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The Late Upper Paleolithic occupation of the northern Tibetan Plateau margin

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Abstract

The pre-Neolithic history of the Tibetan Plateau is virtually unknown. Test excavations of Late Paleolithic sites, described here, provide preliminary evidence that the initial occupation of the plateau's extreme environments was by small groups of foragers probably traveling from lower elevation plateau margins. These foragers occupied very short-term camps focused on the procurement and extensive processing of small-to-medium mammals. Five separate occupations date to 13–15,000 Cal yr BP, but limited survey data suggest mid-elevation locations may have been temporarily occupied as early as 25,000 years ago. Full-time, year-round occupation of the plateau probably did not take place until the early Neolithic advent of domesticated animals.

Keywords: Tibetan Plateau; Upper Paleolithic; Foraging; Extreme environments

1. Introduction

The Qinghai-Tibetan Plateau (Fig. 1) is the largest continuous high elevation ecosystem on the planet. It reaches an average elevation of more than 4000 m a.s.l. and is characterized by extremes of climate and environment and by biotic communities specifically adapted to these extremes [56]. We are currently investigating the Upper Paleolithic occupation of the plateau to help us understand how early human foragers overcame the biological and physiological barriers to the occupation of such extreme environments. Developing an understanding of the biological or behavioral mechanisms involved in this initial occupation is critical in understanding the fundamental biogeographic capacities of early human populations for the movement into other extreme environments such as that of Siberia and Beringia [7].

The initial full-scale occupation of the plateau was, as now, constrained by the high costs of living at high elevation. Food intake necessary to maintain normal metabolic function at 4500 m a.s.l. exceeds sea-level needs by more than double [42], and the ability to work is significantly reduced [14,45]. Hypoxia reduces the ability to absorb certain nutrients and exacerbates these nutritional requirements [42]. Populations at high elevation have significantly lower infant birth weights and concomitantly higher rates of infant mortality ([14,46]; but see [7]). In addition, the low biological productivity characteristic of extremely high altitude ecosystems results in

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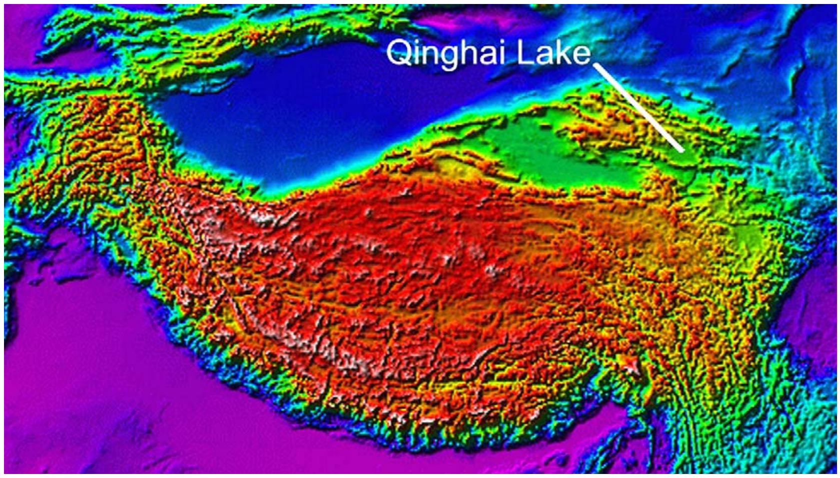

Fig. 1. Digital shaded-relief image of the Himalayas and Tibetan Plateau showing the three major elevational steps of the Tibetan highlands. Low elevation deserts below 3000 m a.s.l. (blue in online version) surround the plateau on the north, east and northwest. Intermediate lake basins are found on the northern and eastern plateau margin at 3000–4000 m (green). The high plateau and mountains above 4000 m in the central and western plateau constitute the third step (red/orange) [US Geological Survey/EROS].

a low carrying capacity [1,55]. Together, these greater nutritional demands, greater capture costs, reduced physiological capacity, reduced fertility rates, and higher mortality rates would have put severe constraints on the initial occupation of the Qinghai-Tibetan Plateau. This suggests that such an initial colonization was sustained by high rates of immigration from source areas around the plateau, and/or by specialized adaptations necessary to increase local intrinsic population growth.

We have hypothesized that the ''colonization'' of the northern Qinghai-Tibetan Plateau occurred in several discrete stages coinciding with major fluctuations in regional paleoclimate over the past 50,000 years, and that each discrete stage of colonization involved very different forms of hunter-gatherer foraging organization [12]. This ''three-step'' chronological model for the occupation of the plateau is based on its three principal elevation steps: (1) the low elevation source areas of the northern plateau below 3000 m a.s.l., consisting primarily of Gansu Province, the Inner Mongolian Autonomous Region and the Xinjiang Uygur Autonomous Region; (2) an intermediate step between 3000 and 4000 m a.s.l., an area including the large internal lake basins of Qinghai Province; and (3) an extreme elevation step above 4000 m that includes portions of Qinghai Province and most of the Tibetan Autonomous Region (see Fig. 1). Elsewhere we have reported on initial archaeological fieldwork relevant to understanding the modern human occupation of the low elevation source areas well prior to the Last Glacial Maximum (LGM) 50,000–25,000 yr BP [13,22,39]. Here, we report initial surveys and test excavation of sites on the intermediate step dating to immediately after the LGM. These consist of a number of temporary foraging camps at elevations of 3200–3400 m around Qinghai Lake (Fig. 2). On both the intermediate and highest steps we have also identified a few scattered surface sites

