



OPEN Radiocarbon chronology and settlement patterns in the Bronze Age of the Qaidam Basin, Northwestern China

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Prehistoric settlement patterns on the Tibetan Plateau, particularly in the Qaidam Basin, have drawn significant scholarly interest. Yet, limited data have hindered a comprehensive understanding the Bronze Age chronology and landscape exploitation in this region. This paper presents 24 newly obtained radiocarbon dates from eight archaeological sites within the Qaidam Basin on the Tibetan Plateau. Integrated with existing ¹⁴C data and spatial analysis, these findings reveal an overall continuous occupation of the basin from ca. 3600–2500 calBP, with a gradual shift from expansive lowland settlements to smaller, ephemeral high-altitude structures, identified around 3350 calBP. This change is consistent with demonstrated periods of climate degradation which likely drove strategic adaptations in landscape management and subsistence methods. Overall, this research not only establishes a more robust chronology for the Qaidam Basin's Bronze Age, but also advances the discussion on human-environment interactions in high-altitude areas during late prehistory.

Keywords Qaidam Basin, Bronze age, Radiocarbon dating, Nuomuhong culture, Agro-pastoralism, Settlement patterns

The prehistoric human expansion on the Tibetan Plateau has drawn significant academic interest in recent years^{1,2,3,4,5}. Archaeological findings have revealed human presence in the northern and central Tibetan Plateau dating back at least 30,000 years^{6,7}. More than a century of archaeological work in China's Qinghai and Gansu regions has helped establish a timeline for the gradual occupation and permanent settlement of the northeastern Tibetan Plateau by Neolithic communities around 6000 calBP and Early Bronze Age groups around 4200 calBP^{8,9,10,11}. This research has been instrumental in framing our understanding of the cultural development of prehistoric populations across this expansive area.

In 1959, excavations at Dalitaliha (also referred to as Talitaliha) on the southeastern edge of the Qaidam Basin uncovered a Bronze Age village, which had presumably been inhabited by communities engaged in wheat agriculture, sheep, cattle, and horse husbandry, as well as hunting. This cultural assemblage was assigned to the Nuomuhong Culture^{12,13}. Over the following thirty years, archaeologists discovered more than forty sites linked to this cultural phenomenon near the oases at the basin's edge¹⁴. More recent investigations in the area have led to a preliminary chronology for the Nuomuhong Culture between 3400 and 2500 calBP^{15,16}. By combining ten radiocarbon dates with studies of subsistence patterns from botanical and faunal remains,¹⁵ suggest that the Nuomuhong population achieved permanent settlement in the Qaidam Basin during the second half of the fourth millennium BP, by adapting to the harsh environmental conditions through a cold-resistant agro-pastoralist economy. Similar findings were reported by^{3,17} in the areas surrounding the Qaidam Basin, the southern and north-eastern Plateau, respectively.

The Bronze Age chronology of the Qaidam Basin, however, still relies on a limited dataset of radiocarbon dates from a few sites, resulting in a fragmentary picture of the region's historical development. Additionally, there is a lack of detailed understanding concerning the nuanced localized transitions in landscape exploitation strategies that facilitated human occupation on the eastern Tibetan Plateau.

To address these gaps, from 2018 to 2020, the School of Cultural Heritage at Northwest University, in collaboration with the Qinghai Provincial Institute of Cultural Relics and Archaeology, conducted annual

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surveys at nine sites in the Qaidam Basin, encompassing both residential and burial areas across diverse ecological settings (Fig. 1). During these surveys, 31 samples were carefully selected for radiocarbon dating. 7 radiocarbon dates from one site (Xiaeryamakebu) have been previously published by¹⁸, while 24 new dates from the remaining 8 sites are presented here for the first time. They were integrated with existing 14 C data to create a more comprehensive chronological framework for the regional Bronze Age. The results were then correlated with spatial distribution data and analyzed alongside artifacts such as pottery, stone tools, and faunal and botanical remains collected during the survey. This comprehensive approach aimed to identify shifts in settlement patterns and changes in human activity within the Qaidam Basin during the Bronze Age.

Study area

The Qaidam Basin, located in the northeastern Tibetan Plateau, is a vast area of relative lowland (ca. 2800–2900 m.a.s.l.) surrounded by towering mountain ranges that rise to over 5000 m.a.s.l. The landscape is diverse but predominantly arid. The name “Qaidam,” meaning “Salt Marshes” in Mongolian, reflects the region’s character, where meltwater from the Altun, Qilian, and Kunlun Mountains forms saline lakes due to the basin’s endorheic nature¹⁹. Scattered oases are typically found where fresh water is accessible from underground sources, mountain-fed rivers, or natural springs²⁰. Historically, nomads who primarily relied on herding and small-scale farming inhabited these areas. Over time, the expansion of the Gobi Desert’s sand dunes has encroached upon much of the basin, leaving only a few piedmont alluvial plains on the southeastern edge suitable for agriculture and animal husbandry. The continued existence of these farming areas is primarily the result of large-scale land reclamation and cultivation efforts initiated in the latter half of the 20th century^{21,22}.

The piedmont zones at the base of the surrounding Kunlun and Qilian Mountains are characterized by alluvial fans—broad, sloping deposits of sediment formed by streams descending from the mountains. There are farmlands of different sizes in these areas, with some sheep husbandry also practiced by the residents of the modern villages²³.

The intermountain valleys are narrow depressions between mountain ranges, which offer sheltered environments with relatively favorable microclimates, protection from harsh winds, and stable water resources. Historical records indicate that these areas have long been home to nomads reliant on herding, a practice that continues today²⁴.

