

Pagoda construction ages reveal historical human migration in the Western Tibetan Plateau

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GRAPHICAL ABSTRACT



PUBLIC SUMMARY

- Early Buddhism reached the western Tibetan Plateau much sooner than previously thought.
- Pagoda building reveals major population movements.
- Pagodas serve as reliable “time capsules” for human history.

Pagoda construction ages reveal historical human migration in the Western Tibetan Plateau

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The Western Tibetan Plateau (WTP), a nexus of Central, South, and East Asia, played a vital role in shaping early Asian cultural and religious exchanges. Understanding human activities in this region is essential for reconstructing these historical interactions, yet the study of settlement and migration here faces significant obstacles due to limited archaeological research and fragmented historical records. This study employs pagoda construction as a targeted approach to investigate human migration and cultural diffusion. We compiled an extensive dataset of pagoda construction ages across the WTP using radiocarbon (¹⁴C) measurements, analyzing organic remains from 29 sites. Our results align ¹⁴C ages with documented construction dates, affirming the approach's consistency. Initial pagoda building in the Zanda Basin aligns with Buddhism's introduction to the Tibetan Plateau in the early 7th century, suggesting that Buddhism entered via multiple routes, beyond the routes in the eastern plateau. Most pagodas, however, emerged during and after the Later Propagation of Tibetan Buddhism (post-9th century), reflecting a resurgence of religious activity. In Zanda, construction spans 7th-20th centuries, while in Purang, most pagodas postdate 15th century, suggesting a significant migration from Zanda to Purang during the late Guge Kingdom and its decline, likely driven by political turmoil, religious conflicts, and climate change. These spatiotemporal patterns, corroborated by regional relic distributions, demonstrate that pagoda ages can uncover hidden histories of human mobility, providing fresh insights into the intricate interplay of early cultures, religions, and population movements across Asia.

INTRODUCTION

The Western Tibetan Plateau (WTP) lies at the intersection of Central Asia, South Asia, and East Asia, has long served as a dynamic crossroads for the exchange of religions, cultures, and diverse human populations (Figure 1).¹⁻³ With altitudes exceeding 4,500 meters and proximity to ancient trade routes like the Silk Road and Himalayan corridors, the WTP is integral to understanding the dynamics of Asian prehistory and history.³ Investigating the migratory and settlement patterns of early inhabitants in the WTP is crucial, as these movements illuminate how disparate cultures interacted, adapted to harsh conditions, and influenced one another over millennia. Several factors likely shaped human migration here. Climatic fluctuations, such as shifts between wetter and drier periods, could have altered resource availability - water, arable land, and grazing pastures - prompting populations to seek more hospitable locales.⁴ Similarly, the advent and spread of major religious traditions, notably Buddhism^{2,5} and, to a lesser degree, Islam,^{1,6} may have drawn communities toward regions where these beliefs were gaining traction, fostering cultural hubs. Yet, the WTP's formidable environment, marked by high altitudes, oxygen scarcity, extreme seasonal weather, and rugged, inaccessible terrain, combined with a paucity of well-preserved historical records, poses substantial challenges to conventional research approaches.

Previous investigations into human migration across the Tibetan Plateau have predominantly leaned on archaeological evidence, including the excavation of ancient artifacts, burial sites, and settlement ruins.⁷⁻¹⁰ These discoveries have offered valuable glimpses into the material culture and lifeways of past inhabitants, revealing tools, pottery, and architectural remnants that hint at their daily existence.^{11,12} However, the WTP's harsh environment often result

in scarce, fragmented remains, making comprehensive interpretation difficult and leaving significant gaps in the historical record. Genetic analyses have complemented these efforts by tracing the origins and dispersal of Tibetan populations using mitochondrial DNA and Y-chromosome markers.^{13,14} While such studies have effectively delineated broad-scale population movements and long-term genetic continuity,¹⁵ they often lack the temporal and spatial resolution needed to capture fine-scale migratory patterns or to elucidate the specific cultural, historical, and environmental factors that drove local population shifts within the western Tibetan Plateau. Additional lines of evidence, including high-resolution archaeological chronologies, are therefore essential to fully decipher these early migrations.