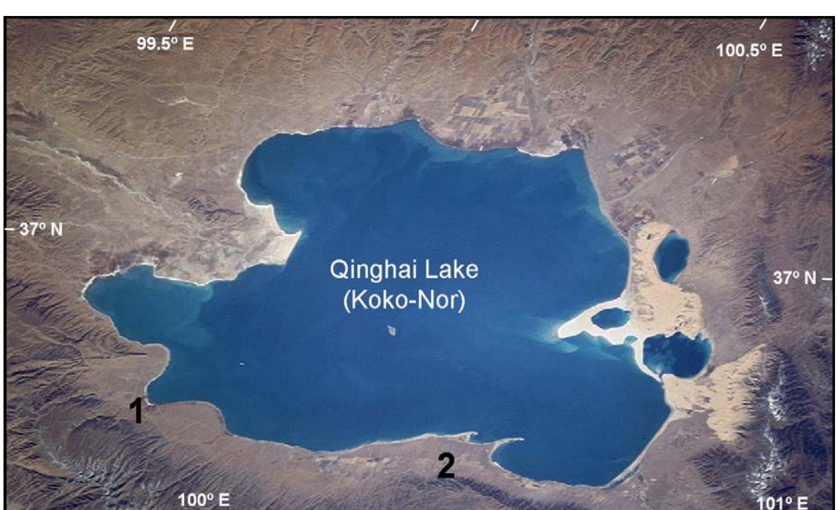

Fig. 2. Satellite image of the Qinghai Lake basin showing the location of the late Upper Paleolithic sites along the southern lake margin: 1, Heimahe #1; 2, Jiangxigou #1 (and possibly Locality 93-13, see text) [NASA/Image Science and Analysis Laboratory].

with diagnostic materials and geomorphic positions suggesting they may date to prior to the LGM, but these have yet to be investigated fully [12].

2. Environmental constraints

The Qinghai Lake basin (Fig. 2) lies between about 36° 20′–37° 20′ N, 99° 20′–101° 20′ E. The modern surface of the lake is ∼3194 m a.s.l. and most of the basin floor varies between 3200 and 3400 m. Higher mountains reaching elevations well above 4500 m surround it. To the south, these are the Qinghai Nan Shan; to the east, the Riyue Shan; and the northwest and northeast the Datong Shan and Daban Shan. These latter ranges are part of the extensive Qilian Mountains and most of the water feeding the lake is derived from these northern sources. Qinghai Lake, with a catchment of 30–35,000 km^2 [35,57,70], is fed by more than 100 small streams, but its principal tributary is the 300 km-long Buha River which supplies more than half its water [51]. The basin has a cold, semi-arid climate with average annual temperatures of about 0prime °C and average annual precipitation (at the level of the lake) of about 350 mm [49]. The basin has long, but relatively dry and quite cold winters, and short, mild summers, with the majority of precipitation (∼65%) falling in the late summer months [70]. The southern margin of Qinghai Lake is primarily a high, cold grassland meadow at present, changing to shrub meadow above ∼3400 m [23]. The dryer northern and eastern lake margins are dominated by dry steppe vegetation.

The post-glacial history of Qinghai Lake is relatively well known [17,31,34,57,65,66,67,70,71,73,75], although most of these data are derived from sediment cores dating to the Holocene and the shoreline history is still lacking in detail. This is particularly true for lake sequences older than Marine Isotope Stage (MIS) 2 (>22 ^{14}C ka). Multiple shorelines have been recorded between the Holocene high stand, ∼9.5 m above the current lake level, and the highest shoreline, ∼140 m above the present lake [17,51], but their age is unclear. For example, Porter et al. [52] suggest the lake did not exceed ∼3210 m during and after MIS 3, Liu et al. [35] (see also [66]) suggest the lake reached elevations of 100–120 m above that of the present between 13.0 and 12.0 ^{14}C ka, and Zhang et al. [74] report dates on the 140 m shoreline they think indicate the lake reached this level during and after MIS 3 in concert with other megalakes supplied by Qilian Shan rivers. Resolution of this lake history is critical for our purposes since the location of middle Upper Paleolithic sites is largely dependent on identifying the MIS 3 shoreline.

Regardless, it is clear that Qinghai Lake was much reduced and possibly dry during the LGM [31,34,70]. Following this prolonged period of aridity, lake level fluctuations reflect millennial-scale climate cycles most likely related to the Dansgaard/Oeschger periodicities recognized throughout much of the world [17,35,70]. Beginning about 15.2 ^{14}C ka, there was a shift from the very cold, dry conditions of the LGM to low amplitude cycling between cold, semi-arid and cool, semi-humid climates. Three cold intervals, 13.4–13.0, 12.0–11.6, and 11.0–10.4 ^{14}C ka, were separated by warmer and more humid periods [35,57]. Intervals of higher lake levels correspond to these warmer periods [34,70]. Pollen in lake cores [19,33,35,56,57] suggest shifts in the lower elevation plant communities from dry, steppe vegetation characterized by open brush communities of *Artemisia*, *Nitraria*, *Ephedra*, and Chenopodiaceae to enhanced grassland meadows are correlated with the cold/dry to cool/wet climate fluctuations. However, these core records represent generalized vegetation from the Qinghai Lake basin as a whole, and, like today, grassland meadows were probably more common along the southern lake margin during even the dryer steppe periods.

3. The Late Upper Paleolithic of Qinghai Lake

Three Late Upper Paleolithic sites composed of five separate occupational events have been investigated and dated along streams feeding the southern margin of Qinghai Lake. We conducted small test excavations at two of these, Heimahe #1 and Jiangxigou #1. A third site, Locality 93–13, has been dated and briefly reported by Porter et al. [52], but was not investigated by us. The three sites are remarkably similar in terms of setting, complexity, and material remains, although they span a depositional interval of more than 1500 years between ∼12.5 and 11.0 ^{14}C ka. Other dates in the range of 12–15 ^{14}C ka on charcoal lenses reported as part of geomorphological investigations [67,71] may also represent similar archaeological deposits.