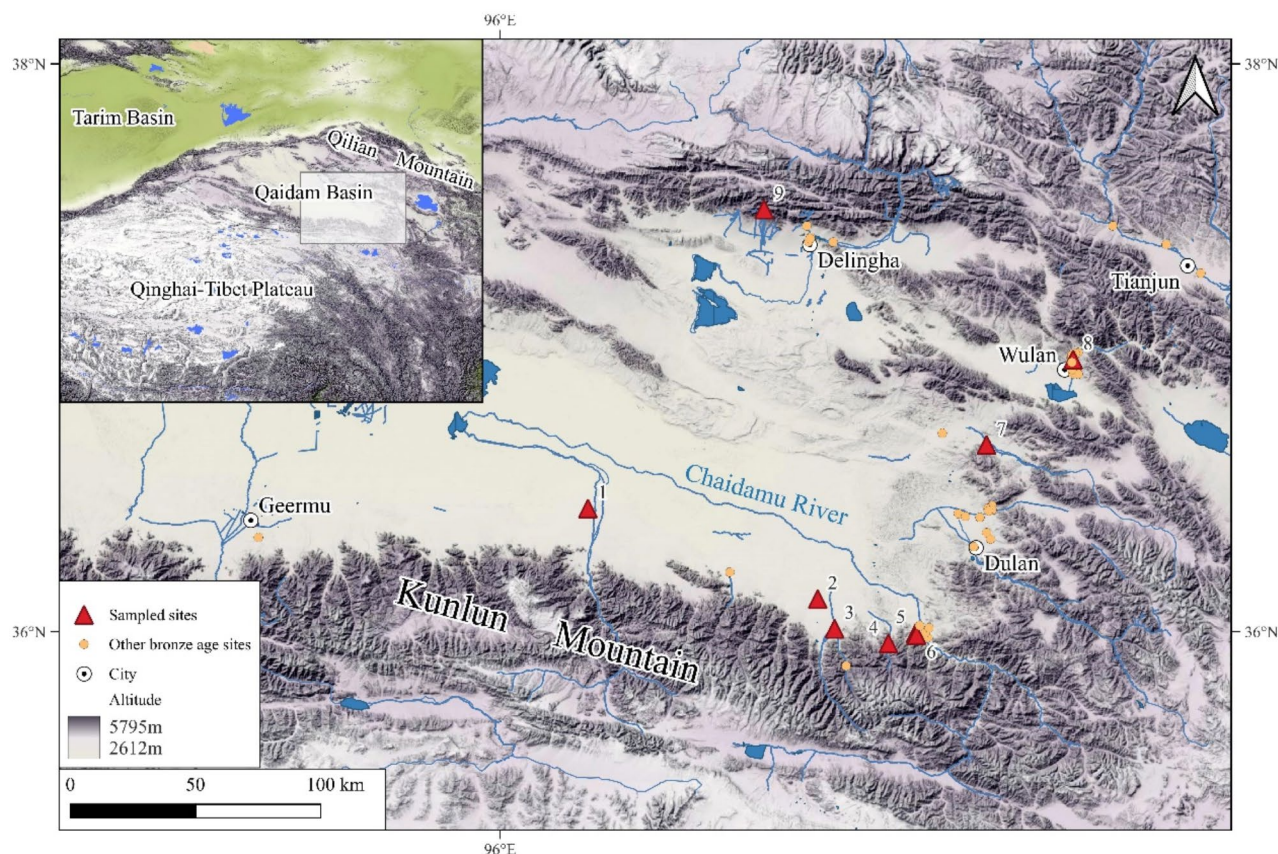


Fig. 1. Map of the Qaidam Basin region, showing the sites sampled during this study and the distribution of other Bronze Age sites in the region: (1) Dalitaliha; (2) Tawendaliha; (3) Xiaeryamakebu; (4) Ke’er; (5) Xiachaikai; (6) Chaixinxinan; (7) Xiachacha; (8) Hongshanzui; (9) Haer-Xierge. The map was created using QGIS (<https://www.osgeo.org/projects/qgis/>).

During the Second National Archaeological Survey of China, a significant number of Bronze Age sites have been identified in the oases, the piedmont region and the intermountain valleys of the Qaidam Basin¹⁴ (Fig. 1). These sites are exclusively associated with the Nuomuhong Culture, which thrived in the region between 3400 and 2500 calBP, making it the sole Bronze Age cultural complex recognized so far in the basin¹⁰.

Result
Spatial distribution and site classification

The spatial distribution analysis included all the 9 sites that were surveyed, which were classified into three categories based on their geographical position and morphology (Table 1).

The edge zone of the piedmont alluvial fan

Located on the gentle surface at the edge of river alluvial fans, these sites are relatively expansive, featuring clusters of buildings with adobe walls that surround central plazas. Tawendaliha (Fig. 1:2) and Dalitaliha (Fig. 1:1), the largest Bronze Age sites found on the southern edge of the Qaidam Basin¹⁴, are characterized by large sandy mounds, formed through human activities. They are covered with numerous naturally washed pebbles and a substantial quantity of pottery fragments. Some graves were also found at these sites (Fig. 2).

The fan apex and valley mouth zone of the piedmont alluvial fan

These sites are situated on river terraces at the mouths of valleys. Here, groups of buildings were constructed with tall stone walls that served as enclosures for the settlements. Likely due to the geographical constraints of the valley mouths, these sites were somewhat smaller in scale compared to the larger settlements located at the edge of the alluvial fans. Representative sites in this area include Xiaeryamakebu (¹⁸; Fig. 1:3) and Hongshanzui (Fig. 1:8). At Xiaeryamakebu, a river divides the residential sector from the burial area. The residential zone contains prominently exposed large stone walls, and sections of earthen walls are visible in the soil's profile. The cemetery includes more than a thousand circular stone burial enclosures. The Hongshanzui site features several large erosion gullies on its surface. This is especially evident in its western part, where numerous pottery fragments and grinding tools were found scattered within the gullies, indicating significant degradation and artifact displacement. The eastern part of the site has well-preserved stone wall structures (Fig. 3).

The intermountain valley zone

In this area, dwellings were constructed on natural small terraces within intermountain river valleys. The sites of Ke'er, Xiachaikai, Chaixinxinan, Xiachacha, and Ha'er-Xierge (Fig. 1: 4–7, 9) are relatively small in scale and situated at higher elevations. Architectural remains on the surface are sparse, with small stone walls built primarily at the entrances, likely for protection, while the surrounding natural gullies served as barriers (Fig. 4).

Sampling

Samples were carefully chosen from different locations in 8 sites and here we present the results of our selection. In Tawendaliha, we examined six profiles (P1–P6) from as many sand mounds to determine the chronological relationship between them and the overall age of the sites. Each profile showed multiple human activity layers, containing animal bones, charcoal, and pottery fragments. Charcoal from the activity layers and one infant urn burial (M2) was sampled for radiocarbon dating (Fig. 2C and E–F). At Dalitaliha, the cultural layer deposits showed similar characteristics. We collected dating samples from the stratified layers in pit profiles P1, P3, P5–P7, located inside and outside the adobe walls in the center and surrounding areas of the site (Fig. 2G–H).

At the Hongshanzui site, located on a terrace at the river valley's mouths, only one layer containing charcoal was identified in the human activity deposits. Charcoal samples were taken from layer P2② (Fig. 3D).

In the intermountain valleys, samples were selected from profiles in the terrace and at the entrance connecting the terrace to the outside. For example, at the Xiachaikai site, samples were taken from the house wall foundations made of mixed adobe and stones on the side of the terrace (Fig. 4D). At Ke'er, where human activity deposits were primarily distributed on the terrace top, we collected one charcoal sample from each of the three profiles in the northern, central, and southern parts of the site (Fig. 4E). Deposits were found on both the

Site name	Location	Area (m ²)	Altitude (m)	Reference in Fig. 1
Dalitaliha	Edge zone of the piedmont alluvial fan	60,000	2,797	1
Tawendaliha	Edge zone of the piedmont alluvial fan	200,000	2,886	2
Xiaeryamakebu*	Fan apex and valley mouth zone of the piedmont alluvial fan	40,000	3,028	3
Hongshanzui	Fan apex and valley mouth zone of the piedmont alluvial fan	25,000	3,047	8
Xiachaikai	Intermountain valley	14,000	3,073	5
Chaixinxinan	Intermountain valley	11,000	3,079	6
Ke'er	Intermountain valley	9,200	3,198	4
Xiachacha	Intermountain valley	1,200	3,172	7
Ha'rxierge	Intermountain valley	2,200	3,734	9

Table 1. Classification of sites in the Qaidam Basin considered in this study. *Radiocarbon dates from Xiaeryamakebu have already been reported in¹⁸.

