of hearth #18 at XTB3: (A) prior to excavation; (B) during excavation; and (C) plan view drawing of the pit feature showing the location of burned rocks in the hearth fill.Note that "f" and "s" represent the flat and sloping orientation of the stream cobbles on the basin floor.

The badly disturbed GH1 feature appears to be the remnants of what appears to be a simple unprepared hearth laid directly on surface alluvium. The simple hearth feature, the limited lithic assemblage, and a lack of faunal remains suggest the hearth is the result of a brief visit to the site by a small party.

Xiadawu #1 (XDW1) is a multi-component site at ~4000 m (35.0019° N, 99.2607° E). XDW1 lies at the confluence of a small stream and a major tributary of the Yellow River that originate on the flanks of the ~6280 m high Amnye Machen (Fig. 12). The stream adjacent to XDW1 is now incised ~12–15 m into older fluvial/alluvial deposits that are overlain by a 1.5–2 m thick surface loess currently covered by alpine meadow vegetation. We conducted an emergency

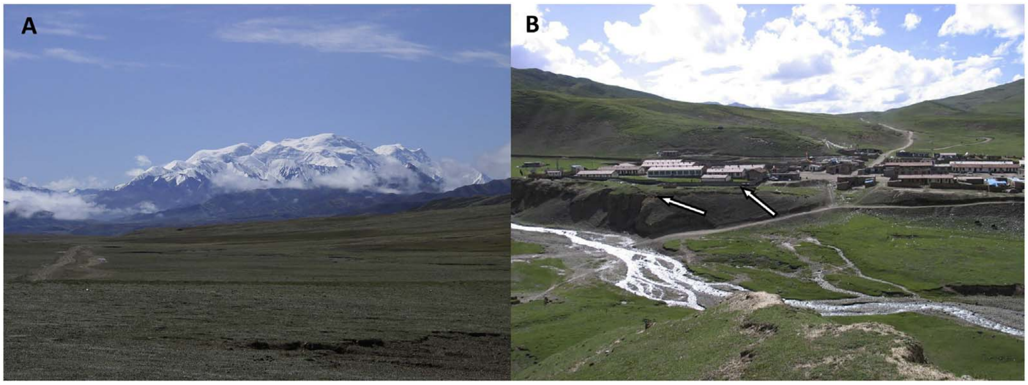

Fig. 12. (A) View of the Amnye Machen 15–20 km southeast of Xiadawu. (B) View of the Tibetan village of Xiadawu looking west showing the location of a probable late Upper Paleolithic earth oven near the village (left arrow).Note that the feature lies at a point where a meander of the small stream is eroding the stream margin during periods of high flood water. The remnant of the simple hearth lies at the base of the loess 40 m downstream from the earth oven (right arrow).

salvage excavation to remove a small area in danger of collapse, and cleaned a 1 m wide section of an exposed profile to determine site stratigraphy.

There are at least two zones of charcoal-stained soil, cobbles, and cultural debris within the surface loess, one near the base and one near the center of the loess stack. The lowest of these, dating to the LUP period, consists of a large rock and charcoal-filled feature and a second smaller hearth located ~40 m to its north. At the time of our investigation the exposed width of the charcoal/rock lens was 3.35 m. We excavated a triangular 1.45 × 2.55 m area along the eroding channel margin, revealing a concentration of dense charcoal and charcoal-stained loess in and around a layer of densely packed small burned stream cobbles (Fig. 13). The ~125 × 115 cm area of dense charcoal and rock occupies a shallow basin originating in the lowest 3–5 cm of surface loess (Fig. 14). Charcoal-stained loess extends out from this central concentration and covers most of the exposed excavation area. Away from the central area of concentrated charcoal and rock this charcoal-stained loess overlies a lightly reddened, slightly heat-oxidized surface indicating the fire associated with the feature covered most of the exposed area. Isolated small stream cobbles are present on this surface on the margin of the central concentration.