3.1. Heimahe #1

Heimahe #1 consists of an isolated hearth and associated use surface situated at an elevation of ∼3210 m a.s.l. along the Black Horse River (i.e., Heimahe) on the southwestern margin of Qinghai Lake (Fig. 2). Here, the small stream meanders through older deltaic alluvium, shoreline sands and gravels, and aeolian sands and silts winnowed from these coarser materials after the lake withdrew from higher elevations. The hearth overlies basal coarse alluvial sands, gravels and cobbles within an "island" of this stratified aeolian sandy loess isolated by the modern meanders. A number of temporarily stabilized surfaces are present in the 3.5 m thick aeolian island, particularly in the lower third of the depositional sequence, and a distinct but weakly developed paleosol is visually evident at the mid-point in the loess sequence (Fig. 3). This paleosol is chronologically constrained by several radiocarbon dates below it (Table 1) that limit the age to younger than about 12,500 Cal yr BP, and an OSL sample taken directly above the paleosol of 11,590 ± 1130 Cal yr BP (UIC-1567). We interpret this soil to represent a brief period just prior to the Younger Dryas, when deposition of loess and sands was reduced, surfaces were moderately stable, though probably slowly accretionary, and vegetation cover was sufficiently developed to promote accumulation of organics in a developing soil. The soil is possibly correlative with the "upper paleosol" in the latest Pleistocene/early Holocene loess in the

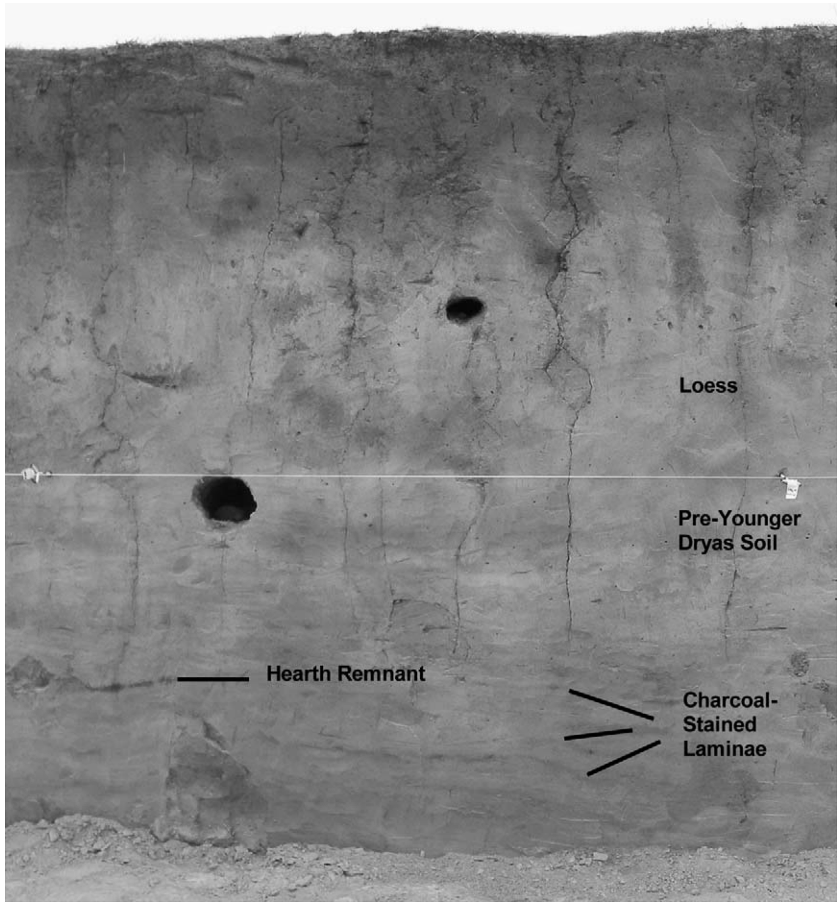

Fig. 3. Heimahe #1 soil profile showing relative position of Holocene soil and charcoal stained laminae. The cultural surface is the uppermost marked laminae. Pins are 2 m apart.

Qinghai Lake Basin [52] and the Baxie paleosol of An et al. [6] (see also [41]).

Four briefly stabilized surfaces are easily recognized by the presence of charcoal stringers on their surfaces. In plan view, these intermittent charcoal lenses have the appearance of burned and collapsed brushy shrubs, suggesting they are a product of range fires. Whether or not these fires are related to occupations by human foragers is difficult to tell from the limited exposures we examined. The only surface with recognizably cultural materials is that associated with the isolated hearth, but it is possible the charcoal on the other surfaces is related to cultural features now eroded away. A charcoal fragment in a loess block encased in fluvial sands at the base of the depositional sequence suggests there may have been an earlier, fifth range fire surface. These surfaces are vertically within 10–15 cm of one another and appear to have been deposited relatively quickly within a space of ~500–600 years.

