The early evidence of naked barley in western Tibet: evidence for cereal cultivation at extreme altitude along the upper Sutlej River, ca. 3500 BP

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Keywords: *Hordeum vulgare,* archaeobotany, Himalayas, South Asia, Central Asia, Indus valley, alpine agriculture

Abstract: The Gepa serul cemetery, located in Ngari Prefecture has produced the earliest evidence of naked six-rowed barley in Tibet dating back to ca. 3500 BP. Despite being nearly 4000 meters above sea level, this region was connected to wider interregional of cereal agriculture. We consider alternative dispersal hypotheses for barley and farmers to the region, including either farmer migrations upwards from the Indus plains, or trade through Central Asian mountain corridors; this was distinct from the pathways by which wheat and barley entered Qinghai or eastern Tibet.

Introduction

Cultural communication and transmission had an important impact on Old World civilizations, and crop exchanges were an important category of cultural transmission since the Third Millennium BC (e.g. Dong *et al*. 2017). One region that has received particular attention is the Inner Asian Mountain Corridor [IAMC] region of Central Asia (*sensu* Frachetti 2008), which has produced the earliest secure evidence of millets of Chinese origin outside of China, as well as wheat and barley before their appearance in central China. (Spengler *et al*. 2014; Stevens *et al*. 2016; Zhou *et al.* 2020). The initial connections across central Asia have been modelled in terms of down the line diffusion of crops through a network seasonally transhumant pastoralists (Frachetti et al. 2017)), but the role expansion by migrating cereal farmers, as they became more adapted to higher elevation environments also need exploration (Motuzaite-Matuzevicute et al. 2020). More generally, such processes of globalization have played a significant role in the evolution and adaptability of crops that lies between initial domestication and modern agronomic diversity, and has been under-theorized (Fuller and Lucas 2017; Jones and Liu 2024).

In the context of Chinese archaeology research has explored how free-threshing wheat was added to millet-centric agriculture from the late Third Millennium BC (Liu *et al*. 2017; Deng *et al*. 2020). In contrast, barley is little known from central China but was important for the expansion of agriculture to higher elevations in Qinghai/Tibet from ca. 1600 BC (e.g. Chen *et al*. 2015; Liu *et al.* 2017; Li *et al.* 2019; d'Alpoim Guedes *et al.* 2015). Unlike other cereals, barley can tolerate cultivation at extremes of altitude, up to ~4200 m.a.s.l. (CSIR 1959).

Barley (*Hordeum vulgare sensu lato*) originated from southwestern Asia undergoing domestication between ca. 11,000 and 9500 BP, initially as a two-row hulled form (Fuller & Weisskopf 2014; Zohary et al. 2012). Barley then diversified into six-row and naked forms, and these varied forms dispersed outwards from the Fertile Crescent to Europe, Africa, and eastwards across Asia. Barley spread initially through Iran and southern Central Asia (Turkmenistan), including both hulled and naked six-row forms (Charles & Bogaard 2010), reaching Djeitun in southern Turkmenistan ca. 8000 BP. It was only around 3000 years later that both kinds of barley and wheats are found in the Inner Asian mountain corridor of northern Central Asia, represented bs Tongtian Cave in the Altai, ~1800 m.a.s.l., ca. 5000 BP (Zhou *et al.* 2020), and Kochkor valley sites of Kyrgyzstan, ~2000 m.a.s.l., ca. 4500 BP (Motuzaite-Matezeviciute *et al.* 2020). After a pause in the Indus region, barley spread to other parts of India east of the Indus from around 4500 BP (Fuller 2006). This indicates a three-stage process of the dispersal of barley and wheat from their region of origin into South Asia or Central Asia.

In China, the early barley discoveries and their dating differ from the evidence for wheat, being generally later in central China. Starting from the earliest barley and wheat from the Tongtian Cave site in the Altai Mountains of Central Asia, dated back to 5200 BP (Zhou *et al.* 2020), the next earliest barley remains come from a group of sites in the northeastern Qinghai (Chen *et al.* 2015), dated between 4000 and 3600 BP. Within the Tibetan Plateau itself finds of barley post-date 3400 BP (Tables S1-S2)

We report here barley remains, dating back to 3500 BP, found in the Gepa serul cemetery in the Ngari region of western Tibet plateau (**Figure 1**; Table S3 provides Tibetan and Chinese versions of placenames). This evidence is now amongst the earliest finds of barley in Tibet and warrants a review of the evidence for the archaeological distribution of various barley forms prior to dispersal to Tibet.

Ngari environment and Gepa Serul setting

Ngari is the highest and coldest region on Tibet Plateau, with an average altitude of 4,800 ~ 5,000 m.a.s.l. (Tashi Tsering *et al.* 2022). The climate here is quite cold, dry, and windy, with annual precipitation less than 50~100 mm and annual mean relative humidity of 30~40%. Soil is thin and sandy, typical of alpine desert. Although the sparse grassland is of low quality, animal husbandry is widely practiced, including sheep and goat for meat, and Yak that also provides milk.