The 88 cobbles we collected from the central concentration average ~5 × 5 × 8 cm. The broader sides of each cobble generally lay flat on the underlying surface. From photographs taken in 1998 (Van Der Woerd et al., 2002), it is evident that many more have been eroded away. Most of these small stream cobbles are burned, but only a few are fire-cracked, suggesting limited thermal stress. The fill in and around these cobbles is mostly charcoal, with little ash or soil, and with many charcoal fragments reaching ~1 cm diameter. The identified fragments are dominated by sea buckthorn with minor amounts of willow and one piece tentatively identified as juniper (*Juniperus* sp.). Radiocarbon age estimates of 9920 ± 60, 9820 ± 60, 9830 ± 60, and 9980 ± 60 ^{14}C BP on unidentified charcoal (Van Der Woerd et al., 2002) have a weighted average of 9888 ± 30 ^{14}C BP or a median calendric estimate of ~11,270 cal yr BP (~11,226–11,353 @2 s.d.).

An array of faunal remains includes an upper M1 or M2 *Equus* sp. tooth that, based on size and modern distributions, may have belonged to a Tibetan wild ass or kiang (*Equus kiang*), and a lower deciduous fourth premolar (dp4) of a small bovid or cervid that looks similar to musk deer (*Moschus* sp.). A number of other bone fragments derived from medium to large mammals, including an artiodactyl phalanx, an artiodactyl metapodial, and 56 long bone shaft fragments, could not be further identified. Most are burned and/or calcined and many have percussion breaks, presumably resulting from marrow extraction. An array of 36 lithic specimens was found in and around the feature, including two proximal microblade fragments and a quartzite core made from a stream cobble. The core exhibits Levallois-like blade flake production techniques, and flake scars indicate production of blade flakes ranging from 55–65 mm long and 10–13 mm wide (Fig. 15).

A ~1 m wide profile cut into the exposed face of a ~1.4 m deep loess section ~40 m north of and downstream from the charcoal feature exposed a small amorphous charcoal-flecked and ash-stained lens near the base of the loess that appears to be the badly disturbed remnant of a small, roughly circular, ~60 cm diameter, simple unprepared hearth (Fig. 16). The lens is 5–8 cm thick and occurs 125–133 cm below the modern surface and ~20 cm above the base of the loess. Two small

Fig. 13. (A) View of the central charcoal and rock concentration within the earth oven feature at XDW1 during excavation; and (B) view of a portion of the concentration showing the dense packing of the rock layer.