Chronological controls for the deposition of the surfaces are provided by seven ^{14}C age estimates derived from charcoal samples (Table 1). These age estimates suggest ~70–80 cm of sandy loess containing briefly stabilized surfaces was deposited between ~11.3–10.7 ^{14}C ka, supporting luminescence derived age assessments of ~10,700 ^{14}C yr BP (12,700 ± 100 Cal yr BP) for a loess sequence just east of Heimahe [52]. The isolated charcoal fragment in the encased loess block is slightly out of place, chronologically, but may have been contaminated by stream flow. The three dates from the cultural surface are derived from *Populus* sp. charcoal from the hearth (beta 149998), charcoal from an adjacent mass of fire-cracked rock, ash, and charcoal apparently raked from the fire (beta 169902), and charcoal on the same surface about 4 m west of the hearth (beta 169901). These age estimates are very consistent and, when averaged, indicate the site was occupied about 11,116 ± 24 ^{14}C yr BP (12,940–13,100 Cal yr BP).

The primary cultural feature at the site consists of an isolated hearth with a surrounding ash- and charcoal-stained use surface. The hearth was first identified in the exposed face of a sheep corral excavated into the loess. We examined

Table 1
Radiocarbon age estimates from Heimahe #1

Feature	^{14}C yr BP	Cal yr BP[a]	Lab number	Material
Surface 4	10670 ± 60	12410–12840	beta 194542	Charcoal
	10850 ± 50	12830–12900	beta 169903	Charcoal
Surface 3 (cultural)	11070 ± 40	12910–13150	beta 149998	Charcoal
	11140 ± 50	12930–13150	beta 169902	Charcoal
	11160 ± 50	12940–13170	beta 169901	Charcoal
Surface 2	11480 ± 60	13220–13440	beta 194545	Charcoal
Surface 1	11220 ± 50	12990–13230	beta 194544	Charcoal
Encased loess block	11040 ± 70	12870–13090	beta 194543	Charcoal

[a] At 2σ using Calib5.0.2 [53,62].

a part of this site by straightening the curved corral margin and exposing a narrow 2 × 7 m hemispherically shaped portion of the use surface (Fig. 4). The remaining part of the exposed feature consists of a simple 1.2 m diameter unprepared hearth laid directly on the stabilized loess surface. Whole and heat-shattered granite and diorite stream cobbles overlie charcoal and ash. A secondary concentration of fire-cracked stream cobbles, mixed with charcoal and ash, is centered ∼1.0 m south of the hearth. It appears to represent materials raked from the original fire, as the underlying surface is unoxidized and it contains numerous unburned artifacts. Surface smears of charcoal and ash feather out ∼ 5 m south and ∼2 m west and north of the main hearth. There is no evidence of a structure or brush enclosure on the exposed surface.

Artifacts on this use surface are restricted to an area within 1.8 m of the fire hearth. These include a concentration of bifacial thinning flakes and a quartzite core centered about 50 cm northwest of the hearth, two microblade fragments found 80 cm southwest of the secondary heat-fractured rock concentration, a bifacially worked slate scraper and a ground stone cobble within the secondary concentration itself, and fragmentary bone splinters in and around the hearth. Grinding on a flat surface of the cobble fragment (the remaining portion was lost during corral construction) is pronounced, but the small, 10.9 × 4.2 cm grinding surface suggests it was used for something other than processing seeds or other foodstuffs. Striations and grooves on the surface suggest the implement may have been used to smooth bone or wooden tools, although it may also have been used as an anvil upon which bones were shattered for marrow extraction and degreasing.

Numerous fragmentary bone specimens were collected from the hearth, from immediately above the occupational surface and from scrapes of the surface itself. The majority of these ($n = 48$) are very small bone splinters that are too fragmentary to firmly attribute to a particular element or mammal size, but most appear to be from a medium-sized mammal. Twenty bone splinters, five of which were recovered in a flotation sample from the hearth, are burned or calcined. Six specimens, including two radii and a femur, come from long-bone elements of a mid-sized ungulate, possibly a gazelle. Three of these have impact fractures. Two calcined scapular fragments from a small mammal were also recovered. Two of the long-bone fragments, including one of the radii, are burned. All of the bone from the site appears to have been broken and shattered for marrow extraction and possibly for degreasing. Seven 0.7 mm-thick eggshell fragments from hen/duck-sized eggs were recovered from the occupational surface. Flotation samples produced no evidence of seed processing or geophyte use.

The limited cultural features and small number and diversity of artifacts suggest that Heimahe #1 represents a short-term, single visit foraging camp occupied by a small group. Subsistence focus seems to have been on the procurement and processing of a gazelle-sized ungulate, a small, unidentified mammal, and possibly on egg collecting. The hearth appears to have been used primarily to heat stream cobbles, possibly for use as boiling stones. The lithic industry includes both microblades and bifacially worked tools. Ground stone, while present, seems to represent tool production rather than food processing.

3.2. Jiangxigou #1

Jiangxigou #1 consists of two simple, stratigraphically separate isolated hearths, in cross-bedded aeolian sand on a wave-cut platform associated with the highest paleoshoreline of Qinghai Lake, ∼3330 m a.s.l. (Fig. 2). The small dune rests on coarse dissected deltaic deposits adjacent the small but perennial Jiangxigou stream, and lies at the juncture of a narrow, steep canyon and the head of an alluvial fan (Fig. 5). The aeolian sand in the dune appears to have been winnowed from the exposed sands and gravels. The Qinghai Nan Shan rise sharply immediately south of the site. To the north, the fan delta grades ∼4.5 km to the modern shores of Qinghai Lake.

Our investigation of the upper northernmost hearth was limited to cleaning the exposed dune profile, mapping and describing the cultural material in that face, and sampling the cultural surface in the dune face. The simple isolated hearth was laid directly on a temporarily stabilized dune surface, with little or no preparation. The hearth surface in the cross-bedded sand is ∼35 cm below the top of the dune and at least 2 m above its base (the bottom of the dune is obscured). These coarser dune sands underlie a ∼1 m thick loess cap. A relatively well-developed paleosol occurs in the lower 1/3–1/2 of the overlying loess.