Pagodas, as enduring religious structures emblematic of Tibetan heritage, transcend their spiritual significance to serve as tangible markers of human presence and community development.^{5,16,17} Their construction is intricately tied to settlement patterns, often coinciding with the establishment of villages or monasteries, and they are frequently linked to pivotal religious events, revered figures, and the propagation of Buddhism across the plateau.¹⁸⁻²⁰ Exploring the history of pagoda construction provides a unique perspective on the social, economic, and religious evolution of Tibetan communities over time.²¹ While prior research has delved into pagoda architecture, iconography, and symbolic roles,²² their construction ages, determined through a blend of scientific techniques like radiocarbon dating and historical corroboration, offer untapped potential to chart the temporal and spatial dimensions of human migration. By integrating radiocarbon (¹⁴C) dating with historical and archaeological data, this study systematically analyzes pagoda construction ages across the WTP, revealing spatiotemporal patterns that illuminate the region's role as a nexus of cultural interplay and migration over the past 2,000 years.

MATERIALS AND METHODS

Sample collection and radiocarbon (¹⁴C) measurement

We surveyed pagodas and collected plant remains for ¹⁴C dating at 61 sites in four WTP counties, including Purang, Zanda, Gar, Rutog (Figure 2). We collected samples from long-abandoned pagodas (Figure 3), as some pagodas undergo continuous repairs and maintenance in Tibet. Plant remains, including twigs, seeds, charcoal, were collected exclusively from deep, structurally integral parts of the pagodas that are highly unlikely to have been replaced during later repairs: wooden beams, pillars, and lintels fully encased within foundation walls or core masonry; short-lived plant remains (twigs, seeds) originally used as temper in the founding layer of rammed earth or clay mortar. No samples were taken from surface plaster, roof elements, or any easily accessible parts that are routinely renewed. The plant remains were carefully picked out using needle-nose pliers, and were stored in Whirl-Pak bags in the field (See Section 3 in Supplementary Information for annotated images of sampled materials). At each site, we tried our best to consult local residents and government officials to learn the legend, history, construction age, religious sect, functions for all pagodas.

In laboratory, the plant remains were examined using microscopes; none showed rootlets, fungal hyphae, or other signs of modern biological contamination (Figure 4). We selected 29 samples to perform ¹⁴C measurements in the Radiocarbon Laboratory at the Lanzhou University.²³ Pre-treatment followed the standard acid-alkali-acid protocol with an additional hot 1%

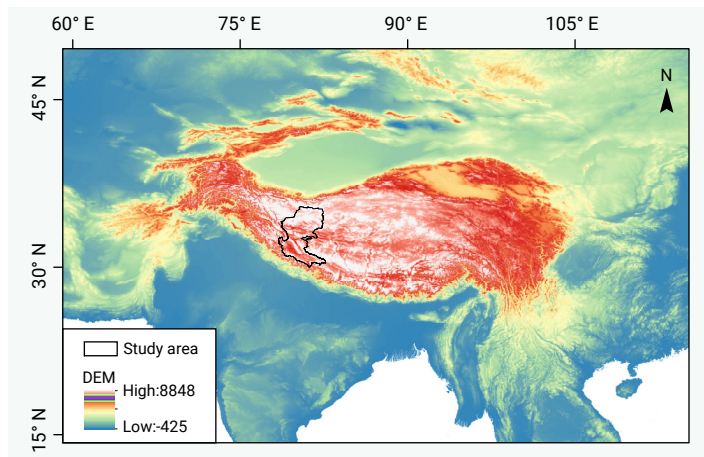


Figure 1. Geographical location of the Western Tibetan Plateau (black outline), situated at the convergence of Central Asia, South Asia, and East Asia.

