

OSL chronology of the Liena archeological site in the Yarlung Tsangpo valley throws new light on human occupation of the Tibetan Plateau

The Holocene
1–10

© The Author(s) 2020

Article reuse guidelines:

sagepub.com/journals-permissions

DOI: 10.1177/0959683620908643

journals.sagepub.com/home/hol



Zhiyong Ling,^{1,2}  Xiaoyan Yang,³ Yixuan Wang,² Yanren Wang,³ Jianhui Jin,^{2,4} Dongju Zhang¹ and Fahu Chen^{1,3}

Abstract

Recent environmental archeological evidence has started to throw light on both the timing and processes of human colonization of the Tibetan Plateau (TP). Yarlung Tsangpo (YT) valley, a very important region of the southern TP for occupation, is home to not only modern Tibetans but also their ancestors. However, a lack of suitable sedimentary strata has limited the establishment of a secure chronology. Here, we report on a new stratigraphic section with prehistoric pottery and cultural layers that was discovered on a terrace of the YT at Liena, in Nyingchi County. The cultural layers are overlain by, and bedded within, eolian and lacustrine sediments. We used the quartz Optically Stimulated Luminescence (OSL) method to date 11 samples and performed geochemical analysis on 100 samples to derive paleoenvironmental indicators. The OSL analysis gave an age of 4.3 ka BP for the cultural layer, which makes it the earliest human activity in the YT valley of Nyingchi to date. In addition, commencement of eolian deposition was dated to at least 8.3 ka, coinciding with the Holocene warm period. We discuss possible causal factors for human occupation in the valley and show that climatic changes played a crucial role in prehistoric human migration c. 8.3–4.3 ka BP. Before the early Holocene, most of the river terraces in the valley were being actively reworked by rivers or covered by lakes. So there were no suitable places for occupation by ancient populations. With the recession of dammed lakes during the Holocene warm period, the relatively flat and wide valley terraces, blanketed with rich eolian deposits (such as sandy loess), provided an attractive place for ancient people engaged in nomadic and even agricultural activities. Hence, the climate conditions of the Holocene warm period drove the environmental changes that provided favorable conditions for ancient human activities.

Keywords

ancient human activities, Nyingchi archeological site, OSL chronology, paleoenvironment, Yarlung Tsangpo

Received 10 September 2019; revised manuscript accepted 12 January 2020

Introduction

The discovery of Denisovan mandible made the earliest origins of migrating people on the Tibetan Plateau (TP) to late middle Pleistocene (Chen et al., 2019). In short, the timing of human occupation on the TP, from the earliest origins of migrating populations through to permanent agricultural settlement, is topical and controversial (Chen et al., 2015, 2019; Zhang et al., 2018). For example, the Nwya Devu Paleolithic site in the Siling Co Basin of the central TP and the other Paleolithic site at Xiao Qaidam Lake on the northern TP have been dated to 40–30 ka BP (Huang et al., 1987; Yuan et al., 2007; Zhang et al., 2018), which falls in the middle stage of the Last Glacial period. A similar date (28–37 ka BP) has been obtained at Lenghu site in the Qaidam Basin using Optically Stimulated Luminescence (OSL) dating (Owen et al., 2006). Genetic studies show that Tibetan ancestors may have entered and settled on the TP about 30 ka BP and the genetic adaptation to hypoxia in Tibetan populations has a natural selection of at least 18 ka BP (Su et al., 2000). Lu et al. (2016) consider that there were already different Paleolithic human groups on the TP in the pre-glacial period, about 40–60,000 years ago. In addition, Zhang and Li (2002) suggested that human activity was present at a site on the central TP in the last glacial period, although the site

was classed as early Holocene in a later study (Meyer et al., 2017). OSL and ¹⁴C dating of a prehistoric hearth in the Qinghai Lake area, in the northeast of the TP, indicate that prehistoric human activities occurred in the Last Deglacial period, about

¹Key Laboratory of West China's Environmental Systems (Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, China

²Key Laboratory of Comprehensive and Highly Efficient Utilization of Salt Lake Resources and Qinghai Provincial Key Laboratory of Geology and Environment of Salt Lake, Qinghai Institute of Salt Lakes, Chinese Academy of Sciences (CAS), China

³Key Laboratory of Alpine Ecology, CAS Center for Excellence in Tibetan Plateau Earth Sciences and Institute of Tibetan Plateau Research, Chinese Academy of Sciences (CAS), China

⁴Institute of Geography, Key Laboratory for Humid Subtropical Eco-Geographical Processes (Ministry of Education), Fujian Normal University, China

Corresponding author:

Zhiyong Ling, College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China.

Email: lingzhiyong@foxmail.com

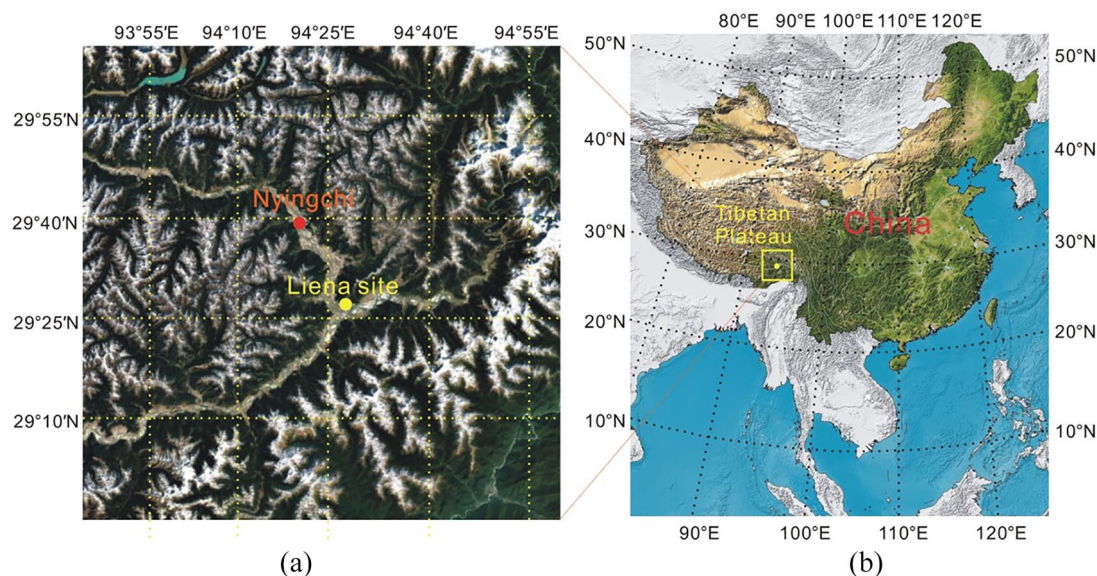


Figure 1. Location of the study area: (a) Satellite image showing location of the Liena archaeological site (base map downloaded from Google Earth) and (b) location of study area within the TP (yellow square).

15–11.6 ka BP (Madsen et al., 2006; Sun et al., 2012), instead of the previously proposed 40–30 ka BP (Hou et al., 2010; Huang et al., 1987; Yuan et al., 2007). Chen et al. (2015) consider that the development of agriculture prompted people to permanently settle on the TP after 3.6 ka BP. Although the chronology of prehistoric human activities acquired by different researchers working in different areas of the TP varies, the accumulation of research on archeological sites has led to a greater awareness of human origins and migration processes in the region.