Not much is left of the hearth, and what remains consists only of a short 50 cm long, 2 cm thick lens of charcoal-stained sand with no underlying fire-reddening. Thus, what remains may represent a secondary concentration raked from a true hearth that may have eroded away. An indistinct use surface

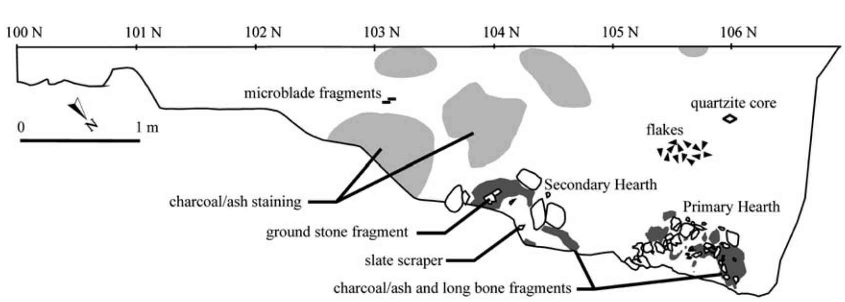

Fig. 4. Plan map of Heimahe #1 use surface.

Fig. 5. Loess capped dune at Jiangxigou #1 showing both the upper hearth remnant to the left and the lower hearth and associated use surface to the right.

can be traced less than 1 m on either side of the exposed hearth. Two granite cobbles (~5 and 12 cm diameter) occur northwest of the hearth on the same surface, 35 and 75 cm away. Two pieces of microdebitage related to microblade production were recovered from the hearth. A complete microblade and two mid-section fragments of long bones from a gazelle-sized animal were recovered from the face of the aeolian sand 5 m east of the hearth. These were recovered from approximately the same level but could not be directly associated with the hearth surface. Charcoal from the hearth dates to 12,420 ± 50 ^{14}C yr BP (14,160–14,830 Cal yr BP; beta 149997). Although little remains of the cultural deposition, it appears that there was little to start with and that the hearth represents a single, short-term visit by a small foraging party.

The other simple hearth consists of a concentration of stream cobbles, broken and burned bone, and charcoal centered on a ~3.5 m diameter use surface formed on a relatively flat-lying dune laminae ~55 cm below and ~13 m east of the upper hearth remnant (Fig. 5). To examine the nature of the hearth and create a mappable profile on the dune face while preserving the main occupational area for future study, an irregular 60 × 110 cm area of this use surface was exposed along the margin of this hearth by excavating an irregularity in the dune profile (Fig. 6). Charcoal on this surface, possibly derived from cinquefoil (*Potentilla* sp.), is concentrated in a 65 cm diameter area. Charcoal and ash staining can be traced 2.5 m west-southwest and 1.5 m east-southeast along the dune face from the center of this concentration. Charcoal in this area of concentration averages 1.0 cm thick, but the surface below the concentration is not oxidized, there is little ash, the charcoal is somewhat discontinuous, and some of the associated cobbles overlie broken bone and lithic debris (Fig. 7). This all suggests the concentration represents a secondary hearth feature consisting of material raked from the primary hearth. This hearth appears to still exist within the unexcavated dune deposits, as the density of charcoal and artifacts increases in that direction.

Charcoal from the hearth produced an age estimate of 12,470 ± 50 ^{14}C yr BP (14,200–14,920 Cal yr BP; beta 208338). This is marginally older than the age estimate for the upper hearth, and is thus consistent with its stratigraphically lower position. However, given the nature of the dune setting in which the hearths are found, the occupations they represent could have occurred within a matter of a few years or less.

A comparatively large array of broken and burned bone fragments was recovered from this small excavation area. Much of this faunal material consists of small fragments of cancellous bone suggesting the possibility it may be associated with boiling and degreasing of a variety of skeletal elements.

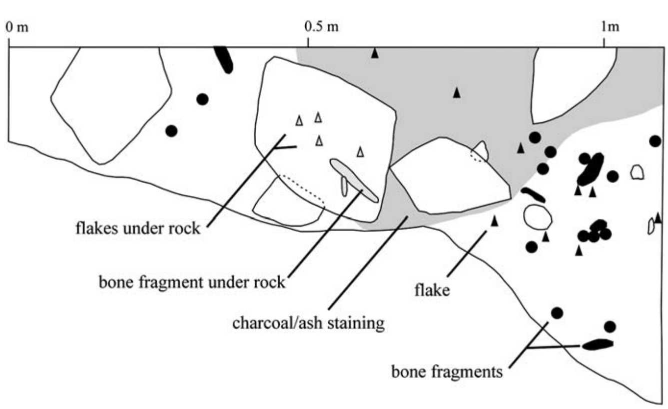

Fig. 6. Plan map of the partially exposed lower hearth and associated use surface at Jiangxigou #1.

Fig. 7. Close-up view of charcoal, bone, and lithic material underlying large stream cobbles on the lower use surface at Jiangxigou #1. The splintered bone is typical of faunal remains associated with the Qinghai Lake hearths.

However, while some small fire-cracked rock fragments were present, four of the granite cobbles were quite large (to 25 cm diameter) and appear to be unburned. These seem rather too large to have been used as boiling stones, but may have been used to extract marrow.

A total of 107 lithic specimens were recovered from in situ contexts in and around the lower hearth. The majority of these specimens ($n = 78$) consist of a fine-grained, black metamorphic rock, followed by a medium-grained, pink granitic rock ($n = 20$) and a few specimens ($n = 9$) of reddish-brown chert. All of the specimens are classified as lithic artifacts, based on the presence of at least two attributes related to direct percussion flaking. We mention this, in part, because granite is an atypical raw material upon which to base a flaked stone technology. The sources of the black metamorphic stone and cryptocrystalline silicate are not known, but the granite is a basement rock in the vicinity of the site.