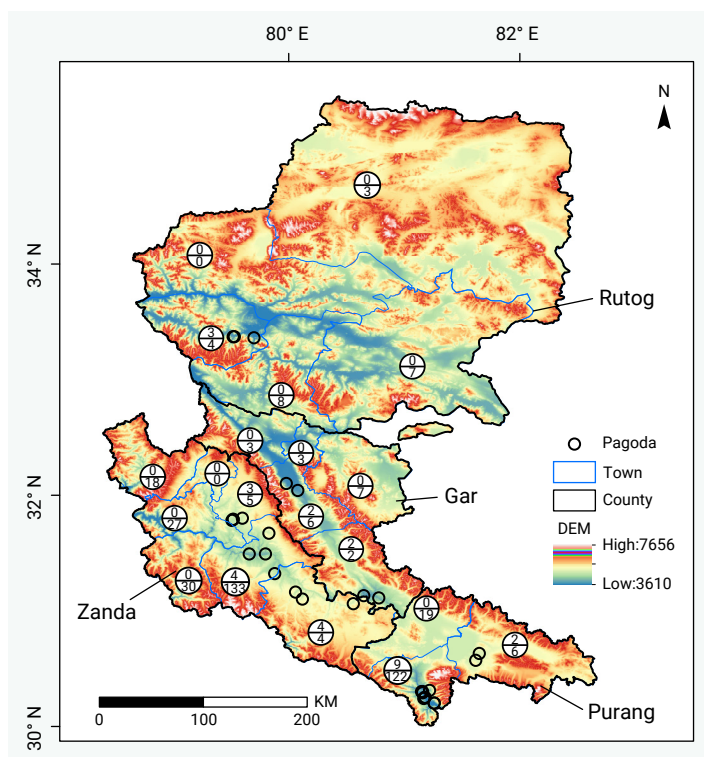


Figure 2. Pagoda distribution across four counties in the Western Tibetan Plateau (Purang, Zanda, Gar, Rutog). Open circles indicate pagodas sampled for ^{14}C dating in this study. Numbers within circles denote the total pagodas in each county (below) and the number sampled (above).

NaOH step to remove any possible mobile humic acids. The ^{14}C ages were calibrated to calendar ages using OxCal v4.4 (<https://c14.arch.ox.ac.uk/oxcal.html>) and the IntCal20 curve.²⁴

Archaeological site data from the Third National Cultural Relics Survey

We used archaeological site data from the Third National Cultural Relics Survey database, covering pagodas, monasteries, houses, tombs, caves, rock art, and other remains across Purang, Zanda, Gar, and Rutog. Most survey sites lack precise ^{14}C dates, with some ages estimated from artifact typologies (e.g., ceramics, architectural styles), yielding broad ranges. We applied a binary-overlap method to cluster these estimated ages into 50-year intervals, balancing their ± 40 –100-year uncertainties with interpretability.²⁵ To test reliability, we analyzed Zanda County data (highest site count) with 50, 100, and 200-year intervals, finding consistent distribution patterns peaking during the period of Guge Kingdom (10th–14th century) (Figure S1). Despite potential