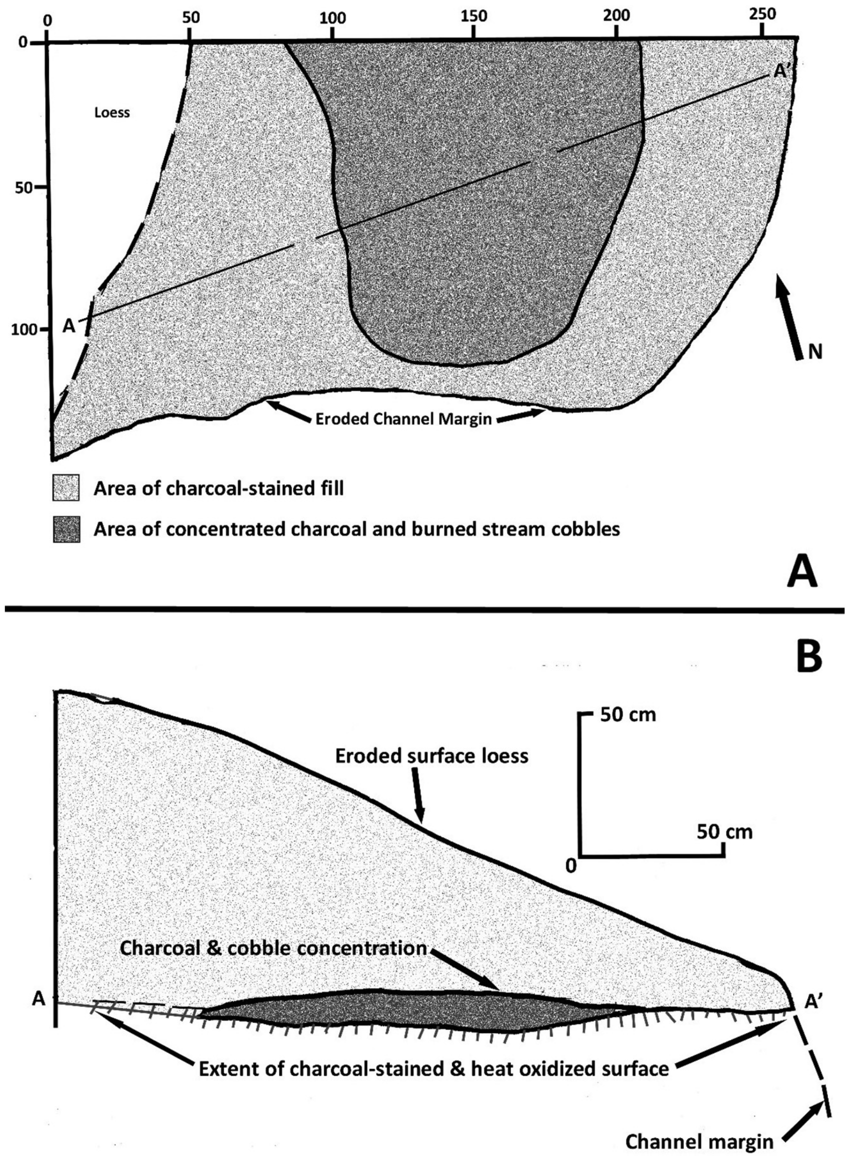

Fig. 14. Plan (A) and profile (B) view drawings of the probable late Upper Paleolithic earth oven at XDW1 showing the area of concentrated cobbles and rock and the extent of the charcoal-stained fill and heat oxidation of the underlying surface. (Note: A-A' in Fig. 4A is the location of the profile shown in Fig. 4B and the sectioned hearth shown in Fig. S33).

Fig. 15. Dorsal (left) and ventral (right) surfaces of a quartzite core from the lower component hearth feature at XDW1. Scars on the core reflect the removal of 55–65 cm long blade flakes.

stream cobbles occur near what was likely the center of the disturbed hearth. A single piece of core shatter was recovered. Charcoal fragments from the hearth are identified as sea buckthorn and date to 10,230 ± 50 ^{14}C BP or ~11,952 cal yr BP (~11,758–12,137 @ 2 s.d.). An isolated sea buckthorn charcoal fragment located 30 cm from the hearth, but at a slightly higher elevation, dates to 9910 ± 40 ^{14}C BP or ~11,301 cal yr BP (~11,222–11,593 @ 2 s.d.). This isolated fragment is approximately the same age as the large rock filled feature and may have originated from it.

We tentatively interpret the major feature related to the LUP occupation of XDW1 as a communal cooking facility involved in processing and cooking of medium-to-large animals, possibly a shallow earth oven. Both the central concentration and the overall charcoal-stained area are much larger than any other LUP hearth feature reported here, but whether it was the product of a single event, or is a palimpsest resulting from a number of fires, is unclear. We favor the former interpretation due to the heavy concentration of charcoal. This large amount of incompletely consumed fuel, and the cobble layer within the hearth, suggest the fire may have been smothered and combustion halted by the resulting lack of oxygen. We presume the function of the cobbles in the hearth was to retain and prolong elevated