None of the specimens from Jiangxigou #1 are typologically diagnostic of a specialized core reduction strategy such as a formal microblade core technology, and no formal retouch tools were recovered. All are either general flakes or flake fragments associated with core or tool preparation. It is possible to say, however, that the distribution of flake and flake shatter sizes is strongly suggestive of either preparation of small cores and/or retouching of relatively large flake tools. In particular, the dominance of flakes and flake fragments in the size range >5 mm and <10 mm in minimum linear dimension is consistent with the initial shaping of microblade cores. The absence of formal microblades or debitage characteristic of core rejuvenation argues against later stage core reduction processes directly associated with the exposed portion of the lower hearth.

While we can say with confidence that the granitic flakes and flake fragments meet a minimum definition of flake stone debitage, it is perhaps more reasonable to conclude that these specimens are byproducts of using granitic cobbles either as bashing tools, boiling stones or some combination of the two. Activities at both Heimahe #1 and Jiangxigou #1 appear to have been focused on intensive processing of bone. In both contexts we find heavily battered and fire-cracked rock that we interpret as evidence for pulverizing and boiling of bone to extract grease. As a result, the granitic specimens from the lower hearth might be thermal spalls, although they appear less like classic ‘‘potlid’’ fractures than percussion flakes.

Overall, the lithic collections from Jiangxigou #1 are virtually identical to those from Heimahe #1 both in the generalized character of the technology and consistently small size of the specimens. Heimahe #1 differs from Jiangxigou #1, however, in that it yielded more examples of formal microblades. Given the small excavated sample from Jiangxigou #1, we anticipate that a more extensive representation of such technologies will eventually be identified here as well.

Faunal remains associated with the lower hearth consist of 158 artiodactyl specimens. Judging from the degree of ossification and epiphyseal fusion evident in this material, specimens from both juveniles and adults are represented. Only three of the long-bone splinters are burned, but a cut mark is evident on one specimen and an impact fracture on another. The majority of these specimens (109) are small fragments of cancellous bone. The remainder consists of long bone and rib fragments, 24 of which are from an adult. All of the splintered and broken long-bone elements may have been broken for marrow extraction and some of the spalling of the granite cobbles may be associated with their use in bone breaking. None of the faunal remains are identifiable to species, but appear to derive from gazelle-sized mammals.

Although our examination of the hearths and associated use surfaces at Jiangxigou #1 was limited, the sample and the extensive profile exposure are sufficient to suggest the two hearth features represent short-term stays by small foraging parties. The very modest disturbance to the soft dune sand on which the hearths lie suggests occupation was of both short duration and limited intensity and is consistent with the equally limited diversity of tools. Neither hearth appears to have been reused and both appear to be associated with the processing and consumption of gazelles or small wild sheep.

3.3. Locality 93-13

Locality 93-13 was initially identified and dated in 1993 as part of a geomorphological investigation of Qinghai Lake depositional environments [52]. The site could not be relocated by us 12 years later and may have been cut away by stream action in the interval. It is mapped as being in the vicinity of Jiangxigou #1 and is of the same approximate age, but differing sedimentary contexts, together with photo imagery, suggest they are different sites. From original field notes (S. Porter, 2005 personal communication), the site apparently consists of two stratigraphically separate isolated hearths in sandy alluvium cut by a small tributary of Qinghai Lake. The site is mapped at an elevation of ~3310 m a.s.l. on an alluvial fan near Jiangxigou #1 ([52], Fig. 1). Alluvium at the site is part of a bajada fan complex formed by the many small streams along the narrow alluvial plain between the Qinghai Nan Shan and the southern lake margin. The ~2 m thick sandy alluvium overlies coarser colluvial materials and underlies ~1.5 m of late glacial and post-glacial loess. A relatively well-defined paleosol is formed between the loess and the underlying alluvium (Fig. 8).

The lowest hearth is 1.4 m below the top of the sandy alluvium and consists of a ~1.7 m long lens of charcoal and fire-cracked stream cobbles. Images of the hearth suggest there is little or no oxidation below this concentration and it represents material raked from a true hearth now either eroded away or still within the stream bank. Charcoal from the hearth dates to 12,420 ± 120 (AA-12319) ^{14}C yr BP (13,975–15058 Cal yr BP). The upper hearth is 20 cm below the surface of the sandy alluvium and consists of a ~2.1 m long exposure of intermittent charcoal concentration and heat fractured granite stream cobbles (Fig. 8). In images of the site the alluvium below this surface appears to be locally oxidized, suggesting it represents a small hearth surrounded by a use surface covered with material raked from the hearth. Charcoal from the hearth dates to 12,370 ± 90 (AA-12318) ^{14}C yr BP (14,047–14,854

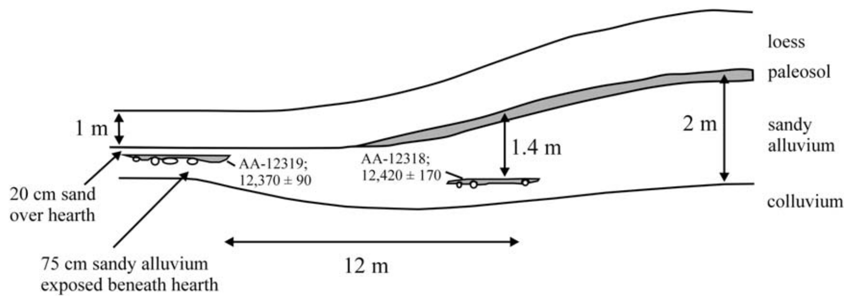

Fig. 8. Locality 93-13 cross-section (image courtesy S. Porter).