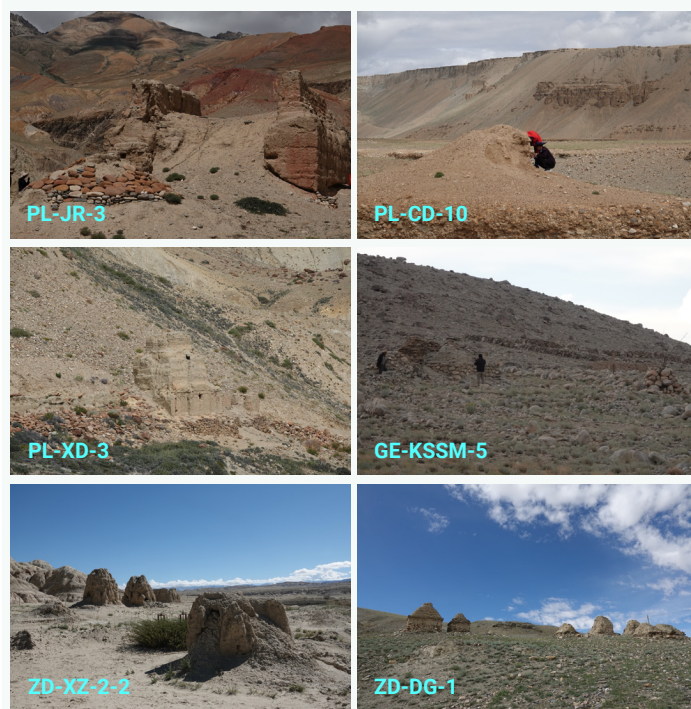


Figure 3. Representative photographs of sampled pagodas and surrounding landscapes from four counties in the Western Tibetan Plateau. Additional images of the sampled pagodas are provided in the Supplementary Information.

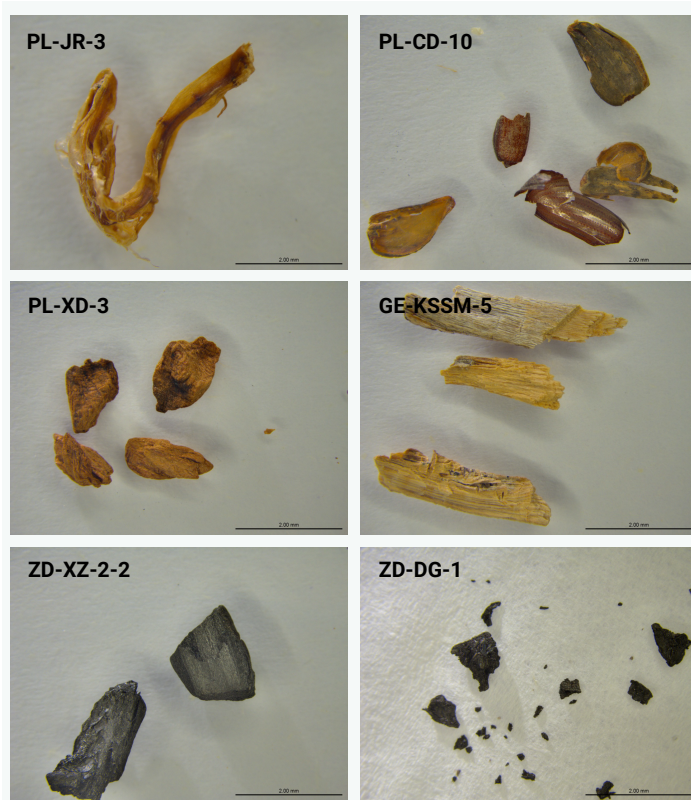


Figure 4. Macroscopic photographs of organic dating samples extracted from pagodas across four counties in the Western Tibetan Plateau. Each image includes a scale bar of 2 mm. See Section 3 in the Supplementary Information for additional photographs of the sampled materials.

sample overlap in wider bins, trends remain stable. Thus, 50-year intervals, presented as relative percentages, capture temporal trends without affecting conclusions.