It is vital to establish a secure chronology in order to understand the development of ancient human activity and paleoenvironmental conditions at prehistoric sites (Kitis and Vlachos, 2013; Meyer et al., 2017). In recent years, numerous studies have applied OSL dating methods at prehistoric sites in China to reconstruct the sequence of ancient human activities (Meyer et al., 2017; Zhang et al., 2018), paleoclimatic conditions (Yuan et al., 2007; Zhang and Li, 2002), and human-environmental interactions (Sun et al., 2017). OSL-based research has been especially important in the TP and has even been used to address controversial problems, such as human adaptation (Chen et al., 2015; Sun et al., 2017) and anthropogenesis of Tibetans (Li et al., 2017; Meyer et al., 2017; Zhang et al., 2018).

The Yarlung Tsangpo (YT) valley, located in the south/south-eastern TP, is subject to relatively amenable weather conditions (Dong et al., 2017) and is inhabited by a large proportion of the present day population of Tibet (Wang et al., 2019); thus, it would seem to be an excellent place for the anthropogenesis of Tibetans. However, many archeological sites in the YT valley lack a reliable chronology because of erosion of strata by water in places of ancient human occupation (Chen et al., 2016; Wang, 1999). Only a few archeological sites in the middle reaches of the YT catchment have an absolute chronology; these include sites such as Qugong, Changguogou, and Bangga in southern Tibet have been ^{14}C -dated to about 3.5 ka BP (Huo et al., 2015). Luminescence dating offers one benefit that allows the direct determination of buried ages for different sediments from different depositional environment (Murray and Olley, 2002), and the test results are in good agreement with ^{14}C dating (Jin et al., 2017; Lai et al., 2009), especially used for the eolian material (Lai et al., 2009). Besides, as most of the archeological sites in the YT valley are buried under eolian deposits, OSL dating has great potential to play an important role in establishing age controls.

In this study, the OSL technique was used to date two profiles at the archeological site of Liena we discovered in Nyingchi

(Figure 1) in the YT valley in order to provide further age controls for human habitation in the region. Geochemical analysis of 100 samples was also undertaken and used to provide insight into paleoclimatic conditions and human-environmental interactions in the YT valley.

Study area and sampling locations

The YT valley, located on the southern TP, between the Himalayas and the Gangdise-Nyainqentanglha Mountains, plays an important role in the human occupation of the TP. The terrain features of Nyingchi county, located downstream of the confluence of Niyang river with the YT gorge, are characterized by wide valleys, snow-capped mountains, alluvial fans, and eolian sedimentary strata. Compared with other parts of the TP, the region is relatively low in altitude and the climate is warm and humid, making it hospitable for human habitation. In terms of understanding the timing of human occupation in the YT valley since the Holocene warm period (*c.* 8–4 ka BP), the Tibetan Neolithic culture is of significance. Archeologists first discovered the remains of late Neolithic period humans in the early 1960s (Wang, 1975; Wang, 1999), and a large amount of research work has been carried out subsequently.

Liena site, one of the archeological sites in YT catchment, located on the tertiary river terrace (with *c.* 4 km²) of the confluence of Niyang river with the YT gorge (Figure 2), was discovered in a field investigation of eolian sediments in 2018. There are many gullies and sections exposed by erosion on the tertiary river terraces (Figure 2b), and archeological relics are scattered in different eolian sections and not concentrated in distribution. Currently, the area of the Liena site has not been approved for excavation, so we selected the relatively good exposed sections with representation of a whole sedimentary strata at the edge of the site for sampling.

Two profiles were chosen for detailed sampling, termed YJP1 and YJP2, located approximately 0.5 km to the northwest of the Liena village, near the northeast bank of the YT valley of Nyingchi city (Figure 2). YJP1 (29°27'20.15"N, 94°28'9.53"E) comprises about 580 cm of sandy loess and lacustrine sediments (Figure 3a), situated atop a terrace about 2944 m a.s.l. The profile can roughly be divided into three layers by geochemical parameters. Layer 1 (0–355 cm) is composed of three sub-level eolian sedimentary strata which are the Layer 1-a (0–165 cm), Layer 1-b (165–325 cm)

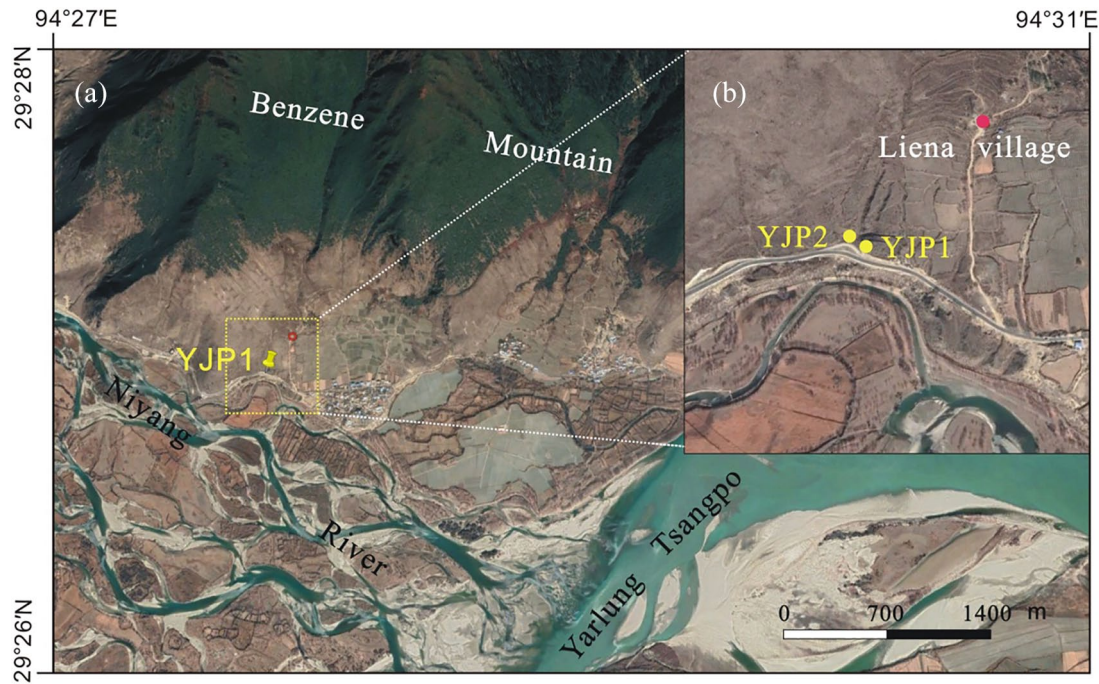


Figure 2. Archeological site of Liena (base map downloaded from Google Earth): (a) Satellite image showing geomorphic unit of YJP1 and the Liena archeological site and (b) details of the surface environmental condition of study area.

and Layer 1-c (325–355 cm). Between Layer 1-a and Layer 1-b, about 110–175 cm depth (Figure 3), there is a Ancient human activity layer which contains pottery (Figure 3b, c), broken bones, and carbonized millet. A hearth (or remains of fire) with carbon debris (Figure 3d) was discovered at the bottom of Layer 1, about 325–355 cm depth, which was considered as Layer 1-c. Layer 2, about 70 cm in thickness (355–425 cm), is characterized by a gray-yellow color sandy strata mixed with eolian and lacustrine sediments, representing a transitional layer. The third layer (425–580 cm, bedrock not reached) comprises gray colored lacustrine sedimentary strata with coarser sandy particles.