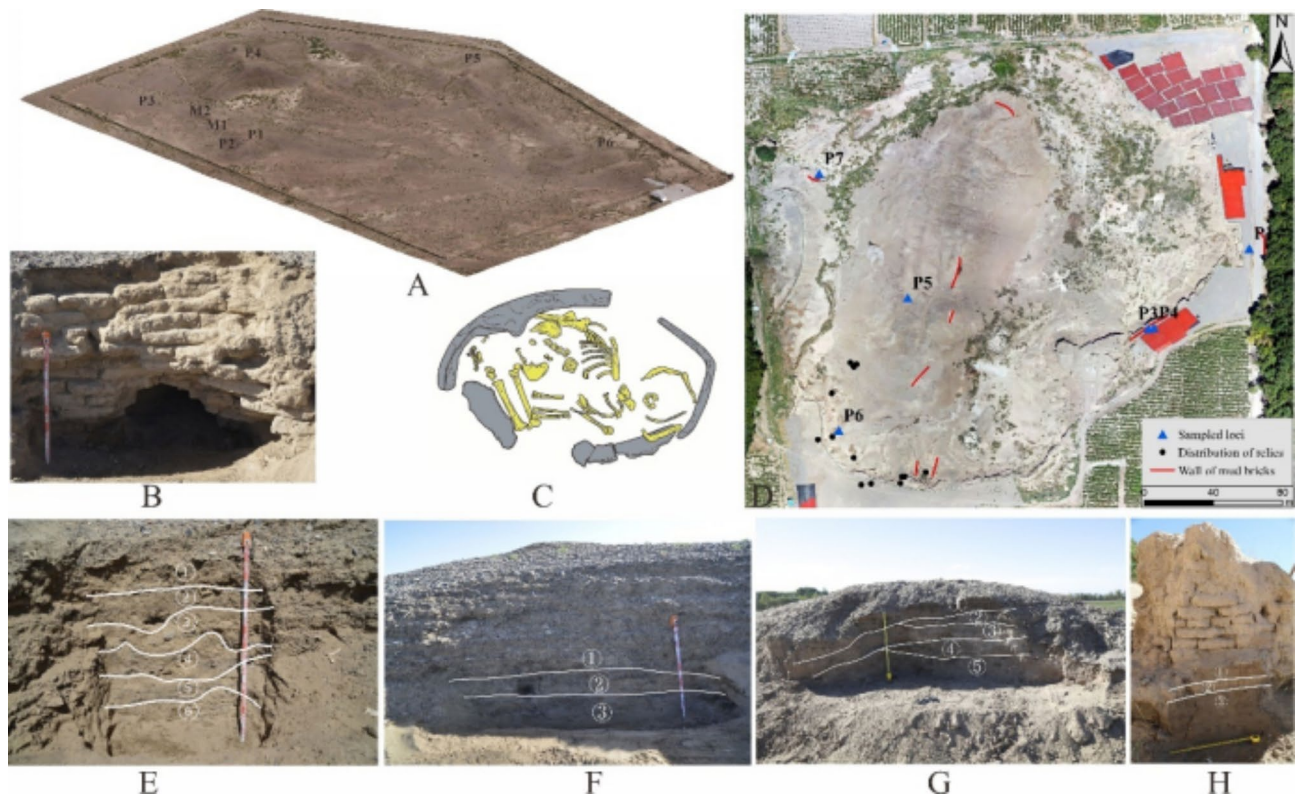


Fig. 2. Tawendaliha and Dalitaliha: (A) Aerial topographic view of Tawendaliha; (B) Mud bricks walls in Tawendaliha; (C) Tomb M2 in Tawendaliha (image created using CorelDraw X8 <https://www.coreldraw.com/en/pages/coreldraw-x8/>); (D) Aerial topographic view of Dalitaliha; (E) Profile P2 in Tawendaliha; (F) Profile P6 in Tawendaliha; (G) Profile P5 in Dalitaliha; (H) Profile P1 in Dalitaliha. Satellite images were taken by Y.H. using a DJI Inspire 2 drone, and modified using QGIS (<https://www.osgeo.org/projects/qgis/>).

terrace and the slope at Chaixinxinan. Samples were collected from profiles in the central and southern parts of the terrace top, as well as from the slope at the terrace's entrance (Fig. 4F).

Radiocarbon dating

24 new radiocarbon dates were generated. They were combined with 17 published data^{3,15,18} and calibrated using OxCal 4.4 and IntCal20 calibration curve^{25,26,27}. 41 dating data points and their calibrated counterparts are presented in detail in Table S1. 38 dates fell within the range of 3600–2500 calBP, while two samples from Dalitaliha (Beta-540261: 4962–4840 calBP and Beta-540264: 427–290 calBP) and one from Ha'er-Xierge (Beta-594456: 4153–3935 calBP) were outliers, and therefore excluded from the subsequent analyses. The consistency in sampling and testing methods for charcoal across all sites suggests that these samples may be contaminations from earlier and later strata at the sites.

We employed the “Sequence” function in OxCal, which organized the 38 data points chronologically from the earliest to the latest (Fig. 5)²⁸. The calibrated dates spanned from approximately 3600–2500 calBP, indicating a sustained period of human activity. We color-coded the results according to geo-ecological zone from which the samples were collected. The result indicated a progressive expansion of human activity, starting at the oases on the piedmont edges, moving up to the terraces, and finally reaching the intermountain valleys (Fig. 5).

Discussion

Chronology of human activity in the Qaidam Basin

24 new calibrated radiocarbon dates, combined with previously published 14 C data, indicate sustained human activity in the Qaidam Basin between ca. 3600–2500 calBP without major cultural disruptions. Cross-referenced analysis of the chronology and spatial distribution of sites suggests that human activity did not, however, develop uniformly across this region (Fig. 5). Rather, there appear to have been a gradual transition from lower to higher altitudes over time, starting from the oasis areas at the edges of piedmont alluvial fans, moving to the terraces, and eventually reaching the intermountain valleys.