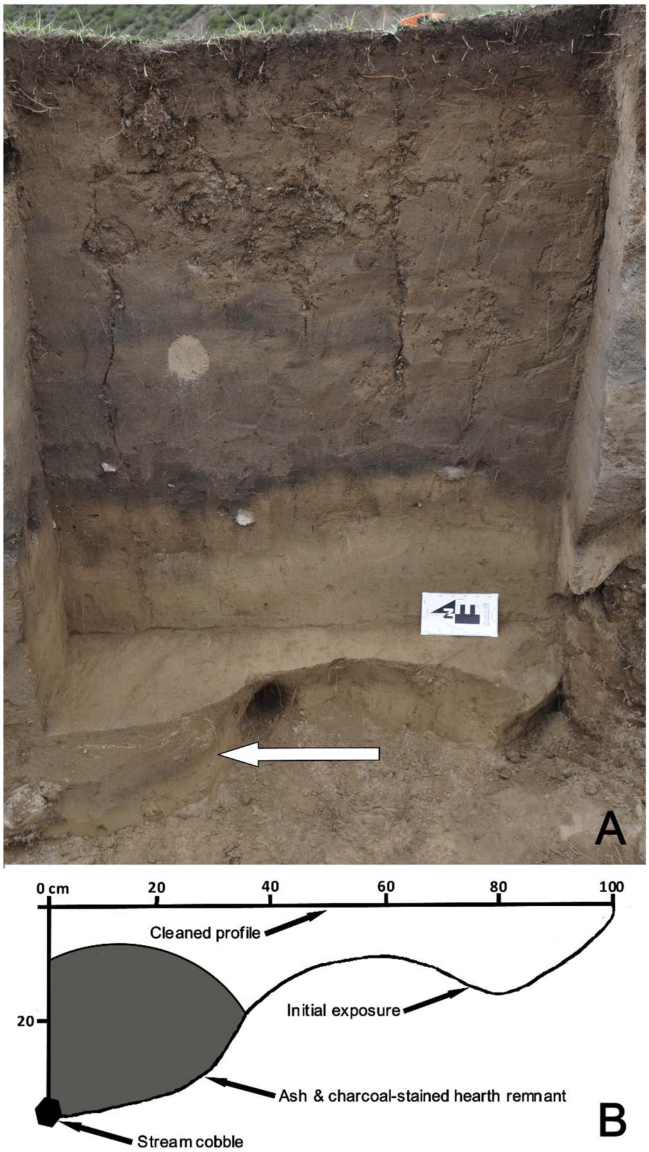

Fig. 16. (A) Ash and charcoal-stained simple hearth remnant 130 cm below the modern loess surface.Note the small stream cobbles within the ash lens. The dark, charcoal-stained midden in the loess above the hearth is the product of later Epipaleolithic occupation(s). (B) Plan view schematic of the simple hearth remnant dating to ~12.0 ka BP.

temperatures once the fire was smothered. The other small ash-stained feature at XDW1 was heavily eroded and its overall form and function are unclear. The lack of associated artifacts or faunal remains suggests it may have been the result of a small fire used for light or warmth. Because age estimates for the simple hearth and those from the earth oven are different, we suggest the two features represent separate occupations.

The lack of any midden formation and the absence of any other cultural features suggest the two features at XDW1 are the result of short-term occupations, but the size and composition of the occupying groups is unclear. The large charcoal/cobble deposit could represent a communal facility, and if the faunal remains represent animals cooked in it, they could feed a large number of people. However, there are other possibilities (such as drying meat for transport and future consumption). If foragers were transporting large quantities of food from Xiadawu to a lower-elevation base camp, they would have faced a long trek of > 270 km along narrow river channels to elevations below 2500 m in the Longyangxia Gorge of the Yellow River. It remains unknown whether the site represents what Meyer et al. (2017) would consider to be evidence for early permanent occupation of the high plateau or, more likely, is the result of a multiple day occupation by a more mobile group seasonally moving around the high plateau from place to place.

4. Archaeological site chronology

With the addition of previously reported age estimates for LUP sites above 3200 m within this area (Van Der Woerd et al., 2002; Madsen et al., 2006) to those reported here, there are now 26 ^{14}C dates from eight sites for the 15–10.5 ka BP LUP period (Table 1). Sites with components dating to this occupational phase uniformly consist of one or more small isolated hearths, each of which is surrounded by a very modest collection of artifacts limited in both number and diversity. HMH1 and GH1 contained single hearths, but multiple hearths were identified and investigated at the remaining eight sites. With the exception of two hearths at JXG1 and three at XTB3 with statistically similar dates, the hearths are chronologically or stratigraphically distinct enough to suggest they represent a minimum of 18 separate occupational events at the eight locations. An additional 12 hearths identified at XTB3 and 3 identified at YTD1 could not be dated, but a number of them also likely date to LUP and may also represent separate site visits. Together these occupational events provide a relatively coherent picture of early adaptive strategies on the high TP.