Profile YJP2 is located in a small ravine, about 50 m to the north of YJP1, which is a cross section on the edge of a river terrace (Figure 2b), about 2945 m a.s.l. The profile consists of three main layers, *c.* 245 cm of total thickness: eolian loess, alluvial gravel, and lacustrine sediment. The sandy loess layer is 170 cm thick and contains many small holes and several snail-shell bodies. At the bottom of the loess, there is a layer of alluvial gravel about 30 cm thick, which is on the top of gray-color lacustrine strata, and the lacustrine deposits can be extended to the base of the modern riverbed.

Methods

Sampling

To provide a chronological framework for the Liena site, 10 samples for OSL dating were collected from YJP1 and one sample from YJP2. The approximate positions of each OSL sample in YJP1 are shown in Figure 3a; the sample from YJP2 was collected from the bottom of the eolian layer at a depth of 170 cm. All OSL samples were enclosed in a stainless steel tube and secured with plastic tape to provide protection against light and breakage during transportation. Samples were also taken for geochemical analysis to calculate major and trace element parameters of sediments for use as indicators of paleoclimate and paleoenvironment. A total of 100 geochemical samples were taken at 5-cm intervals from profile YJP1. In addition, several pottery pieces were recorded and collected from the

YJP1 section to indicate stratigraphic information about the activities of the ancient population.

OSL dating

An automated Risø TL/OSL-DA-20 reader for TL/OSL dual-purpose dating, equipped with a $^{90}\text{Y}/^{90}\text{Sr}$ beta source, produced in the Danish Risø Laboratory, was used for OSL measurements in the optical luminescence laboratory of Qinghai Institute of Salt Lakes, CAS. The signal was stimulated by blue diodes ($\lambda = 470 \pm 20 \text{ nm}$) at 130°C for 40 s, and a Hoya U-340 (7.5 mm) filter, placed in front of the photomultiplier tube (9235QA), was used for detection and recording.

Single aliquot regenerative-dose (SAR) technology was used for the equivalent dose (D_e) determination of the OSL measurement with quartz (Murray and Wintle, 2000). The D_e , tested using medium size (38–63 μm) quartz extracted from the sediments of YJP1 and YJP2, was estimated by interpolation of the natural luminescence signal onto the growth curve. The growth curves were constructed using regeneration doses, including a dose of 0 Gy for monitoring the thermal transfer effect and a repeated first regeneration dose for checking the accuracy of the sensitivity correction. A fixed, small test dose after the natural and regenerative OSL measurements was used to adjust the sensitivity. The preheat temperature for natural and regenerative doses of samples was 260°C for 10 s, and cut-heat was set at 220°C for 10 s. The first 1.6-s integral of the primary OSL signal, minus a background signal estimated from the last 8-s integral, was used for D_e estimation.

Concentrations of U, Th, and K were measured using neutron activation analysis at the China Institute of Atomic Energy. The contribution of cosmic rays to the annual dose was calculated from the altitude, geographical location, and sampling depth of the samples (Prescott and Hutton, 1994). For the 38–63 μm quartz grains, an alpha efficiency factor of 0.035 ± 0.003 was assumed to estimate the alpha contribution to the dose rate (Lai et al., 2008). The parameters used to calculate the annual dose were based on the standards provided by Aitken (1998) and are shown in Table 1. Long-term water content was assumed to be $5 \pm 5\%$,

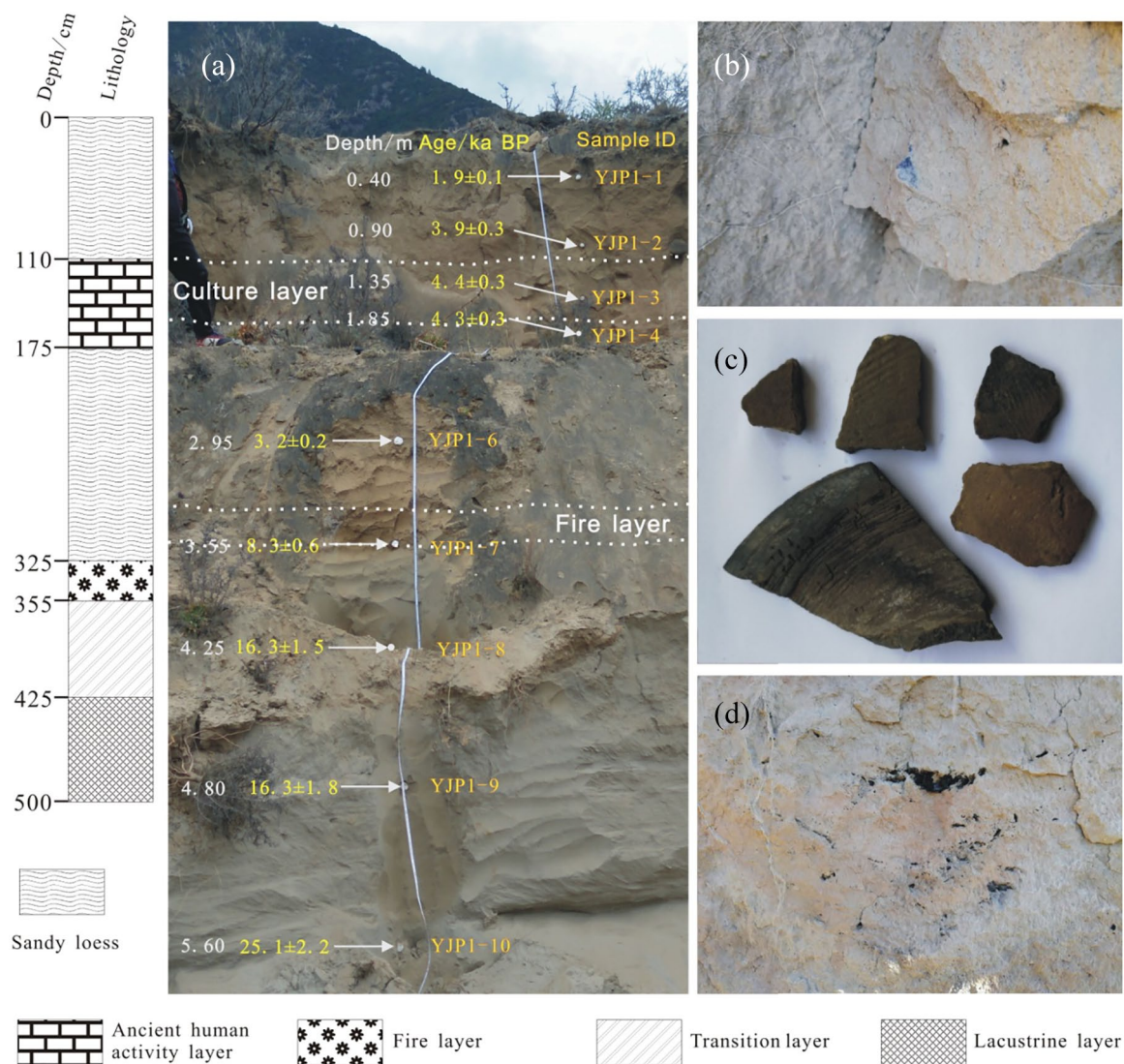


Figure 3. Section YJPI and its columnar lithology: Photo showing (a) OSL sampling sites with their ages; (b) small portion of different pottery in the sandy loess layer, 110–175 cm depth; (c) gray pottery and red pottery; and (d) hearth or remains of fire with carbon debris in the sandy paleosol layer, 325–355 cm depth.

Table 1. Summary of U, Th, and K content, dose rate, D_e , and OSL ages for profiles YJPI and YJP2.