To gain deeper insights into the development of Bronze Age settlements in the Qaidam Basin, we analyzed radiocarbon dates from Xiaeryamakebu¹⁸, Tawendaliha, and Dalitaliha using OxCal's “Phase” function in “contiguous”. This approach modeled periods of activity and defined the start and end of the occupation phases at these sites²⁸. The three selected sites not only offered relatively rich dating data, but also featured thick cultural layers, over one meter deep, which included continuous deposits of animal bones, charcoal, and broken pottery

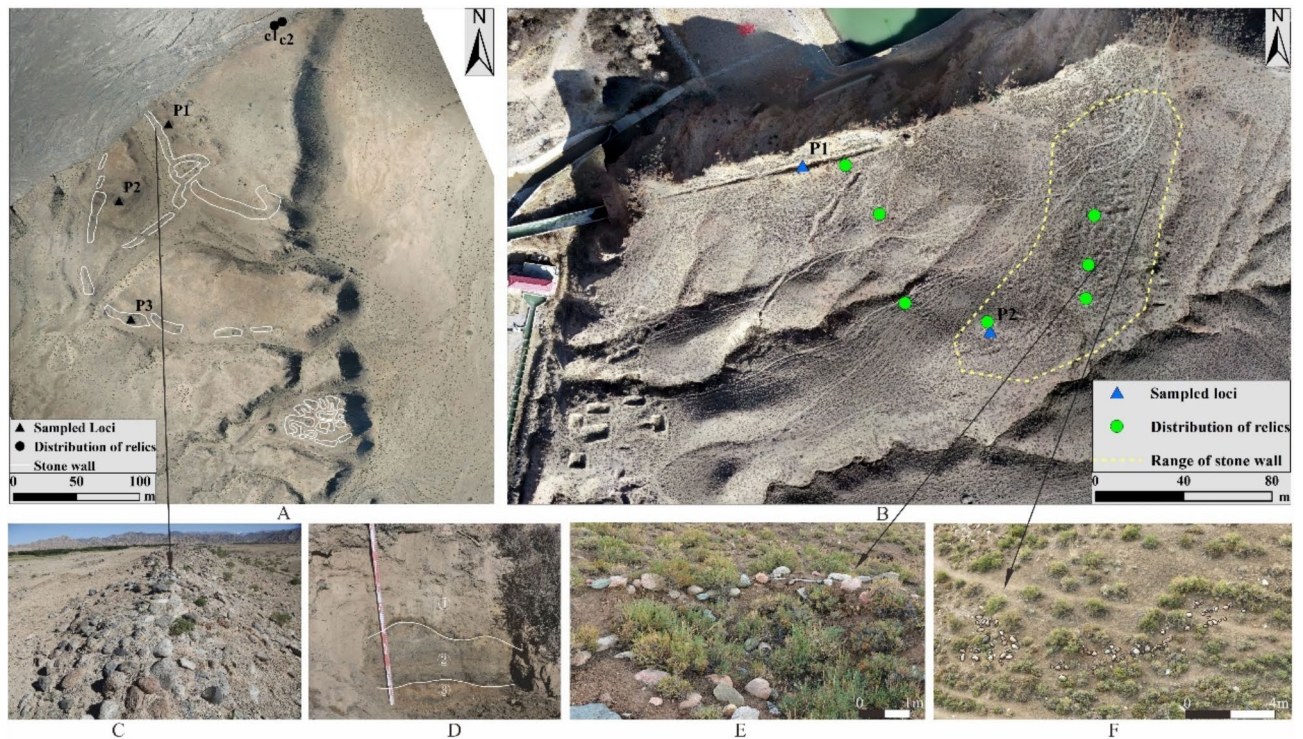


Fig. 3. Xiaeryamakebu and Hongshanzui: (A) Aerial topographic view of Xiaeryamakebu, showing the stone walls; (B) Aerial topographic view of Hongshanzui; (C) Xiaeryamakebu stone wall; (D) Profile P2 in Hongshanzui; (E) Hongshanzui stone house wall; (F) Hongshanzui stone wall. Satellite images were taken by Y.H. using a DJI Inspire 2 drone, and modified using QGIS (<https://www.osgeo.org/projects/qgis/>).

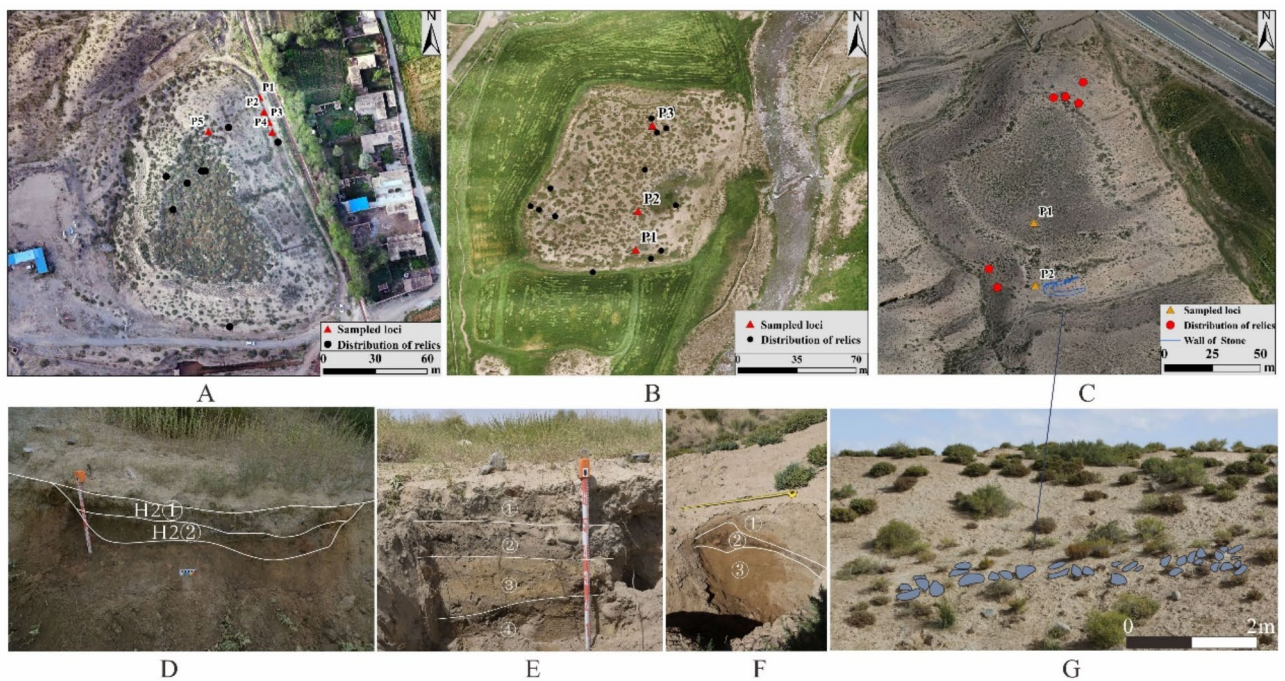


Fig. 4. Xiachaikai, Ke'er and Chaixinxinan: (A) Aerial topographic view of Xiachaikai; (B) Aerial topographic view of Ke'er; (C) Aerial topographic view of Xiachaikai; (D) Profile P2 in Xiachaikai; (E) Profile P2 in Ke'er; (F) Profile P2 in Chaixinxinan; (G) Stone wall in Chaixinxinan. Satellite images were taken by Y.H. using a DJI Inspire 2 drone, and modified using QGIS (<https://www.osgeo.org/projects/qgis/>).