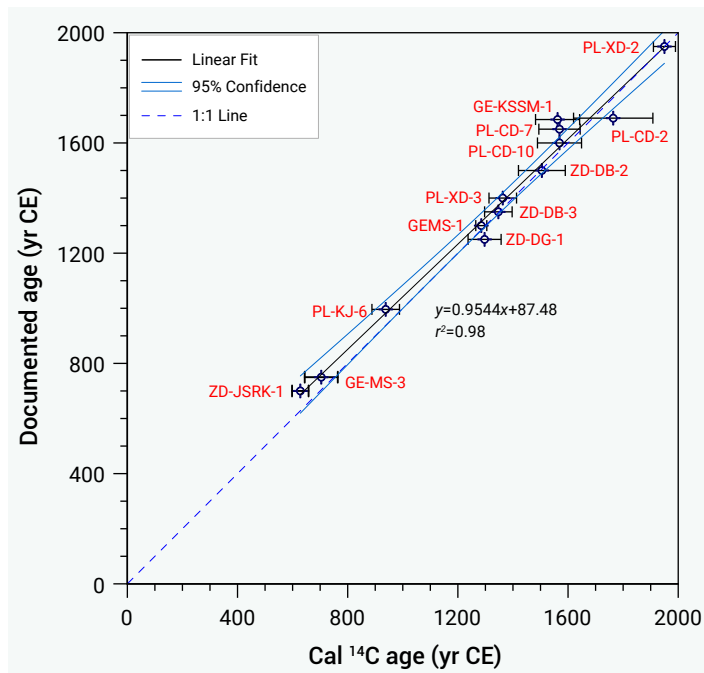


Figure 5. Correlation between mean calibrated ^{14}C ages (with 1σ error bars) and documented ages for selected pagodas (names indicated). For documented ages, PL-KJ-6 (Korqag Monastery) is dated to 996 CE. Most other pagodas have estimated age ranges, omitted from the figure for clarity (Table S1). The dashed line represents the 1:1 correlation, and the solid line shows the linear regression.

RESULTS

Documented ages for some pagodas are available from local chronicles of the four WTP counties and early Tibetan manuscripts. For example, Korqag Monastery's construction in 996 CE is recorded in Sönam Gyaltzen's 1388 CE Tibetan manuscript, translated by Per K. Sørensen,²⁶ which documents establishment of monasteries in Ngari to promote Buddhism, including Korqag to honor Rinchen Bzanpo. Zashi Quelin Monastery's construction (1100–1300 CE) is documented in an early Tibetan manuscript, translated by Roberto Vitali,²⁷ noting its role in consolidating Buddhism in Zanda. Some other documented ages can be found in local chronicles (Table S1).

To cross-validate with documented records, we compared mean calibrated ^{14}C ages with documented ages (Figure 5). For instance, Korqag Monastery in Purang (Sample i.d. PL-KJ-6), constructed in 996 CE to honor the revered translator Rinchen Bzanpo, yielded a calibrated age range of 888–987 CE, slightly predating but encompassing the historical date. Similarly, Zashi Quelin Monastery in Zanda (ZD-DG-1), recorded as built between 1100 and 1300 CE, returned a calibrated age range of 1278–1394 CE, aligning with its later documented phase. Guru Bajalin Monastery in Gar (GE-MS-3), documented at 700–800 CE, produced a calibrated age range of 658–744 CE, reinforcing consistency (Figures 5 & 6). This strong correlation between calibrated ^{14}C ages and historical ages instills confidence in applying the technique to most pagodas lacking historical records. However, anomalies emerged: some ^{14}C ages postdate documented construction, suggesting later repairs or rebuilds. For example, Rebkong Monastery in Zanda (ZD-XZ-RBJL), built in the 15th century, yielded 1694–1917 CE, indicating significant restoration. Conversely, two outliers, Lhakhang Karpo Monastery (ZD-DB-4) and Ruqiong Archaeological Site (ZD-XZRG-1) in Zanda, dated to ~300 BCE, likely due to the use of ancient wood in construction, and were excluded from further analysis.

Across the WTP, most pagodas were constructed between 600 and 1900 CE (Figure 6). In Zanda County, construction ages span this full range, reflecting a long and continuous occupation. In contrast, Purang County's pagodas predominantly postdate 1400 CE, hinting at a later settlement surge. Gar County shows pagodas from 700–1600 CE, and Rutog from 1100–1600 CE, though both have fewer sites, suggesting less intensive activity.