Sample ID	Depth (m)	K (%)	Th (ppm)	U (ppm)	Dose rate (Gy/Ka)	D_e (Gy)	OSL age (ka BP)
YJPI-1	0.40	2.05 ± 0.04	15.06 ± 0.8	1.45 ± 0.3	3.62 ± 0.26	6.8 ± 0.1	1.9 ± 0.1
YJPI-2	0.90	2.04 ± 0.04	15.23 ± 0.8	1.65 ± 0.3	3.65 ± 0.26	14.2 ± 0.2	3.9 ± 0.3
YJPI-3	1.35	2.05 ± 0.04	15.28 ± 0.8	1.73 ± 0.3	3.66 ± 0.27	16.2 ± 0.2	4.4 ± 0.3
YJPI-4	1.85	2.09 ± 0.04	15.69 ± 0.8	1.93 ± 0.3	3.76 ± 0.27	16.0 ± 0.2	4.3 ± 0.3
YJPI-5	2.45	2.23 ± 0.04	17.60 ± 0.8	1.80 ± 0.3	3.97 ± 0.29	20.4 ± 0.4	5.1 ± 0.4
YJPI-6	2.95	2.13 ± 0.04	17.05 ± 0.8	1.92 ± 0.3	3.85 ± 0.28	12.5 ± 0.2	3.2 ± 0.2
YJPI-7	3.55	2.17 ± 0.04	18.22 ± 0.8	3.64 ± 0.4	4.41 ± 0.32	36.6 ± 1.0	8.3 ± 0.6
YJPI-8	4.25	2.24 ± 0.04	15.95 ± 0.8	2.94 ± 0.4	4.10 ± 0.30	36.8 ± 3.5	16.3 ± 1.5
YJPI-9	4.80	2.17 ± 0.04	11.87 ± 0.7	2.00 ± 0.4	3.48 ± 0.27	56.8 ± 4.3	16.3 ± 1.8
YJPI-10	5.60	2.19 ± 0.04	10.10 ± 0.7	2.01 ± 0.4	3.36 ± 0.26	84.1 ± 3.5	25.1 ± 2.2
YJP2	1.70	2.07 ± 0.04	10.94 ± 0.7	1.64 ± 0.3	3.34 ± 0.24	36.8 ± 1.0	11.0 ± 0.9

OSL: Optically Stimulated Luminescence.

similar to the using in the adjacent areas (Lai et al., 2009) and was added to each value in the age calculations.

Geochemical element determination

The content of major element compounds (e.g. SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , MgO , Na_2O , and K_2O) and trace elements (e.g. Ba, Rb, Sr, Zn, and Zr) in the sediments was determined

by x-ray fluorescence spectrometry (XRF), using an AXIOS Pw4400 instrument manufactured by PANalytical in the Netherlands. Mineral effects, particle size, and spectral lines of samples were optimized to control experimental influencing factors so that the relative standard deviations of the components under test were below 3.5% (RSD, $n = 10$) and could meet the detection requirements of each component in the sediment.

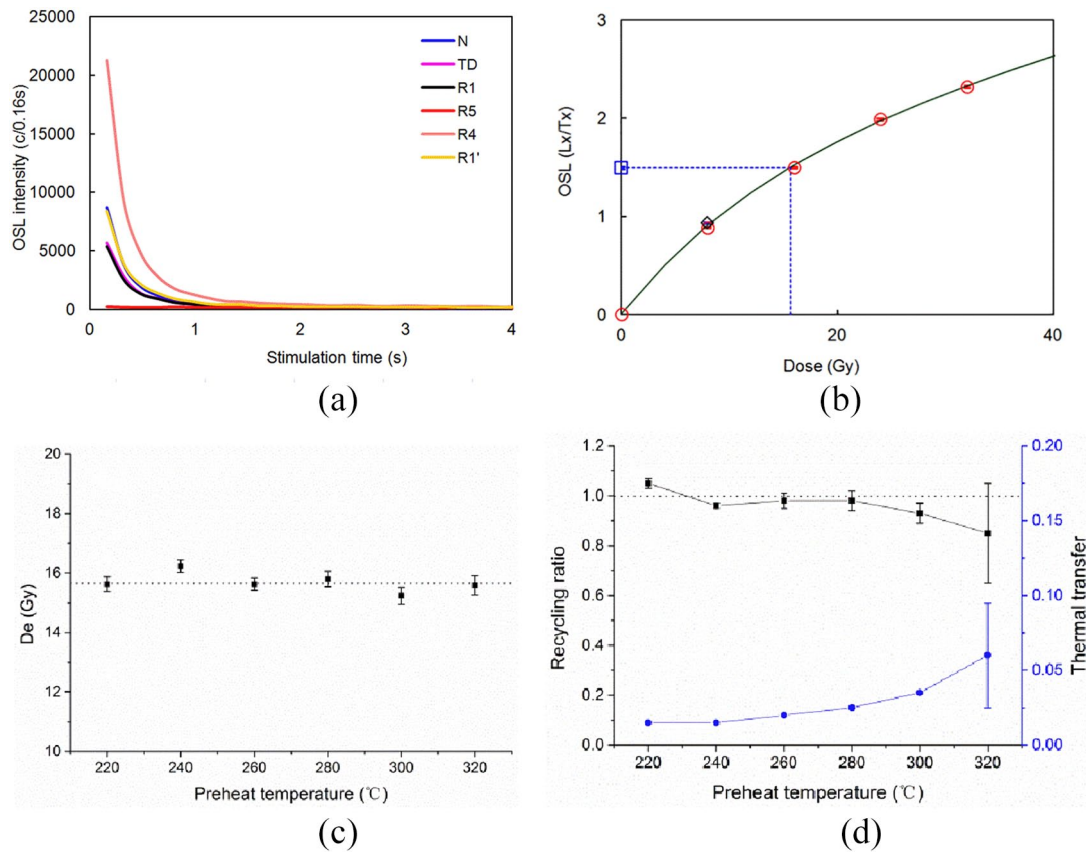


Figure 4. Typical sample quartz luminescence characteristics, based on sample YJP1-3: (a) Shine-down curves, where *N* is the natural dose, *TD* the test dose, and *R1*–*R7* regenerative doses; (b) growth curve derived by integration of the signals of the first 0.64 s stimulation; (c) preheat plateau and dose recovery test for medium grained quartz; and (d) recycling ratio (black) and thermal transfer effect (blue).

Results

OSL characteristics

Typical sample quartz OSL age characteristics are shown in Figure 4, based on sample YJP1-3. The OSL signal decreases very quickly within the first second of stimulation (Figure 4a), suggesting that samples are dominated by the quartz fast component. The growth curve (Figure 4b) shows that the signal is still increasing at a dose of 40 Gy. A zero-dose cycle was incorporated in the SAR protocol to test the effect of thermal transfer. The decay curve of 0 Gy regeneration dose shows negligible thermal transfer (Figure 4d). The recycling ratios are consistent to within 10% of unity (0.9–1.1) for all samples (Figure 4d).

The preheat plateau and dose recovery test were used to choose a suitable preheat temperature and to evaluate the suitability of the SAR protocol. For the preheat plateau test, 24 aliquots from sample YJP1-3 were used. Six preheat temperatures, 220°C, 240°C, 260°C, 280°C, 300°C, and 320°C, were selected (held for 10 s) and four aliquots were tested at each temperature point. The cut-heat was 220°C for 10 s. The results of the preheating test show little variation in equivalent doses at temperatures between 220°C and 280°C and the test errors increase above 280°C (Figure 4c). Therefore, a preheat temperature of 260°C was chosen for the SAR measurement. In addition, at temperatures between 220°C and 280°C, the recycling ratio and thermal transfer (recuperation) are also within acceptable limits (Figure 4d). For dose recovery test, 10 aliquots were bleached with blue LED for 100 s at room temperature. A laboratory dose of 16 Gy was then given, followed by SAR measurements to determine the *De*. The average recovered *De* is 15.63 Gy. The ratio between the given and measured dose is close to unity (0.98), indicating that a known-laboratory dose can be recovered.