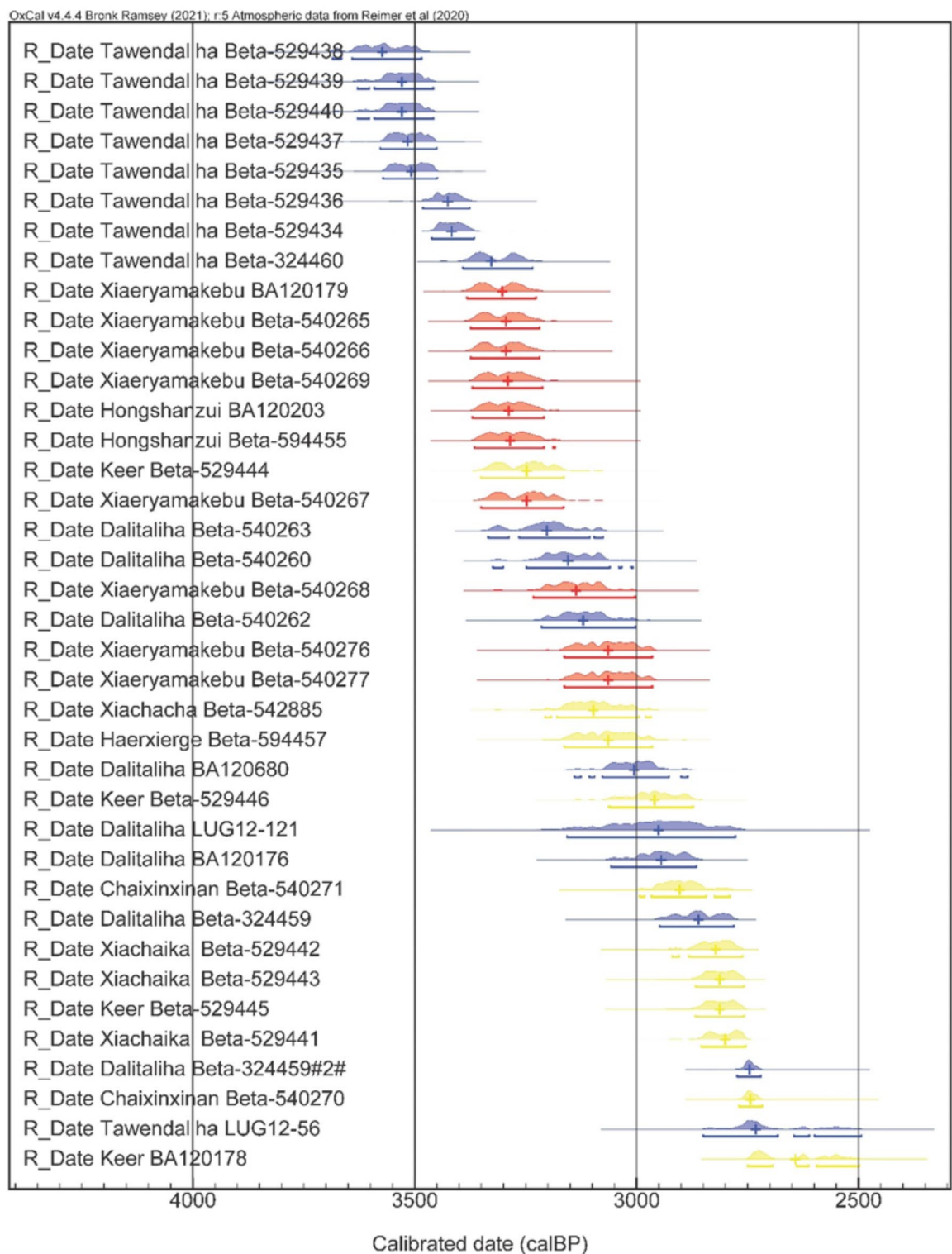


Fig. 5. Multiplot showing AMS 14 C results sorted sequentially. The different colors signal the location of the site: in blue are the sites located in the edge zone of the piedmont alluvial fan; in red are represented the sites in the fan apex and valley mouth zone of the piedmont alluvial fan; the yellow marks the sites situated in the intermountain valley^{25,26,27}.

(Fig. 2E–G). The results established a chronological framework that, along with data from other sites, enhances our understanding of the nuanced transitions in settlement patterns during the Bronze Age of the Qaidam Basin (Fig. 6).

Tawendaliha, located in the oasis area at the edge of the piedmont alluvial fan, represents the earliest settlement with 9 radiocarbon dates. It appears to have been used between 3600–3300 calBP, with Beta-529438 (3686–3483 calBP; median = 3573 calBP) and Beta-324460 (3392–3256 calBP; median = 3328 calBP) representing the start