Cal yr BP). Both hearths are the result of simple fires laid directly on the underlying surface with little or no preparation. No associated cultural material was identified during the geomorphological investigations.

3.4. Synthesis

Five separate occupations at the three Qinghai Lake sites suggest Late Paleolithic populations on the northern Tibetan Plateau margin employed a very consistent foraging and settlement strategy. The isolated hearths around which the five occupations centered are all the result of simple fires laid directly on the ground surface. The primary purpose seems to have been the heating of 10–20 cm diameter stream cobbles. These heated rocks appear more likely to have been used as boiling stones rather than in earth ovens in that the size of the hearths is limited (~1.5 m average diameter) and there is nothing to indicate they were covered. These boiling episodes, if that is what they were, were apparently rather brief as experimental data suggest boiling stones often begin to shatter much more completely after only 2–3 reheating episodes [24,28,50]. There is no evidence of even temporary structures at the sites and the surrounding use surfaces are ephemeral and recognizable only a few meters around the hearths. Associated artifacts are limited. The lithic technology includes both microlithic and bifacially worked tools. Raw material consists of locally available chert/chalcedony, quartzite, and shale. Ground stone is adjacent only one of the six hearths and the single specimen appears to have been used in tool manufacturing rather than food processing. Foraging appears to have focused on hunting of small ungulates, possibly gazelles and/or wild sheep, and other small game.

The splintered long bone at the sites, together with the evidence of rock heating, suggests a primary activity may have been grease and marrow extraction, possibly by boiling in skin or woven bags [43,47,48,60,69]. Splintering bone accelerates the extraction of grease [18] and, hence, reduces the energetic costs involved in the process. Splintering and boiling may also have been involved in the production of bone tools. Boiling not only removes the grease and adhering soft tissue from bone, but also further softens the green bone for ease in tool shaping. Bone tools were widely used in early-to-middle Upper Paleolithic sites [39,44], and are also common in Late Paleolithic sites [4,16,21,26].

The limited amount of bone from the sites makes it difficult to be completely confident that grease extraction was the principal reason for heating cobbles at the Qinghai Lake sites. Munro and Bar-Oz [48], for example, use a negative relationship between percent survivorship and fragmentation of cancellous bone to help identify the extraction of grease from gazelle bones in Middle Eastern Epipaleolithic sites, an approach we cannot employ here due to the modest size of the faunal assemblages and the fact that some elements are derived from juveniles. Moreover, the absence of other skeletal parts may imply limited grease extraction, as boiling makes bone unattractive to animal scavengers and they are less likely to be dragged away [3,32,36,58]. It is also possible the rocks in the hearths were being heated, in part, to prolong the energetic effects of limited supplies of fuelwood. As Thoms [63:93] notes, "rock heating elements also appear to be characteristic of fuel-poor environments where it is often necessary to capture heat from flames generated by small, fast-burning fuel." The heat captured by rocks can enhance a longer cooking process using less fuel, and may provide additional warmth through cold nights.

The limited array of tools and food residue at the sites suggests occupation by a very small group, for a very short, perhaps only overnight, stay. While some short-term forager sites are characterized by dispersed camps occupied simultaneously by multiple camp groups [30], careful examination of the extensive exposed profiles around the Qinghai Lake sites suggest they were simple camps occupied by a single small group. This suggests, in turn, that the Late Upper Paleolithic foragers along the margin of Qinghai Lake were operating from residential bases located elsewhere. These were likely at lower elevations, such as areas below 2400 m along the Yellow and Xining rivers less than 75 km from the eastern margin of the lake. However, we cannot rule out the possibility that residential sites occur elsewhere in the lake basin. Despite the paucity of subsistence data from the sites and the possibility these logistical camps may have had other uses, the apparent boiling of bone for grease suggests the small foraging groups who occupied the sites had a relatively broad diet. Experimental evidence for caloric return rates associated with bone boiling [36,37,38,54] indicates that they are much lower than those associated with the collection of many kinds of plants and animals. If these foragers were choosing to extract grease rather than searching for and collecting higher ranked resources, then foraging theory [15,29,61] suggests such resources were relatively scarce. However, grease extraction has other virtues beyond energetic efficiency and raw caloric values, as fats are particularly important in the diet, especially for nursing mothers and children [15,37]. Moreover, grease can be preserved for much longer periods than even cooked or dried meat, and can help extend the use-life of meat when mixed into pemmican or similar products [64].

4. Discussion

We have hypothesized that the desert margins of the Qinghai-Tibetan Plateau were first colonized by early Upper Paleolithic hunter-gatherer groups, who first ventured into the desert regions surrounding the Qinghai-Tibetan Plateau during MIS 3 [12], when lakes were at their highest stands of the late Pleistocene and steppe environments supported large wild ungulate populations [11]. These groups arrived perhaps as early as 40 ^{14}C yr ka [9,10] and certainly by 29–25 ^{14}C yr ka [39], and were engaged in a high mobility foraging strategy that focused on medium- and large-sized game and employed a unique type of stone technology based on large stone blades. As a result of the relatively uniform abundance of resources on these steppe landscapes, early Upper Paleolithic hunter-gatherers were able to move frequently from one lake basin to another as high-ranked resources became locally depressed. Populations following such a logistical foraging strategy may thus have first reached the middle elevation step (3000–4000 m a.s.l.) incidentally around 25 ^{14}C yr ka.