OSL ages of YJP1 and YJP2

The chronological results calculated from the equivalent dose and the annual dose rate are shown in Table 1 and Figure 3. In general, there is a good correspondence between OSL ages and stratigraphy; that is, the dates are in chronological order – upper sedimentary strata have young ages and lower strata have older ages – with one exception. The age of sample YJP1-6 appears to be too young for its stratigraphic position. As the luminescence characteristics of the sample are reliable, we surmise that the anomalous age may be because of introduction of younger material from above perhaps as a result of collapse. It can be seen from the chronological results (Table 1) that lacustrine deposition in YJP1 (below 425 cm depth) roughly corresponds to the Last Glacial Maximum (about 25.1–16.3 ka BP). The gradual transition from lacustrine to eolian sediments between 425 and 355 cm roughly corresponds with the Late Glacial to early Holocene period (16.3–8.3 ka BP). And the dating results, from YJP1-7 to YJP1-10, especially between YJP1-7 and YJP1-8, show that there should be a depositional hiatus, but it does not affect the definition of the cultural layer age. The loess layer of YJP2 profile on the alluvial gravel layer is consecutive with an OSL age of 11 ka BP for the bottom which the oldest age for the eolian materials on this terrace suggests that the eolian deposition that is characteristic of the YT valley in the region have been initiated in the early Holocene.

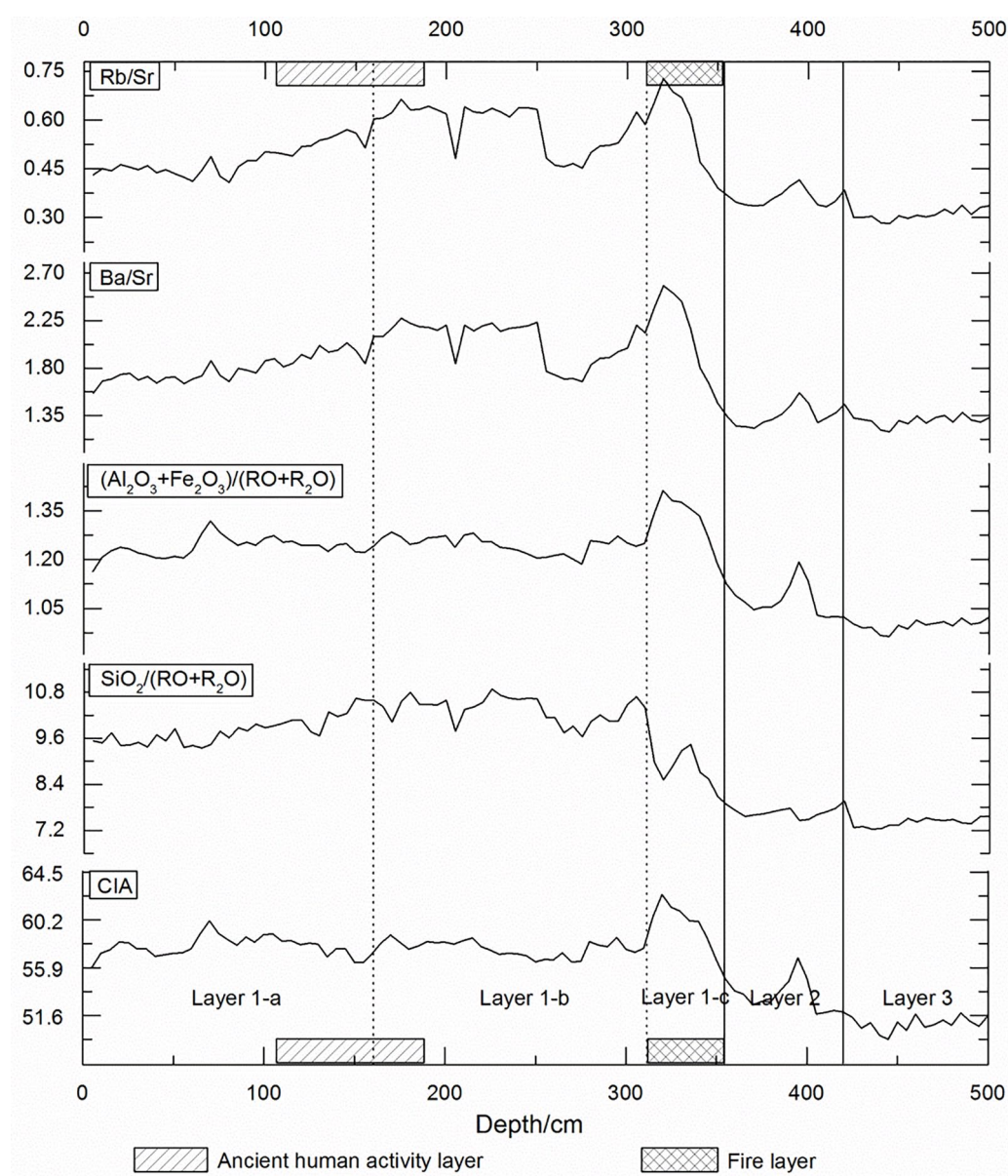
Elemental geochemical parameters

Geochemical data can be used as paleoenvironmental indicators for conditions such as drought and wetness (Li et al., 2014; Ling et al., 2016; Nesbitt and Young, 1982; Vital and Stattegger, 2000). Generally, high value of the ratio of Rb/Sr, Ba/Sr, (Al_2O_3 +

Table 2. Numerical range (NR), average value (AV), and coefficient of variation % (CV) for elemental geochemical parameters in different layers of profile YJPI.

Sedimentary layer/ depth (cm)	Statistic type	Rb/Sr	Ba/Sr	(Al ₂ O ₃ + Fe ₂ O ₃)/ (RO + R ₂ O)	SiO ₂ / (RO + R ₂ O)	CIA
Layer 1-a/0–165	NR	0.41–0.61	1.56–2.10	1.16–1.32	9.35–10.64	55.91–60.11
	AV, CV	0.48, 11	1.81, 8	1.24, 2	9.83, 4	57.83, 2
Layer 1-b/166–320	NR	0.45–0.73	1.67–2.58	1.19–1.41	8.52–10.88	56.41–62.49
	AV, CV	0.59, 13	2.08, 11	1.25, 3	10.25, 5	57.86, 2
Layer 1-c/321–355	NR	0.37–0.69	1.35–2.51	1.13–1.38	7.87–9.44	54.87–61.33
	AV, CV	0.52, 26	1.91, 24	1.29, 8	8.69, 7	58.94, 4
Layer 2/356–425	NR	0.30–0.42	1.23–1.57	1.00–1.19	7.27–7.96	51.44–56.80
	AV, CV	0.36, 8	1.35, 7	1.07, 5	7.64, 2	53.20, 3
Layer 3/426–580	NR	0.28–0.34	1.20–1.38	0.96–1.02	7.23–7.57	49.43–51.84
	AV, CV	0.31, 6	1.30, 4	1.00, 2	7.42, 1	50.81, 1

CIA: chemical index of alteration; NR: Numerical range; AV: average value; CV: coefficient of variation.
CIA of profile YJPI is chemical index of alteration.