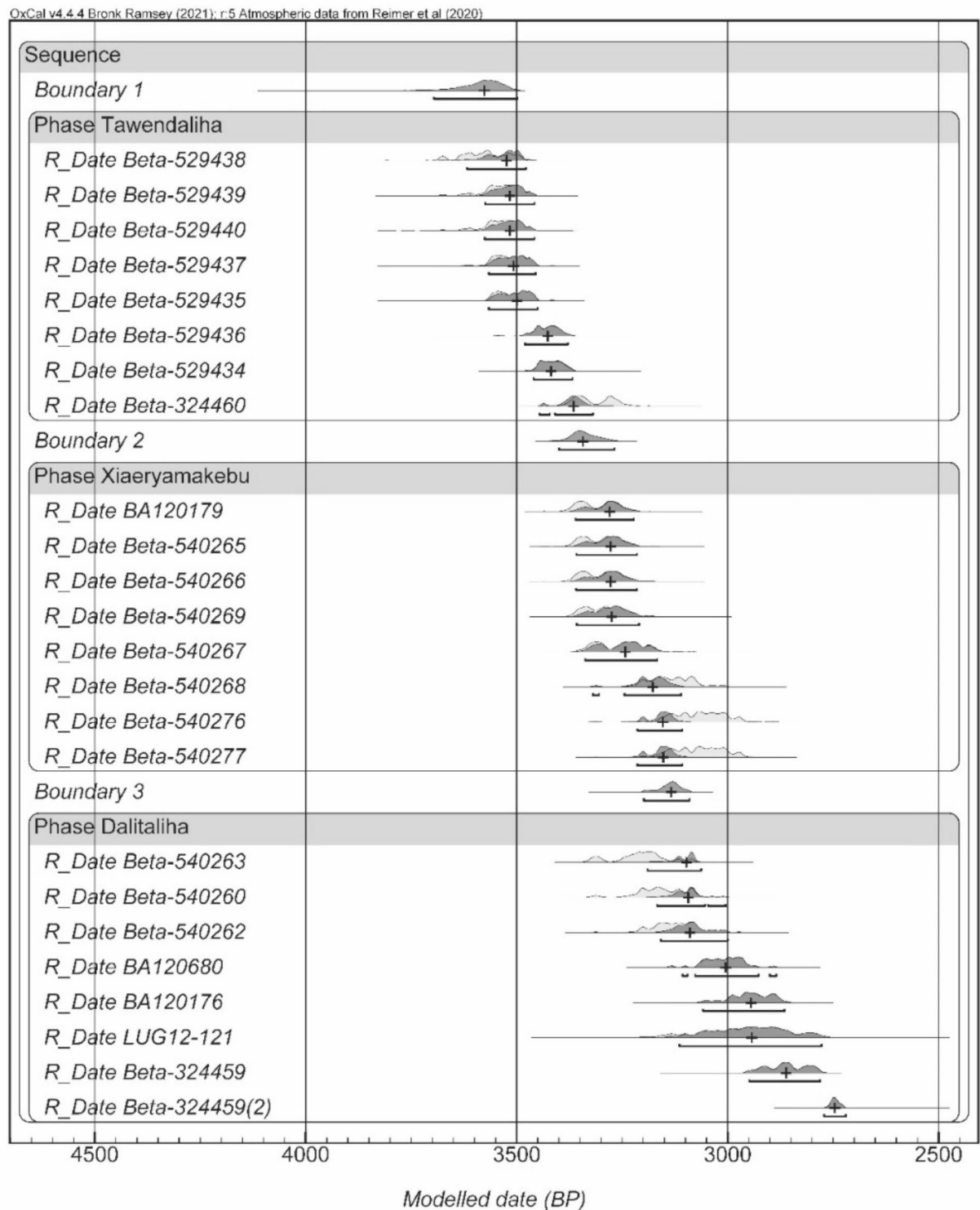


Fig. 6. Calibrated dates from Tawendaliha, Xiaeryamakebu, and Dalitaliha, showing their occupation phases^{25,26}.

and the end of the main phase, respectively. One significantly later, isolated date (LUG12-56: 2848–2492 calBP; median = 2731 calBP) likely marks the site's final stage. As the primary occupation at Tawendaliha ended, the sites of Xiaeryamakebu (BA120179: 3385–3247 calBP; median = 3303 calBP) and Hongshanzui (BA120203: 3365–3217 calBP; median = 3288 BP) emerged on the terrace tops of the piedmont alluvial fan, alongside Ke'er (Beta-529444: 3345–3165 calBP; median = 3248 calBP) in the intermountain valleys. Xiaeryamakebu, with 8 dating data points from residential and burial areas, falls within the range 3300–3050 calBP. At the end of its occupation, Dalitaliha started to be used in the piedmont oasis, with 8 radiocarbon dates concentrating around 3050–2500 calBP. In this period, Ha'er-Xierge, Xiachacha, Xiachaikai and Chaixinxinan appeared in the intermountain valleys.

Settlement pattern and human-environment interaction in the Qaidam Basin during the Bronze Age

The gradual shift in settlement preference from the oasis at the base of the piedmont alluvial fans, up through the terraces, and into the intermountain valleys observed in the Qaidam Basin points at a gradual emergence of new landscape exploitation strategies in the regional Bronze Age. In Northwest China, environmental changes, particularly substantial reductions in precipitation, have historically influenced land use practices, settlement preferences and human mobility^{29,30,31,32}. The delicate ecology of the Tibetan Plateau renders it particularly vulnerable to these climatic variations³³. Historical ice core records^{34,35}, annual precipitation data³⁶, and organic peat analysis³⁷ have identified two distinct cold-dry episodes in the Qaidam Basin around 3400–3200 calBP and 3000–2800 calBP, respectively (Fig. 7). These climatic events coincide with the migration of settlements from the piedmonts to the intermountain valleys, as evidenced by our radiocarbon dating results, indicating a correlation between climatic deterioration and settlement preferences in this region.

Observed variations in the size and type of settlements and architectural structures across three distinct ecological zones in the Qaidam Basin — the edge zone of the piedmont alluvial fan, the fan apex and valley mouth zone, and the intermountain valleys — provide deeper insights into the evolution of regional settlement patterns. Larger settlements, predominantly found at lower altitudes throughout all phases, were characterized by substantial adobe or stone walls and thick cultural layers exceeding one meter (Fig. 2E–G; Table 1). In contrast, the intermountain valleys hosted much smaller occupation sites, typically less than 10,000 square meters, suggesting they accommodated smaller groups. These sites featured small, narrow stone wall foundations at their entrances and generally displayed only a thin ash layer about 0.1–0.2 m thick, indicative of transient human activities (Fig. 4D–G). These findings mirror those at the Kayue cultural site of Baotiazang in eastern Qinghai³⁸ and high-altitude enclosures at Bangga and Jiaritang in the present-day Tibetan Autonomous Region, associated with Bronze Age seasonal pastoralist groups^{39,40}. Contemporary mobile pastoralists utilize similar low-investment structures at their summer camps across the plateau^{24,41}.

Pottery from the intermountain valley was significantly less abundant and differed in characteristics compared to that from oasis and piedmont sites. It was smaller, with thinner walls, which may have enhanced portability but reduced its storage capacity (Fig. 8C). The pottery landscape on the Tibetan Plateau is multifaceted, featuring a diverse range of types associated with both local sedentary and pastoral groups, as well as their interactions with neighboring communities^{42,43,44,45,46}. Although a comprehensive pottery analysis in the Qaidam Basin is yet to be completed, our preliminary observations suggest similarities in type and distribution between ceramics collected from the intermountain valleys and those from the Late Bronze Age sites of Shirenzigou and Adunqiaolu, in Xinjiang's Tianshan Mountains, associated with seasonal pastoralists^{47,48}. Ethnoarchaeological research in the Great Basin of North America has established a link between the population mobility and the time and effort invested in making ceramics, demonstrating a negative correlation between the two^{49,50}. It is plausible that the observed variations in ceramic production across different ecological zones in the Qaidam Basin reflect varying degrees of population mobility.

Research has consistently shown that the development of regional cultures in the Qaidam Basin was supported by a flexible agro-pastoralist economy, potentially on a seasonal basis^{3,8,15,51,17}. Around 5400 carbonized grains, primarily barley and wheat — including wheat ears — were discovered at our sites, along with some wild species suggesting the local practice of a low-investment cold-resistant agriculture (Fig. 8A). Scattered grinding tools were likely used for processing these grains (Fig. 8C:4). Forty-two animal bone fragments found during our survey could be identified. They were predominantly from horses, cattle, and sheep, in addition to some wild fauna (Table S2). Domestic horse and sheep bones were found at Tawendaliha, Dalitaliha, Xiaeryamakebu, and Ke'er. The Xiachaikai site also included horses, cattle, sheep, and dogs' skeletal elements (Fig. 8B). The faunal taxonomic variety from our sites is roughly consistent with zooarchaeological findings from contexts associated with mobile and semi-mobile pastoralism on the Tibetan Plateau^{15,17}, the Tianshan Mountains of Xinjiang⁵², and Central Asia⁵³. Large quantities of Chenopodiaceae found at the sites could have been used as livestock fodder⁵⁴, supporting the idea of a mobile, possibly seasonal, pastoralism in the Qaidam Basin (Fig. 8A:12).

As cold-dry conditions intensified, the relocation to higher altitudes would have provided more reliable water sources, a richer variety of vegetation, and better thermal regulation than the increasingly arid lower regions, thus benefiting both agriculture and animal herding. Today the highlands around the Qaidam Basin are considered optimal for seasonal pastoralism, and well-suited for the movement and grazing of livestock²⁴. Archaeological evidence collected at the sites suggests that the shift from expansive lowland settlements to smaller, high-altitude, ephemeral structures in the Bronze Age of the Qaidam Basin can be associated to a transition in subsistence strategies, towards increasingly mobile agro-pastoralism, in response to environmental and climatic changes. The growing importance of pastoral activities in this region is also reflected in the late-stage remains at Dalitaliha, which include dedicated animal enclosures, woollen textiles, and artifacts made from animal bones¹³.