In Tibet, the primary cereal crops are barley, wheat, and pea, while secondary crops include broad bean (*Vicia faba*), potato, buckwheat, maize, and at lower elevations rice and finger millet (*Eleusine coracana*) (Wang 2012). Naked barley (six-row), commonly named *qingke* is dominant, occupying 81.5% of the sown area (TCSTP, 1984). Ngari prefecture has the lowest agricultural production of a Tibetan region.

Gepa serul (79 ° 48 ' E, 31 ° 34 ' N, 3780 m.a.s.l) is a cemetery on the east terrace of Sang dar lung shur brook (**Figures 2, 3**) a northern branch of Glang-chen Gtsang-po river, which becomes known as the Sutlej in India.

Gepa serul is near the northern Himalayan border of India. This region is the place of origin of three great rivers of South Asia-- the Brahmaputra, the Ganges and the Indus, and is famous for the sacred Mount Kailash and Lake Manasarovar (Fig. 1). In the past, the Zhang zhung kingdom and Gu ge kingdom were centered in this territory (Zhang 2009; Huo 1997).

The Gepa serul cemetery was first discovered and investigated in 1999 (Li 2001). In 2017, the archaeological union of the Institute of Cultural Relics Protection of Tibet Autonomous Region, Shaanxi Academy of Archaeology, and the School of Cultural Heritage of Northwest University renewed excavations at the Gepa serul, focusing on eight tombs belonging to phase I (ca. 3600-3000 BP) of Gepa serul cemetery.

Materials and methods

During the 2017 excavations, 34 soil samples were collected from tomb M2, including 12 from inside ceramics (Fig. 4). The total volume ~11 litre of soil samples was dry sieved at Northwest University (Xi'an, China) to 0.4mm to recover plant remains. Identifiable carbonized grains came only from jar No. 8. One grain was directly dated by AMS radiocarbon.

Results

Two carbonized cereal grains, 24 carbonized rachis and one carbonized smaller grass grain were found (**Figure 5**). The carbonized grains and rachis are identified as domesticated naked six-rowed barley (*Hordeum vulgare* L. subsp. *vulgare* var. *coeleste* L., syn. *H. hexastichum* L. var. *coeleste*) (on taxonomy see Zohary *et al.* 2012). Spikelet trifurcation can be seen on the rachis node of barley, which is typical of six-rowed barley (Fig. 5, D-I). Six-row barley has substantial lateral floret bases that flare outwards at the top of each rachis segment. Naked forms have persistent raised floret bases extending above the top of the rachis segment, although they may be damaged and removed through charring or post-depositional processes, which can make naked forms emulate hulled forms (but not vice versa). The barley grain is large, 6.98 mm long, and 4.17 mm wide; it lacks the angular cross-section of hulled barley (Fig. 5A). .

The presence of copper artifacts at Gepa serul indicates that this site represents the Tibetan Metal Age (Tong 1985), which falls between the Second Millennium BC and the early centuries AD. The directly dated grain has a calibrated range of 1505-1397 cal. BC (95.4%) (based on Reimer et al. 2020) (Beta489360 3170±30 B.P., d13C -22.2).

The single grain of weedy grass is identified as *Bromus* in the section *Bromus*. Based on its form, size and geography it is referred to *Bromus* cf. *ramosus,* although it is not possible to determine this confidently to species level (Fig. 5, C-D).

Discussion

As the barley from Gepa serul appears to be six-row, naked (based on small sample size), we can ask where else contemporary or earlier such barley was found (**Figure 6, Table S1-S2**). Based on an updated version of Asian Crops Archaeobotanical Database (updated after Stevens *et al.* 2016), we have plotted naked barley (Fig 6a) and hulled barley (Fig 6b). While two-row forms may be included in these distributions, we expect six-row to be normally present by the periods covered here, and to tend to dominate unless there is strong cultural and environmental selection to maintain two-row forms because six-row barley is typically has three times the seed production of two-row (Palmer et al 2009). This is also implied by the genetic data, as naked forms with soft hulls appear to have evolved just once by the *nud* mutation (Taketa *et al.* 2004; Lister & Jones 2013), whereas six-row forms evolved multiple times (Komatsuda *et al.* 2007; Palmer *et al.* 2009).

Six-row barleys and naked barleys both occurred before the end of the Pre-Pottery Neolithic in Western Asia as early as 10,000-9500 BP (Zohary et al. 2012). In central Anatolia, Çatalhöyük (from 9100 BP) has returned the full range of barley varieties but two-row naked barley was dominant (Bogaard *et al.* 2017)). This barley diversity appears quite typical not just of Neolithic Anatolia but also the initial dispersal of cereals into Europe, as represented by Knossos (~8500 BP) (Kotzamani & Livarda 2018). Both hulled and naked barleys reached Central Asia in the Neolithic, and indeed six-row naked forms are reported to be the dominant barley at Djeitun (~8000 BP) in southern Turkmenistan (Charles & Bogaard 2010) and at Mehrgarh in Pakistan (~7000 BP) (Fuller 2006). The further spread of barley eastwards slowed, with most finds from the Indus region eastwards dating after 4500 BP (Fuller 2006; Liu *et al.* 2017). One reason for this may have been the necessary adaptation to warmer winters and shifts to earlier harvests. Although there was a diversity of barley for early farmers to choose from in Central and Southern Asia, hulled barleys were less favoured, with naked barley dominant, from southern Turkmenistan, to highland steppe of eastern Kazakhstan, and mountain valleys in Kyrgyzstan (Spengler *et al.* 2014; Motuzaite Matuzeviciute *et al.* 2018; 2020). In South Asia, both barleys, including hulled barley, were found from the western edge of the Himalaya (Spate *et al.* 2021; Yatoo *et al.* 2020; Betts et al. 2019; Pokharia *et al.* 2017).