With the exception of GH1, all of the hearths are in open sites located adjacent to permanent streams at the mouths of canyons. Such locations allow access to both mountain ecosystems and to relatively flat open areas on valley floors or the open upper plateau. The hearth forms are relatively uniform, consisting of small 50–100 cm diameter features containing small 10–20 cm diameter stream cobbles. Most hearths were laid on unprepared flat surfaces or in shallow basins and contain 1–3 to as many as 6–8 stream cobbles, but a few were constructed as small pits deeper than their diameter and contain as many as 32 cobbles. In a number of cases many of the cobbles, along with ash and charcoal, appear to have been raked from the hearth onto adjoining aprons. Some of these cobbles are heat fractured, but the large majority show little alteration suggesting hearth temperatures were relatively low. The purpose of these cobbles is unclear, but we speculate they were used to prolong the thermal inertia of low-grade fires for personal warmth or during the roasting of animals. Charcoal from the hearths is derived from shrubs including, most commonly willow, and more rarely, sea buckthorn and peashrub (*Caragana* sp.). Limited ash-staining and scattered charcoal occur on small 1–2 m diameter aprons around the hearths, as do small numbers of micro-blades, microlithic debitage, and more generalized flake tools and debris. Small amounts of broken unidentified burned and calcined bone fragments, derived primarily from small-to-medium gazelle-sized animals, occur in and around the hearths. These fragments appear to result from the processing of long bone elements for marrow. The exception to this relatively consistent pattern is the large hearth/from XDW1 at 4000 m on the high plateau. XDW1 also differs in that the large blade core helps confirm suggestions that core-and-blade lithic production techniques common to the early and middle Upper Paleolithic periods in China continued to be used in addition to microlithic techniques, and that large blades on TP surface sites are not temporally diagnostic to earlier Upper Paleolithic technologies (Brantingham et al., 2013).

These 18 dated occupational events, together with the undated hearth features, suggest these LUP occupations represent very short stays by small groups of individuals. This is based on the simple nature of the hearth features, the minimal cultural deposition around them, the limited number and diversity of artifacts, and the presence of only a small assortment of faunal remains. It is unlikely such short stays by only a few people represent the provisioning of lower elevation camps, since it would require round trips of ~100–350 km to elevations < 2500 m, the elevation most often used in studies of hypoxia and other altitude related health issues as a "working definition of high altitude"

Table 1
Dated hearth features from late upper Paleolithic sites above 3200 m on the northeastern Tibetan Plateau.

Site	Feature	Lab #	^{14}C BP	2 s.d. age range	Median age cal yr BP	Reference
JXG1	Hearth 3	Beta 149997	12,470 ± 60	14,252–15,024	14,639	Madsen et al., 2006
JXG93-13	Lower hearth	AA 12318	12,420 ± 170	13,997–15,172	14,561	Madsen et al., 2006
JXG1	Hearth 1	Beta 208338	12,420 ± 50	14,183–14,875	14,515	Madsen et al., 2006
JXG93-13	Upper hearth	AA 12319	12,370 ± 90	14,081–14,917	14,444	Madsen et al., 2006
JXG1	Hearth 4	Beta 282120	12,190 ± 50	13,918–14,250	14,080	This paper
HZYC1	Hearth 1	Beta 227185	11,720 ± 70	13,428–13,729	13,541	This paper
HMH1[a]	Hearth	NA	11,116 ± 24	12,902–13,084	13,017	Madsen et al., 2006
HZYC1	Hearth 3	Beta 262354	11,020 ± 60	12,738–13,034	12,887	This paper
HZYC1	Hearth 2	Beta 257186	11,010 ± 60	12,731–13,025	12,877	This paper
YTD1	Hearth 1	Beta 262389	10,470 ± 60	12,116–12,569	12,408	This paper
YTD1	Hearth 2	Beta 262388	10,360 ± 60	11,983–12,513	12,224	This paper
XTB3	Hearth 17	Beta 212117	10,280 ± 50	11,822–12,378	12,053	This paper
XDW1	Hearth 1	Beta 305774	10,230 ± 50	11,758–12,137	11,951	This paper
YTD1	Hearth 3	Beta 262390	10,230 ± 60	11,650–12,367	11,949	This paper
XTB3	Hearth 15	Beta 282116	10,170 ± 50	11,620–12,057	11,859	This paper
XTB3	Hearth 10	Beta 282113	10,100 ± 50	11,401–11,973	11,696	This paper
XTB3	Hearth 18	Beta 282118	10,050 ± 50	11,321–11,811	11,565	This paper
XTB3	Hearth 2	Beta 262392	10,000 ± 60	11,263–11,749	11,485	This paper
XDW1[b]	Earth oven	NA	9888 ± 30	11,226–11,353	11,270	Van Der Woerd et al., 2002
GH1	Hearth	Beta 331976	9750 ± 40	11,110–11,241	11,195	This paper
XTB3	Hearth 9	Beta 282112	9510 ± 50	10,600–11,085	10,822	This paper