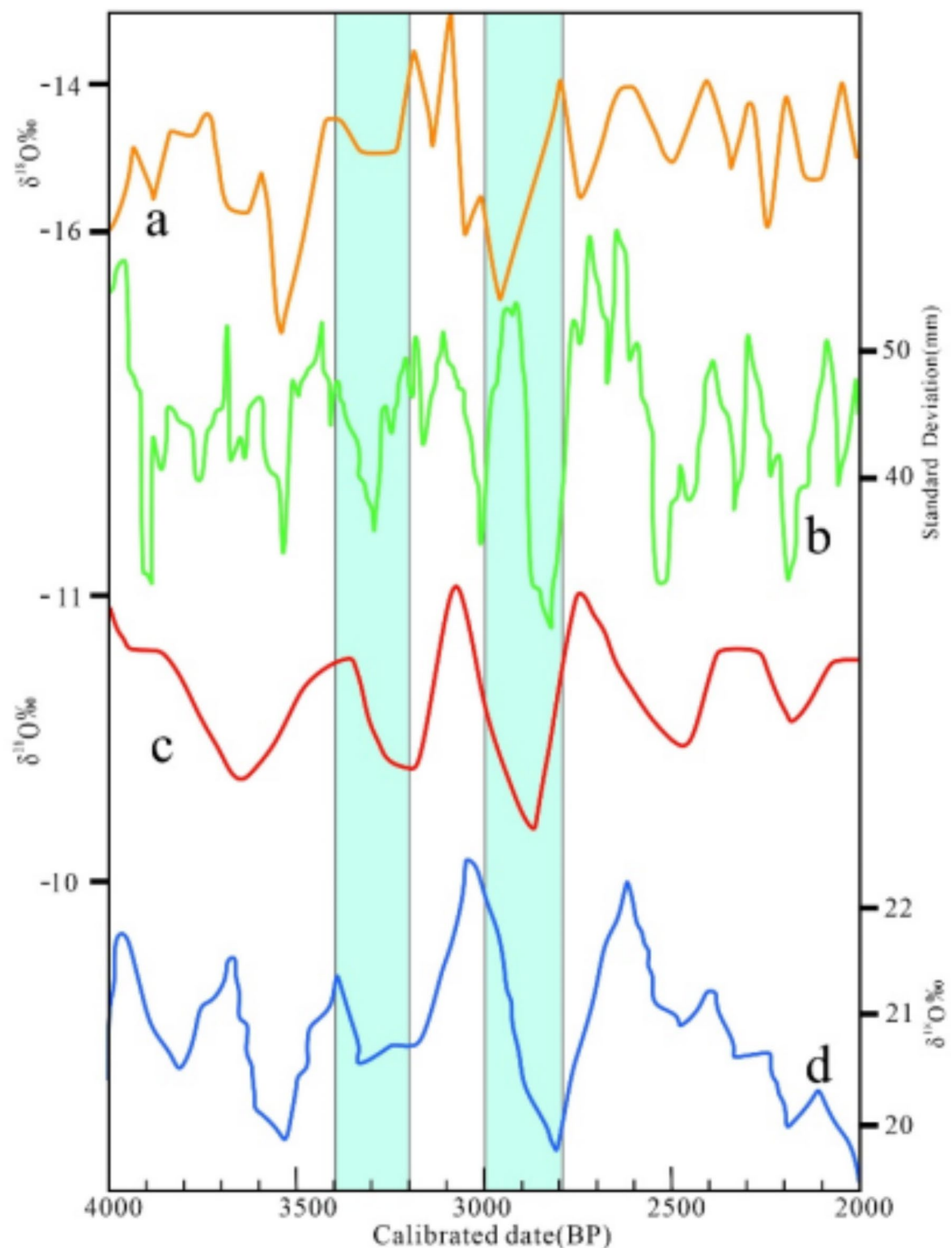


Fig. 7. Multi-proxy environmental records in the Qinghai-Tibet Plateau between 4000 calBP and 2000 calBP: (a) Puruogangri ice cap oxygen isotope curve³⁵; (b) Delingha mean annual precipitation curve³⁶; (c) dunde ice cap oxygen isotope curve³⁴; (d) Hongyuan peat cellulose oxygen isotope curve³⁷. The light blue vertical bars signal the two cold-dry periods identified in the Qaidam Basin.

Conclusion

Combined with 17 existing ^{14}C results, our 24 newly generated radiocarbon dates refine the Bronze Age chronology of the Qaidam Basin, demonstrating continuous regional occupation without major interruptions. This updated timeline, along with spatial analysis, shows a progressive shift from extensive lowland settlements