The earliest pagoda, dated 602–654 CE near Gyirong Cave in Zanda County, coincides with Buddhism's introduction to the Tibetan Plateau in the

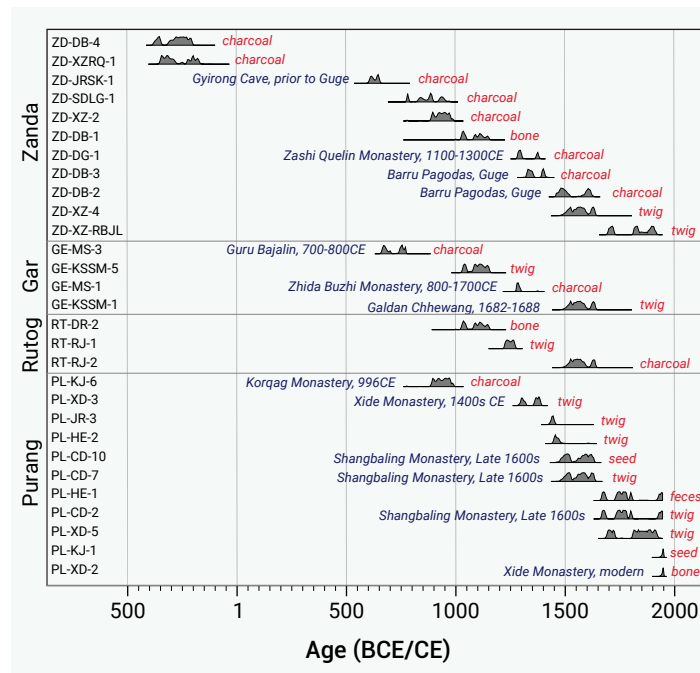


Figure 6. Distribution of calibrated ^{14}C ages for pagodas in four Western Tibetan Plateau counties (Zanda, Gar, Rutog, Purang). Red letters on the right denote dating materials, while blue letters on the left indicate site and documented ages. Note that ZD-DB-4 and ZD-XZRG-1 were excluded from discussion in the text.

early 7th century, following Songtsen Gampo's unification of Tibetan tribes and his marriage to Nepalese princess Bhrikuti, credited with introducing Buddhist practices via Himalayan routes through Nepal.²⁸ Despite the WTP's remoteness from Lhasa, the Tibetan Empire's political and cultural center, this early pagoda suggests Zanda was a religious hub, likely due to its accessible valleys and milder microclimates. This finding, contrasting with Lhasa-centric routes from India through the eastern plateau,²⁹ indicates at least two distinct pathways for Buddhism's entry, highlighting Zanda's role in early religious diffusion.

A second wave of pagoda construction peaked during and after the Later Propagation of Tibetan Buddhism, beginning in the late 9th century after the Tibetan Empire's collapse. This period saw Buddhism flourish anew in the WTP, driven by local royalty and religious figures. For example, Toling Monastery in Zanda and Korqag Monastery in Purang, both built in 996 CE under Guge Kingdom patronage for Rinchen Bzanpo, mark this resurgence. Between 1000 and 1400 CE, Zanda remained a focal point, with construction gradually extending to Gar and Rutog, albeit in smaller numbers, indicating a slow expansion of settlement and religious influence. After 1400 CE, Purang experienced a dramatic increase in pagoda building, contrasting with Zanda's broader timeline. This shift suggests a substantial migration from Zanda to Purang during the late Guge Kingdom (15th - 17th centuries) and its eventual decline, potentially driven by political instability, economic shifts, or environmental pressures, as explored in the discussion.

DISCUSSION

The spatial distribution of dated pagodas is uneven across the four counties for three well-documented reasons (Figure 2). First, preservation conditions vary dramatically: many pagodas in the remote northern and western parts of Rutog and Gar are almost completely buried by active sand dunes or reduced to low mounds, making safe and meaningful sampling impossible during the study period. Second, military and border-permit restrictions prevented access to several clusters of known sites near the international boundaries. Third, we deliberately prioritized the historical core zone of the former Guge kingdom, where both Tibetan and Chinese historical sources place the earliest introduction and most intensive development of Buddhism in western Tibet. Consequently, while Zanda and Purang contain the majority of dated sites, these counties also host the largest number of well-preserved, accessible early pagodas. The 29 dated examples therefore constitute a representative