We have further hypothesized that the second stage in the occupation of the plateau occurred during the transition from MIS 3 to the LGM (MIS 2), when changes in the fundamental character of resource distributions likely had a dramatic impact on the organization of hunter-gatherer adaptations. Around 24–23 ^{14}C yr ka, MIS 3 lakes started to retreat and desert environments began to replace steppe environments on the Qinghai-Tibetan Plateau and in the surrounding source areas of the plateau. Both vegetation and game likely concentrated around the receding lakes in each basin, producing a patchy distribution of resources. Simulation models indicate that a high-mobility foraging strategy becomes increasingly untenable as the patchiness of resource distributions increases and correlations in the quality of adjacent resource patches decreases. Theory [59,61,69] suggests that small hunter-gatherer groups operating under increasingly patchy landscape conditions on the middle elevation step of the plateau would have to (1) increase their diet breadth to incorporate lower ranked resources concentrated around the receding lakes such as small, fast game or plant resources with higher processing costs, and/or (2) engage in more systematic seasonal strategies of landscape use (i.e., non-random walk).

The degree to which such changes in foraging behavior were accomplished may have determined if it was possible for occasional specialized foraging parties operating from lower elevation residential bases to have reached the highest levels of the Qinghai-Tibetan Plateau during this second stage, but also if populations on the middle step managed to survive the LGM (22–18 ^{14}C yr ka). Even during the height of the LGM, water availability, and consequently biological productivity, would have been somewhat greater on the high elevation step of the plateau compared with both the middle elevation step represented by the Qarhan, Qaidam and Qinghai Lake basins and the low elevation source areas represented by the deserts of northwest China. These middle elevation basins and low elevation deserts are all within the rain shadow of the high plateau and receive limited precipitation from the Indian and Southeast Asian summer monsoon [8,40,68]. Hunter-gatherer groups confronted with receding middle elevation lake basins at the onset of the LGM (23–22 ^{14}C yr ka) may have been forced to exploit the high elevation step of the Qinghai-Tibetan Plateau at least seasonally when lakes were completely desiccated during the height of the LGM (20–18 ^{14}C yr ka). Post-LGM environments in greater northeast Asia remained patchy in terms of both food and water resource distributions, suggesting that when late Upper Paleolithic hunter-gatherer groups finally colonized the plateau after the LGM (<18 ^{14}C yr ka) they would not have been able to adopt the high mobility foraging strategy employed by early Upper Paleolithic groups. Rather, structured seasonal exploitation of different patches with longer residence times on the various elevation steps may have been a prerequisite of successful occupation.

We can test some aspects of this model using evidence from our work around Qinghai Lake, together with limited survey data from other middle step lake basins and the plateau itself [2,12]. Possible pre-LGM sites on the middle and upper steps of the plateau identified so far consist of surface lithic scatters with relatively few artifacts. A few sites on lake shorelines on the northern margin of the plateau were apparently occupied after the lakes reached their MIS 3 maximum, but before desiccation of the LGM and hence likely date to 25–20 ^{14}C yr ka [12]. Most sites are only typologically dated to ~30–20 ^{14}C yr ka and a controlled chronology is thus limited. They are, however, widely scattered over the plateau [2,5,11,12,25,27,72]. As Aldenderfer and Zhang [2] note, all these sites are characterized by core-and-blade technology with both large blade tools and tools made on simple flakes. Assessment of the subsistence strategy employed by these pre-LGM groups must be correspondingly tentative, but the limited diversity and quantity of tools in these sites suggests they were produced by small foraging groups operating from larger residential bases, likely at lower elevations. The presence of such sites in the central and western plateau, 3–400 km from lower elevation plateau margins, might argue against such a model and perhaps suggest a more permanent occupation. However, a variety of evidence from eastern and central Europe (e.g. [20]) indicates that toolstone was transported 3–400 km during the Middle Paleolithic and perhaps even longer distances during the Upper Paleolithic, suggesting similar distances were likely within the range of pre-LGM foraging groups in Tibet as well.

If so, the foraging behavior of hunter-gatherers on the northern margin of the Qinghai-Tibetan Plateau was very similar immediately before and after the LGM. That is, small, mobile foraging parties operating from lower elevation residential bases occupied short-term foraging camps around lake margins on the middle and highest steps of the plateau. Whether these lake margin habitats were occupied as a result of a particular foraging strategy, because of the localized availability of yak dung (the principal fuel source on the plateau), or a combination of the two is as yet unknown. While the overall diet breadth appears to have been relatively broad, the subsistence focus at any one site was limited. This, in turn, implies that human foragers may not have become fully adapted to these high elevation environments until after the transition to the Holocene. It is clear that these groups employed technologies suitable for temporary occupation of the plateau, but adaptive strategies necessary for the year-round ''colonization'' of the plateau were not yet in place. It may be that such a fully adapted occupation did not take place until the development of pastoralist societies who could bring many of the resources on which they were dependent with them to the Tibetan high country.

In sum, some aspects of our original model for the occupation of the Qinghai-Tibetan Plateau may require modification. We still favor a three-step model, but based on what we now know, we suggest (1) an initial stage occupation of lower elevations 40–25 ^{14}C ka by highly mobile foragers following a logistical mobility pattern and focused on the collection of high ranked resources, (2) a second stage dating to immediately prior to and after the LGM (25–10 ^{14}C ka) during which broad-spectrum foragers operating from more permanent home bases along the lower elevation margins of the plateau occupied temporary, short-term, special purpose foraging sites on the middle and upper steps of the plateau, and (3) full-scale, year-round occupation of the upper regions of the plateau by early Neolithic pastoralists.

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