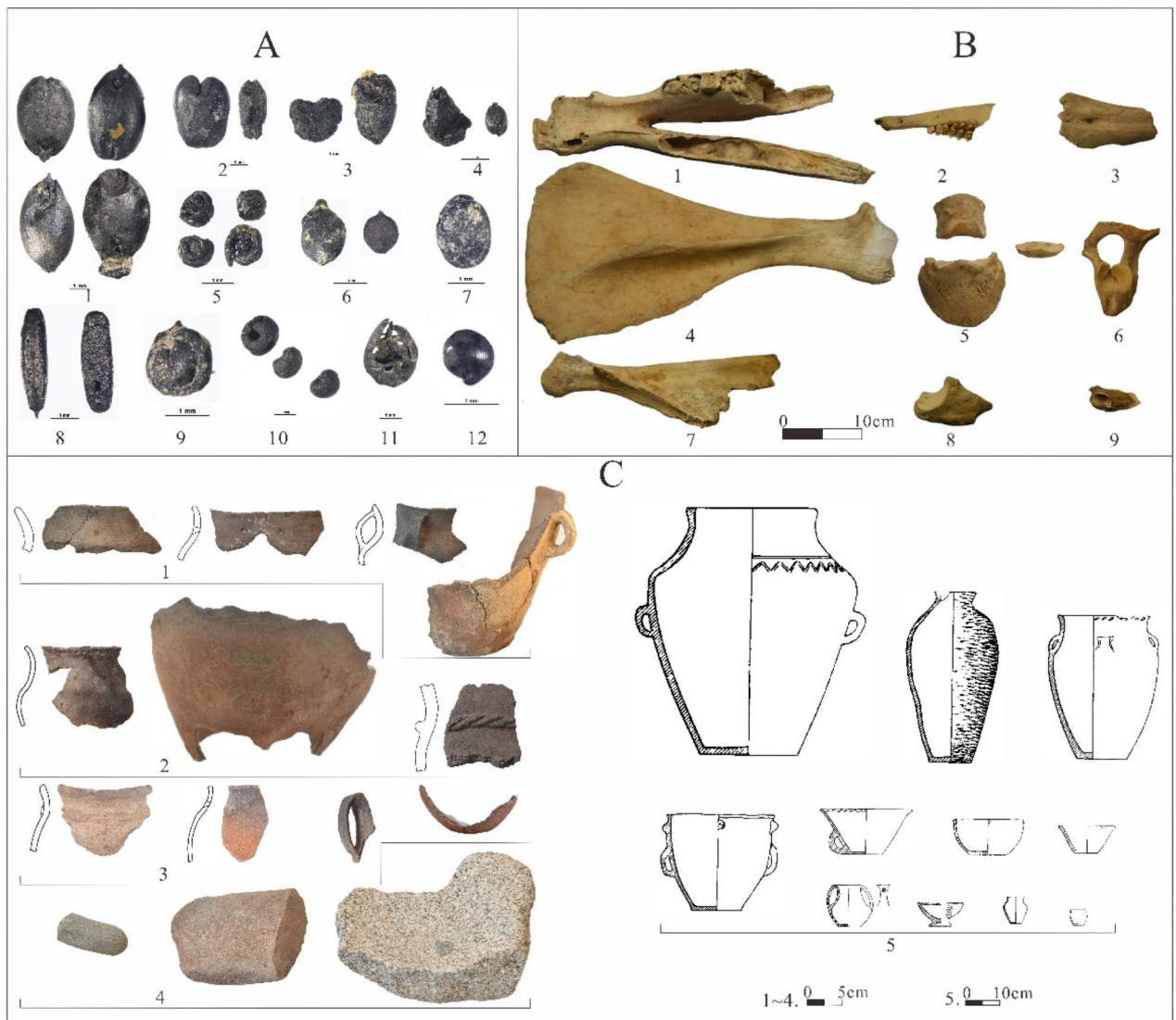


Fig. 8. Archaeological finds collected in the Qaidam Basin during our survey. A) Botanical evidence: (1) *Hordeum vulgare* from Dalitaliha, Xiaeryamakebu, Xiachacha, and Chaixinxinan; (2) *Triticum aestivum* from Dalitaliha and Xiaeryamakebu; (3) *Panicum miliaceum* from Dalitaliha; (4) *Setaria italica* from Dalitaliha; (5) *Salsola collina* from Xiaeryamakebu; (6) *Carex* from Xiaeryamakebu and Xiachacha; (7) *Corispermum* from Xiachacha; (8) *Avena fatua* from Dalitaliha; (9) *Agriophyllum squarrosum* from Chaixinxinan; (10) *Galium aparine* from Xiaeryamakebu; 11. *Nitraria sibirica* Pall from Dalitaliha. 12. Chenopodiaceae from Tawendaliha; B) Faunal remains: (1) *Equus caballus*, mandible from Ke'er P1③; (2) *Ovis aries*, mandible from Tawendaliha P3③; (3) *Bos primigenius*, metatarsal from Tawendaliha P2③; (4) *Equus asinus*, scapula from Xiachaikai; (5) *Equus caballus*, phalanges 2, 3 from Xiachaikai P1③; (6) *Ovis* sp., innominate from Tawendaliha; (7) *Pseudois nayaur*, scapula from Xiachaikai P3③; (8) *Bos taurus*, phalanx 3 from Tawendaliha P5③; (9) *Ovis* sp., tibia from Tawendaliha P6③; C) Cultural material: (1) Jar and urn fragments from Tawendaliha; (2) Urn fragments from Xiaeryamakebu; (3) Jar fragments from Chaixinxinan; (4) Grinding stone from Xiachaikai; (5) Jars and urns from Dalitaliha (after 13, p. 37, Fig. 5).

to smaller, temporary structures at higher elevations. These movements correspond with deteriorating climate conditions, suggesting the development of new landscape management strategies and a shift towards more mobile agro-pastoralist practices in response to environmental changes. These results align with strategies observed on the southern and eastern ridges of the Tibetan Plateau^{15,17}.

While our research highlights climatic change as a key factor influencing settlement preferences during the Bronze Age in the Qaidam Basin, this was likely just one of several factors affecting prehistoric landscape exploitation strategies and subsistence practices on the Tibetan Plateau³. Studies by^{46,55,56,57,58} have shown that cultural shifts between the second and first millennia BCE significantly impacted resources exploitation and mobility across the plateau. To fully comprehend these dynamics in the Qaidam Basin, more archaeological excavations and detailed research into subsistence strategies—including in-depth analyses of botanical and

faunal remains, as well as pottery and other archaeological evidence—are essential; meanwhile, the radiocarbon dates presented in this study provide a crucial spatio-temporal framework for exploring these processes.

Materials and methods

Spatial distribution and sites' classification

9 sites were selected on the basis of the information from the Second National Archaeological Survey of China conducted in the 1980s¹⁴. These sites (1) exhibited clear characteristics of the Bronze Age Nuomuhong Culture; (2) were sufficiently well-preserved; (3) allowed for the collection of features and artifacts without extensive excavation; and (4) were situated across diverse geo-ecological zones, providing a representative sample of the geographical and ecological distribution of Bronze Age sites in the Qaidam Basin. The 9 sites were surveyed and mapped onto satellite and contour maps in QGIS (<https://www.osgeo.org/projects/qgis/>) permitting a clear understanding of the elevation and physical geography of the sites. The proximity to the nearest river, elevation, and, where possible, the modern vegetation at the site were recorded. These factors were then combined to group the sites by type of site location: the edge zone of the piedmont alluvial fan, the fan apex and valley mouth zone of the piedmont alluvial fan and intermountain valley.

Sampling

Samples were taken from profiles located in both the central and peripheral areas of the sites. We identified and marked layers of human activity and collected soil samples containing seasonal plant remains, animal bones and charcoal samples for dating. Further samples were obtained through water flotation. We collected additional samples of faunal and botanical material at various sites according to different cultural layers and relic units, recording location and taxon. The taxonomic identification of these animal bones and botanical remains was carried out at the Laboratory of Animal and Plant Archaeology ("One Belt, One Road" Joint Laboratory of Human and Environment in China and Central Asia) at Northwest University. However, in this paper, faunal and floral finds are only briefly discussed in terms of taxonomic frequency, as the complete zooarchaeological and archaeobotanical analysis is ongoing.

Radiocarbon dating

24 samples were selected for radiocarbon dating. All testing procedures were conducted at the Beta Radiocarbon Dating Laboratory. Chemical pretreatment was performed on different types of samples to remove impurities. CO₂ was reduced with hydrogen using a cobalt catalyst, and the resulting graphite targets were placed in the AMS instrument for testing. The samples were combusted at temperatures above 800 °C in a 100% oxygen environment to release CO₂. The released CO₂ was first dried using methanol/dry ice and then collected with liquid nitrogen for subsequent graphitization reactions. The final results (BP or pMC) were obtained by measuring the 14 C/13 C ratio of the samples compared to the 14 C/13 C ratio of Oxalic Acid II (NIST-4990 C). All tests were completed using the laboratory's internal SNICS ion source particle accelerator. The newly obtained dates and 17 existing radiocarbon dates for the Qaidam Basin^{3,15,18} were calibrated using Oxcal 4.4 and IntCal20 calibration curve^{25,26}.

Data availability

Data are available in the Supplementary Material.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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