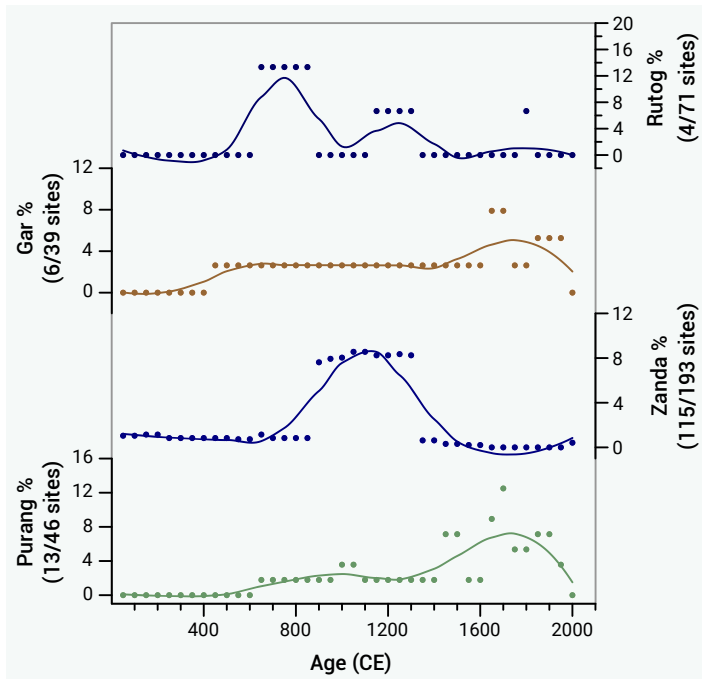


Figure 7. Temporal frequency distribution of archaeological sites per 50-year interval across four counties in the Western Tibetan Plateau Solid circles represent the percentage of sites with estimated ages; solid lines show the LOESS-smoothed trend for each county. Sample sizes are indicated (e.g., Zanda: 193 total sites, 115 with estimated ages). Data are from the Third National Cultural Relics Survey database (Tibet Institute for Conservation and Research of Cultural Relics).

sample of the most informative portion of the total population of documented pagodas.

The spatiotemporal distribution of pagoda construction ages in this study finds support in the Third National Cultural Relics Survey (Figure 7), a comprehensive catalog of national archaeological sites, though most of the ages were primarily inferred from site characteristics and historical documentation (Data from Tibet Institute for Conservation and Research of Cultural Relics). The Survey documents diverse features, including houses, tombs, rock art, and fortifications, that directly reflect human occupation and migration, complementing the pagoda dataset.³⁰ While pagodas primarily signify religious activity, their ages also trace a complex pattern of human mobility across the WTP over the past millennium. This synergy between datasets reinforces the reliability of our findings and underscores pagodas' broader historical significance.

In the Zanda Basin, early pagoda construction (7th – 10th centuries) likely arose from a confluence of political stability, Buddhist expansion, and environmental optimum. The Guge Kingdom's prosperous era (10th – 13th centuries) catalyzed a significant uptick in pagoda building across Zanda, Gar, and Rutog, as local rulers bolstered their authority through religious patronage. The Later Propagation of Tibetan Buddhism, ignited by Atisha's arrival in Guge in 1041 CE, further intensified this trend, promoting pagoda construction as a symbol of renewed faith across Zanda and neighboring regions. Speleothem oxygen isotope records from North India⁴ reveal a warm, humid climate during the 10th–13th centuries, enhancing Zanda's agricultural potential and supporting larger, settled populations. These conditions likely made Zanda an attractive early hub, as evidenced by the proliferation of pagodas during this period.