**Figure 5.** Changes in geochemical parameters with depth for profile YJPI. The main changes in stratigraphy (Layers 1–3) and human activity are also shown.

Fe₂O₃)/(RO + R₂O), SiO₂/(RO + R₂O), and CIA was used to indicate the warm or humid climate conditions. On the contrary, it was used to indicate a dry or cold climate (Li et al., 2014; Ling et al.,

2016). Selected elemental geochemical parameters for indicator samples for different layers of profile YJPI are shown in Table 2 and Figure 5. The average values of the geochemical parameters in

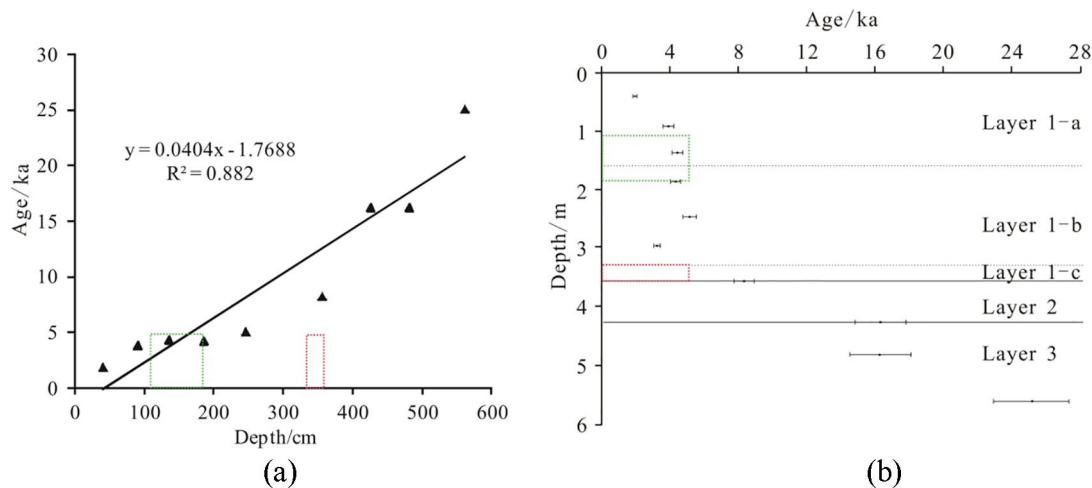


Figure 6. (a) Age-depth correlation and (b) OSL dating results for profile YJP1, with main stratigraphic layers labeled. The green and red dotted boxes correspond to the depth of the culture layer and the fire layer, respectively.

Layer 1 with larger range and CV are higher than Layer 2 and Layer 3, reflecting different climate conditions or sedimentary environment. In general, the values of these parameters in YJP1 show a tendency to increase first and then decrease from top to bottom, which are fluctuating.

Figure 4 shows variations in geochemical parameters with depth for profile YJP1, with sedimentary units (Layers 1–3) as classified in the field also identified (Table 2, Figure 5) along with human activity and fire layers. The figure provides a basis for analyzing changes in paleoenvironment in different periods of human occupation of the site.

Overall, the geochemical parameters show similar patterns of change with depth, with several major and minor peaks that correspond with changes in stratigraphy and/or human activity. The human activity layer from *c.* 110–175 cm depth corresponds with generally higher values for the main geochemical parameters, indicating a relatively wet climate condition. Much pottery and bones debris was present at this depth in areas around profile YJP1, giving a strong indication of human occupation of the site during this period. The fire layer between 320 and 355 cm depth also has a clear geochemical signal and seems to reflect a shift in climate from wet to drier conditions. As the lacustrine environment of Layer 3 receded, progressive surface exposure would provide potential activity sites for the ancient population.

Discussion

OSL chronologies and indication of the earliest human activities

Figure 6 plots OSL ages obtained for profile YJP1 against depth, with the main stratigraphic units identified. Overall, the dates show a good linear relationship with depth and are in correct stratigraphic order, apart from sample YJP1-6 (295 cm) which, as discussed above, appears too young. Accordingly, sample YJP1-6 was omitted from the age-depth correlation shown in Figure 6a; the relationship between age and depth is fitted with a linear equation of the form $y = 0.0404x - 1.7688$ ($R^2 = 0.882$).

The consistency of OSL ages in Figure 6a and b show that, overall, the OSL ages of YJP1 are credible and provide a good representation of the ages of the buried stratigraphy. Previous studies have confirmed that the OSL technique is reliable enough to record accurate depositional ages, especially for eolian sediments (Chen et al., 2015; Lai et al., 2008; Meyer et al., 2017). Consequently, the OSL chronology provided in this study provides a reliable age control for the Liena site for at

least the past 8.3 ka BP, which can cover the period of human activity at this site.

The cultural remains are not found in the burn layer, which is dated to 8.3 ka BP by OSL. And those traces of burn cannot be used as the conclusive evidence of human activity, because there is no evidence to prove those burn traces were marked by human activities. Thus, we choose the layer with cultural remains (the depth 110–170 cm) as the signal of the beginning of human activity in our region which was dated to *c.* 4 ka BP (one is 4.3 ka BP and the other is 4.4 ka BP) suggests the earliest time of the human occupation in this valley. Compared with the age results of Qugong site, Changguogou site, Bangga site (Huo et al., 2015), and Liena site, at least, the *c.* 4 ka BP can be determined to the earliest human activities in the middle and lower reaches of the YT catchment.

Paleoenvironmental changes of the YT valley since 25 ka BP

Based on sedimentary characteristics and geochemical parameters of the YJP1 profile, the paleoenvironment of the YT valley in the area of present day Nyingchi city has fluctuated since 25 ka BP. Before the early Holocene (8.3 ka BP), the location of the Liena cultural site was riverine and inundated by river or dammed lake water, as indicated by fluvial sand at the lower part of YJP1. The sediment geochemical parameter curves (355–500 cm depth) show relatively small fluctuations, except in the top *c.* 75 cm which forms the transition layer between riverine facies and eolian sediments. The riverine or lacustrine context renders the site unsuitable for human occupation/activity in this period. Because there is no space or place suitable for the activities of the ancients.

After 8.3 ka BP, the river at the Liena site retreated and the area was exposed to sandy loess deposition and soil development, providing a more suitable place for ancient human occupation. Peaks in most of the geochemical parameter curves reflect warm and humid environmental conditions, especially between 8.3 and 4.3 ka BP which corresponds to the Holocene warm period. However, there is no evidence of human activity at Liena at this time, suggesting that ancient humans had not yet migrated to the area and may indicate that climatic conditions were no longer a decisive factor in human activities at this stage. After 4.3 ka BP, the advancement of agricultural technology and the spread of high-altitude crops pushed ancient humans to migrate to the YT River valley where the Liena site was located. Hence, the cultural layer of the Liena site appeared right at the end of the Holocene warm period.

Human occupation in the YT valley

Brantingham et al. (2001) proposed a ‘three-level jump’ model for ancient human colonization of the TP that has been widely accepted (Brantingham et al., 2001, with revisions in Brantingham et al., 2007; Brantingham and Gao, 2006). The model proposes that foragers began exploring the TP for hunting and gathering potential at 25–15 ka BP or earlier (Zhang et al., 2016), but it was only after 12–11 ka BP (Younger Dryas (YD)) that occupation sites began to be constructed, for temporary or short-term residence (Brantingham et al., 2010). After 8 ka BP, the positive impact of the prolonged Holocene warm period on climate suitability was an important driver human occupation of the TP. The ceramic and microlithic artifacts indicated Epipaleolithic human occupation of the upper YT valley after 6.6 ka BP (Hudson et al., 2014, 2016), which is also the supporting evidence for widespread colonization of the TP in the early or middle Holocene during warm, wet post-glacial conditions. However, it was the advancement and dissemination of agricultural technology after 3.6 ka BP that laid the foundation for permanent settlement on the TP (Chen et al., 2015).