Date ranges are calibrated using Calib 7.1 (Stuiver et al., 2017; IntCal13, Reimer et al., 2013). All dates were run on hearth charcoal.
[a] Average of 3 ^{14}C age estimates.
[b] Average of 4 ^{14}C age estimates.

(Beall, 2014: 252). However, because such sites are unlikely to have functioned as part of a logistical provisioning system does not mean that they therefore must represent 'permanent', year-round occupation (sensu Meyer et al., 2017). Rather, given the lack of structures or evidence for prolonged stays, these early high elevation sites were presumably brief and seasonally restricted occupations. We conclude that small parties were operating on the upper margins of the TP at elevations above 3400 m by ~15 ka BP, and by ~12 ka BP small group occupations had reached the high plateau above 4000 m.

5. Summary and interpretation

The archaeological data we report here, together with those reported for later occupational phases (Rhode et al., 2007; Chen et al., 2015; Zhang et al., 2016), suggest human colonization of the TP occurred in four stages: (A) Upper Paleolithic foragers occupied middle Yellow River drainages by ~35–20 ka BP and may have reached lower elevation river valleys along the TP margin itself. (B) Beginning ~16 ka BP, after the extremely cold and dry LGM, LUP foragers began to move into the upper drainages, and small parties occupied camps above 3200 m for very short intervals. The delayed occupation of the high-altitude TP may have been a result of the limited biotic productivity of this extreme environment, which provided few resources for early foragers prior to the end of the LGM (Madsen, 2016). XDW1, currently the oldest well-dated site ≥ 4000 m, suggests seasonal trips to the high TP may have started by ~12 ka BP. (C) After ~9.5 ka BP, warm early-to-mid Holocene climatic conditions may have led to the expansion of millet farming at higher elevations (Brantingham et al., 2007) and to the expansion of occupations ≥ 4000 m as the high plateau began to be intensively occupied, again probably seasonally. (D) By ~4 ka BP the introduction of more cold-tolerant barley led to the emergence of high altitude farming communities at elevations of 3000 to ≥ 4000 m (Chen et al., 2015; Barton, 2016).

Chronologically, this archaeologically derived scenario for the human colonization of the TP fits well with most genetically-based reconstructions of Tibetan population history (Qi et al., 2013; Lou et al., 2015; Kang et al., 2016; Lu et al., 2016). These time estimates suggest a population expansion beginning ~20–10 ka BP, with an even greater expansion ~5 ka BP. Our archaeologically-based chronology is consistent with genetic analyses which suggest that "most of the Tibetan gene pool is of modern human origin and diverged from that of Han Chinese ~15,000 to ~9,000 years ago" (Lu et al., 2016: 580). These genetically-based time estimates are consistent with an appearance of foraging populations on the high TP after ~16 ka BP and accelerating after ~9.5 ka BP. We find no archaeological evidence for the occupation of the high TP prior to the LGM, but it is possible nearby early-to-middle Upper Paleolithic populations (Morgan et al., 2011; Li et al., 2013; Madsen et al., 2014) reached into some of the upper river drainages along the TP margins. As foragers along the upper Tibetan rivers began to move to elevations > 3200 m after the LGM they became increasingly differentiated, especially so after ~9.5 ka BP when they began to more fully settle the high interior plateau.

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