The post-1400 CE increase in Purang pagodas, dated via ¹⁴C, aligns with historical records of the Guge Kingdom's decline, including wars with the Ladakh Kingdom (15th – 16th centuries)³¹ and Mughal incursions,^{1,6} which likely displaced Zanda communities. Archaeological data from the Third National Cultural Relics Survey, showing a parallel rise in non-religious sites (e.g., houses, tombs) in Purang (Figure 7), further support migration. Both regional speleothem record⁴ and paleolimnological record³² indicate cooling during the Little Ice Age (14th – 19th centuries), reducing Zanda's agricultural capacity, while Purang's trade routes offered economic incentives. While

Buddhist expansion, driven by Gelugpa–Kagyupa rivalries,^{29,33} contributed to pagoda construction, the concurrent rise in settlement indicators favors migration as a primary driver, though we acknowledge that ¹⁴C dates and archaeological patterns suggest, rather than confirm, population movement without exhaustive documentary evidence.

Inferring settlement and migration from pagoda ages has limitations. Later repairs or expansions can skew ¹⁴C dates, as seen in discrepancies with documented records or oral histories (e.g., Rebkong Monastery's 15th-century origin vs. 1694–1917 CE calibrated ¹⁴C range). Moreover, pagodas' connection to human activity is not always straightforward. Built in remote locations for spiritual purposes, they may not mark settlements, and their construction could lag behind or precede population shifts, complicating causal links.

The radiocarbon-dated pagoda sequence presented here does not stand alone as evidence of population movement but forms a precise chronological skeleton that can be meaningfully confronted with independent historical, archaeological, and genetic datasets. Historical documents on Tang and Tibetan Empire period, including Old Tibetan Annals,³⁴ later Tibetan sources (mNga'ris rgyal.rabs),²⁷ Old and New Tang Books explicitly record two major corridors of cultural and demographic exchange into western Tibet: an early southern route through the Maryum La and Nepal during the 7th–8th centuries, and a later western/northern route centered on the Guge kingdom from the late 10th century onward. Remarkably, these documented phases coincide almost exactly with the two phases in pagoda construction revealed by our ¹⁴C chronology: an initial cluster in the Zanda Basin at 600–800 CE and a second, broader wave after ~950 CE that progressively extends from Zanda into Purang, Gar, and Rutog. Recent ancient DNA studies further corroborate this pattern, documenting significant gene flow from northern India and Central Asia into the western and central Tibetan Plateau precisely during 700–1000 CE and again around 1400–1700 CE.^{13–15} When combining pagoda construction phases and known historical routes and aDNA sampling locations, a dynamic picture emerges of repeated, directionally coherent pulses of Buddhist transmission and accompanying human mobility along the southern Himalayan fringe and across the western plateau—pulses that our pagoda chronology now dates with unprecedented spatial and temporal resolution.

This study opens new research avenues: future work could disentangle pagoda–migration relationships by integrating detailed oral histories, landscape-scale archaeological surveys, and additional relic data. Refining ¹⁴C techniques – accounting for repair biases – and applying them to other Tibetan Plateau regions or comparable high-altitude zones could further illuminate human, environment, and culture interactions, enhancing our grasp of Asia's historical mobility.

CONCLUSION

We demonstrated that the radiocarbon dating results of pagodas in the western Tibetan Plateau are consistent with their historically documented construction ages. The spatiotemporal patterns of these radiocarbon ages can reveal the spread of Buddhism and human migration during historical periods—an invaluable insight for the western Tibetan Plateau, where scarce historical documents and limited archaeological evidence hinder traditional historical analysis. This novel methodology holds broader applicability for similar research in other regions.

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AUTHOR CONTRIBUTIONS

J.H. designed the study. Q.Q. performed radiocarbon measurements. All authors collected samples in the field trip in Western Tibetan Plateau. J.H., G.H., and X.H. wrote and revised the manuscript. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.

DATA AND CODE AVAILABILITY

The radiocarbon data can be found in the supplementary Information.

SUPPLEMENTAL INFORMATION

It can be found online at <https://doi.org/10.59717/j.xinn-geo.2026.100202>.