The presence of pottery and carbonized millet at the Liena site at *c.* 4 ka BP indicates that the area was under the influence of agricultural production to some extent, but it is uncertain whether the agriculture was local or distant. At a minimum, it shows that there were settled residents in the YT River basin since at least *c.* 4 ka BP. Other early archeological sites in the region, the Nyingchi and Niyang River basins, contain cultural relics, including ancient human skulls, stone tools, pottery pieces, animal bones, and fishing nets that date to as early as the Late Neolithic (Lin, 1961; Wang, 1975), which was judged from the characteristics of the materials, without ages data. Hence, there is circumstantial evidence for human activities before the middle early Holocene. Furthermore, fossils of ancient vertebrate mammals such as cattle, horses, and sheep have been found on both sides of the Niyang River, suggesting the basin would have provided a good environment for the survival of Nyingchi people (Wang, 1975; Wang, 1999).

The ancient human remains and associated cultural relics discovered in the Nyingchi and Niyang River basins make a significant contribution to understanding the colonization and settlement of the TP and indicates that the area was one of the most important bases for Chinese ancient human activities (Wang, 1975). The cultural characteristics of the southeastern Tibetan cultural relics are closely related to the Neolithic culture in the upper reaches of the Yellow River (Shi, 2011; Wang, 1975). Some of the stone tools found in Nyingchi are common in the Qijia cultural sites in Gansu and Qinghai (Wang, 1975; Wang, 1999), reflecting cultural integration and tribal migration in ancient times.

In the early and middle period of the Holocene, the ecological environment of the TP was improved due to the warm and humid prevailing climate. The adjacent Loess Plateau had developed rapidly and wind-blown sediments were spreading to surrounding areas, driving hunter-gatherers to explore the relatively rich and sparsely populated TP, with some evidence of seasonal inhabitation (Zhang et al., 2016). Around 6–4 ka BP, millet agriculture spread from the middle reaches of the Yellow River to valleys in the northeastern TP, and along the eastern edge of the plateau to the west of Sichuan and Tibet, albeit the altitudinal limit for millet cultivation at *c.* 2500 m a.s.l. restricted agricultural populations to lower elevation valleys (Chen et al., 2015). Although the YT valley in southern Tibet is nearer 3000 m in elevation, it may have been suitable for cultivation of crops such as millet because of its amenable climatic conditions. There is some evidence for millet and panicum cultivation at similar altitudes and climate conditions on the southeastern TP at this time; for example, at an altitude of 3100 m in the Karuo region of Changdu city in Lantsang valley between 4.7 and 4.3 ka BP (D’Alpoim Guedes et al., 2014).

Human presence on the TP expanded rapidly after 4–2.3 ka BP, particularly after 3.6 ka BP, with the development and advancement of agricultural technology and introduction of wheat crops, livestock, and sheep, and adaptation of agriculture and animal husbandry economy to the alpine environment (Chen et al., 2016; Zhang et al., 2016). This expansion prompted humans to migrate to, and eventually settle on, higher altitude regions, such as the plateau farming culture that developed at the Changguogou and Bangga sites in the YT catchment (Wang, 1999).

Besides, the OSL ages of the cultural layer at Liena are young in comparison to the around sites mentioned in the previously researches, for example, the Qinghai Lake (Madsen et al., 2006), the north slope of Kunlun Mts. (Brantingham and Gao, 2006), the Nwya Devu site (Zhang et al., 2018), the Karuo site (D’Alpoim Guedes et al., 2014), and the Lunana Charcoal site (Meyer et al., 2009). This phenomenon indicates that the ancient population of Nyingchi could migrate from the surrounding areas at a stage when the climate is suitable, especially after the agricultural technology developed.

Conclusion

In this study, we have shown that the quartz OSL method is suitable for dating eolian strata at Liena archeological site in the YT catchment, on the southeastern TP. Using OSL, we have dated the ancient human activity layer at Liena to *c.* 4.3 ka BP, depth 185 cm, which is earlier than has been previously reported for other early archeological sites in the middle and lower reaches of YT. Commencement of eolian deposition is dated to at least 8.3 ka BP (could be as early as 11 ka BP). Climatic changes in the Holocene warm period (8.3–4.3 ka BP) played a crucial role in prehistoric human migration; the relatively warm and humid paleoclimate of the YT catchment provided suitable conditions for human exploration and settlement.

Before the early Holocene, most of the river terraces in the valley were inundated by river or lacustrine material, making them unsuitable for human activities. After the recession of ancient dammed lakes, the relatively flat and wide valley terraces provided amenable locations for exploration and settlement of ancient people, and the rich eolian deposits (such as sandy loess) provided good soil material for nomadic and even agricultural activities. Since 4.3 ka BP, the development of agriculture and high-altitude crops might have been the dominant factor that drove the migration of ancient humans and their settlement in the valley of the YT; climate changes provided the favorable environmental setting for ancient human activities.

Acknowledgements

We are grateful to Liang Chen for the field and Derong Wang for lab assistance in XRF testing. We are thankful to two anonymous reviewers for their constructive comments on a previous version of the manuscript.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was financially supported by the Second Tibetan Plateau Scientific Expedition and Research Program (Grant No. 2019QZKK0601 and 2019QZKK0602), the National Natural Science Foundation of China (Grant No. 41930323), the National Key R&D Program of China (Grant No. 2018YFC0406605), and the Qinghai Provincial Science and Technology Innovation Platform (Grant No. 2018-; ZJ-T03, and 2018-ZJ-T10).

ORCID iD

Zhiyong Ling  <https://orcid.org/0000-0002-3322-0830>

References

- Aitken MJ (1998) *An Introduction to Optical Dating: The Dating of Quaternary Sediments by the Use of Photon-Stimulated Luminescence*. Oxford: Oxford University Press.
- Brantingham PJ and Gao X (2006) Peopling of the northern Tibetan Plateau. *World Archaeology* 38(3): 387–414.
- Brantingham PJ, Gao X and Olsen JW (2007) A short chronology for the peopling of the Tibetan Plateau. In: Madsen DB, Chen FH and Gao X (eds) *Late Quaternary Climate Change and Human Adaptation in Arid China*. New York: Elsevier, pp. 129–150.
- Brantingham PJ, Ma HZ and Olsen JW (2001) Lithic assemblages from the Chang Tang region, northern Tibet. *Antiquity* 75(288): 319–327.
- Brantingham PJ, Rhode D and Madsen DB (2010) Archaeology augments Tibet's genetic history. *Science* 329: 1467–1467.
- Chen FH, Dong GH, Zhang DJ et al. (2015) Agriculture facilitated permanent human occupation of the Tibetan Plateau after 3600 B.P. *Science* 347(6219): 247–250.
- Chen FH, Liu FW, Zhang DJ et al. (2016) The process and driving force for peopling the Tibetan Plateau during prehistoric periods. *Chinese Journal of Nature* 38(4): 235–240 (in Chinese with English abstract).
- Chen FH, Welker F, Shen CC et al. (2019) A late middle Pleistocene Denisovan mandible from the Tibetan Plateau. *Nature* 569: 409–412.
- D'Alpoim Guedes J, Lu HL, Li YX et al. (2014) Moving agriculture onto the Tibetan plateau: The archaeobotanical evidence. *Archaeological and Anthropological Sciences* 6(3): 255–269.
- Dong ZB, Hu GY, Qian GQ et al. (2017) High-altitude aeolian research on the Tibetan Plateau. *Reviews of Geophysics* 55(4): 864–901.
- Hou GL, Xu CJ and Fan QS (2010) Three expansions of prehistoric humans towards northeast margin of Tibetan Plateau and environmental change. *Acta Geographica Sinica* 65(1): 65–72 (in Chinese with English abstract).
- Huang WW, Chen KZ and Yuan BY (1987) Paleolithic artifacts from Xiao Qaidam Lake in Qinghai Province, China. In: Sino-Australian Quaternary Cooperative Study Group, Chinese Academy of Science (ed) *Papers of the Sino-Australian Quaternary Symposium*. Beijing: Science Press, pp. 168–172 (in Chinese with English abstract).
- Hudson AM, Olsen JW and Quade J (2014) Radiocarbon dating of interdune Paleo-Wetland deposits to constrain the age of Mid-to-Late-Holocene microlithic artifacts from the Zhongba site, South-western Qinghai-Tibet Plateau. *Geoarchaeology* 29: 33–46.
- Hudson AM, Olsen JW, Quade J et al. (2016) A regional record of expanded Holocene wetlands and prehistoric human occupation from paleowetland deposits of the western Yarlung Tsangpo valley, southern Tibetan Plateau. *Quaternary Research* 86: 13–33.
- Huo W, Wang Y and Lu HL (2015) *Archaeological Discoveries and History of Tibetan Civilization (Vol. 1): Prehistoric Era*. Beijing, China: Science Press (in Chinese).
- Jin JH, Li ZZ, Huang YM et al. (2017) Chronology of a late Neolithic age site near the southern coastal region of Fujian, China. *The Holocene* 27(9): 1265–1272.
- Kitis G and Vlachos ND (2013) General semi-analytical expressions for TL, OSL and other luminescence stimulation modes derived from the OTOR model using the Lambert W function. *Radiation Measurements* 48: 47–54.
- Lai ZP, Kaiser K and Bruckner H (2009) Luminescence-dated aeolian deposits of late Quaternary age in the southern Tibetan Plateau and their implications for landscape history. *Quaternary Research* 72: 421–430.
- Lai ZP, Zöller L, Fuchs M et al. (2008) Alpha efficiency determination for OSL of quartz extracted from Chinese loess. *Radiation Measurements* 43(2–6): 767–770.
- Li F, Zhu C, Wu L et al. (2014) Environmental humidity changes inferred from multi-indicators in the Jiangnan Plain, central China during the last 12,700 years. *Quaternary International* 349: 68–78.
- Li Z, Wu X, Zhou L et al. (2017) Late Pleistocene archaic human crania from Xuchang, China. *Science* 355 (6328): 969–972.
- Lin YP (1961) Ancient human skeletal remains from Linchih village, Eastern Tibet. *Vertebrata Palasiatica* 3: 241–244 (in Chinese with English abstract).
- Ling ZY, Li ZZ and Jin JH (2016) Late Holocene paleo-environment reconstruction with paleosol from Kekdala profile in Yili of Xinjiang. *Marine Geology & Quaternary Geology* 36(5): 157–164 (in Chinese with English abstract).
- Lu DS, Lou HY, Yuan K et al. (2016) Ancestral origins and genetic history of Tibetan highlanders. *The American Journal of Human Genetics* 99: 580–594.
- Madsen DB, Ma HZ, Brantingham PJ et al. (2006) The late upper Paleolithic occupation of the northern Tibetan Plateau margin. *Journal of Archaeological Science* 33: 1433–1444.
- Meyer MC, Aldenderfer MS, Wang Z et al. (2017) Permanent human occupation of the central Tibetan Plateau in the early Holocene. *Science* 355: 64–67.
- Meyer MC, Hofmann CC and Gemmell AMD (2009) Holocene glacier fluctuations and migration of Neolithic yak pastoralists into the high valleys of northwest Bhutan. *Quaternary Science Reviews* 28: 1217–1237.
- Murray AS and Olley JM (2002) Precision and accuracy in the optically stimulated luminescence of sedimentary quartz: A status review. *Geochronometria* 21(1): 1–16.
- Murray AS and Wintle AG (2000) Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* 32(1): 57–73.
- Nesbitt HW and Young GM (1982) Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature* 299(5885): 715–717.
- Owen LA, Finkel RC, Haishou M et al. (2006) Late Quaternary landscape evolution in the Kunlun Mountains and Qaidam Basin, Northern Tibet: A framework for examining the links between glaciation, lake level changes and alluvial fan formation. *Quaternary International* 139: 154–155.
- Prescott J and Hutton J (1994) Cosmic ray contributions to dose rates for luminescence and ESR dating: Large depths and long-term time variations. *Radiation Measurements* 23(2–3): 497–500.
- Shi S (2011) The appearance of Tibetan Neolithic people and their relationship with the surrounding culture. *Journal of Tibetology* 7: 10–25, 256–257 (in Chinese).
- Su B, Xiao CJ, Dekar R et al. (2000) Y chromosome haplotypes reveal prehistorical migrations to the Himalayas. *Human Genetics* 107(6): 582–590.
- Sun YJ, Lai ZP, Madsen D et al. (2012) Luminescence dating of a hearth from the archaeological site of Jiangxigou in the Qinghai lake area of the northeastern Tibetan Plateau. *Quaternary Geochronology* 12(5): 107–110.
- Sun YJ, Chongyi E, Lai ZP et al. (2017) Luminescence dating of prehistoric hearths in Northeast Qinghai Lake and its paleoclimatic implication. *Archaeological and Anthropological Sciences* 10(6): 152–1534.
- Vital H and Stattegger K (2000) Major and trace element of stream sediments from the lowermost Amazon River. *Chemical Geology* 168: 151–168.
- Wang C, Kan AK, Zeng YL et al. (2019) Population distribution pattern and influencing factors in Tibet based on random forest model. *Acta Geographica Sinica* 74(4): 664–680 (in Chinese with English abstract).
- Wang HJ (1975) Neolithic age sites found in Nyingchi County, Tibet Autonomous Region. *Archaeology* 21(5): 310–315 (in Chinese).

- Wang RX (1999) *Qugong in Lhasa: Excavations of an Ancient Site and Tombs* (Institute of Archaeology Chinese Academy of Social Sciences & Bureau of Cultural Relics Tibet Autonomous Region). Beijing, China: The Encyclopedia of China Publishing House (in Chinese with English abstract).
- Yuan BY, Huang WW and Zhang D (2007) New evidence for human occupation of the northern Tibetan Plateau, China during the late Pleistocene. *Chinese Science Bulletin* 52(19): 2675–2679.
- Zhang D and Li SH (2002) Optical dating of Tibetan human hand and footprints: An implication for the palaeoenvironment of the last glaciation of the Tibetan Plateau. *Geophysical Research Letters* 29: 1072–1074.
- Zhang DJ, Dong GH, Wang H et al. (2016) History and possible mechanisms of prehistoric human migration to the Tibetan Plateau. *Science China Earth Sciences* 59: 1765–1778.
- Zhang XL, Ha BB, Wang SJ et al. (2018) The earliest human occupation of the high-altitude Tibetan Plateau 40 thousand to 30 thousand years ago. *Science* 362: 1049–1051.