In China, it is also the case that six-row naked barleys appear more common. This includes the early finds at sites in Qinghai, 4,000-3500 BP (Chen 2015), and the several sites in southeastern Tibet dating the period 3500-3000 BP (Table S1). Hulled barley finds in China have been fewer, but are notably present amongst finds from Bronze Age Yunnan, for example at Bronze Age Haimenkou (~3400 BP) (Xue *et al.* 2022).

Contrasts between the Chinese central plants and Tibetan plateau suggests that diffusion of wheat and barley were separate. Some Barley likely entered the Tibetan plateau from the northeast, via. Qinghai province, while wheat spread at lower elevations eastwards to central China (d'Alpoim Guedes *et al.* 2015; Chen *et al.* 2015). Somewhat later and more in central Tibet, Phrang mgo indicates the mixed agriculture of millet, wheat and barley (Fu & Ruan 2000; Lv 2016). In addition, the latest barley dating result from Chu kong near Lhasa is 3369-3211 BP (Gao *et al.* 2020). Most of the reported evidence is 1100-1600 km east of Gepa serul.

The northward dispersal of wheat and barley to the Tian Shan Mountain region and then eastwards into the northern latitudes of China would have required the acquisition of spring seasonality, to avoid growing through the very cold winters (Liu *et al.* 2017; d'Alpoim Guedes *et al.* 2016), and there is no reason to assume that both barley and wheat evolved these genetic adaptations equally quickly. Indeed the hexaploid status of bread wheat may have allowed for adaptational flexibility due to dosage effects of variant alleles across its 3 genomes (Dubcovsky & Dvorak 2007).

Barley originated from the low altitude region with mild, rainy winters in Southwest Asia and is a kind of long-day plant, which flowers in later Spring as days lengthen. This is underpinned by genes affecting photoperiod response, as well as vernalization genes that are activated by cold winter days (Fu *et al.* 2005; Cockram *et al.* 2011; Liu *et al.* 2017). The distribution of these spring-adapted genotypes is rare in wild barley but appears to occur in populations of the mountains of northern Iran, suggesting a genetic contribution from these populations, but whether this means that all spring barleys derive from this region is by no means clear. Warm winters in parts of the lower Indus Valley, for example, could favor spring sown varieties too to avoid the need for vernalization.

Ngari in western Tibet may have received crops directly from the west rather than via northwest China. Previously naked barley from the Ting dom site, not far from the Gepa serul cemetery, dating 2400- 1900 BP, was also suggested as possible diffusion from the Indus region (Lv 2014). Gepa serul pushes western Tibetan barley substantially earlier, earlier than central Tibet and nearly as early at Qinghai.

We consider two westerly routes for dispersal of barley to southwest Tibet. On the one hand, it may spread from the Indus valley, upwards through Himalayan river valleys, such as the Sutlej. On the other hand, it may spread along the northern margin of the Iranian Plateau, through the Pamir mountains, especially the Wakhan corridor, then via the Kashgar region of southern Xinjiang, into Ngari. A riverine dispersal might be hypothesized to have involved winter-grown barley perhaps evolving into spring-grown varieties as it moved up the Indus and its tributaries into mountain regions. In contrast, a mountain corridor route would be expected to have been based on an earlier evolution of spring barley, that would have stayed in higher elevations or spread to higher latitudes.

In hypothesis 1, the journey is from South to North. For the development of the economy of the border area, a modern government study states that Mountain passes Shipki La (Srib kyi la), Chongnyi La, Niti, Kungribinri, Darma, Lipu Lekh (Byang-La), etc. will be opened (Wu *et al.* 2021), highlighting the potential of these passages for connecting southwestern Tibet with the Indian subcontinent. This could be argued to fit the hypothesis of Zeng *et al.* (2018) that highland barley originated in the south, entering southern Tibet 4500-3500 BP through northern Pakistan, India, or Nepal. However, against this hypothesis is the analysis of Lister *et al.* (2018) who found quite divergent genotypes of modern barley in the lower Indian plains from those in Tibet. We would also note that barleys of the lower plains of the Indus were distant in adaptations from those needed in Tibet, as the southern regions have higher winter temperatures, winter cultivation is the norm and harvests are in the spring, around March (see Petrie & Bates 2017).

In hypothesis 2, we can consider a journey from northwest to southeast through the Pamirs. This posits a route similar to China National Road No. 219, also named the Xinjiang-Tibet line, which follows a path that connected Xinjiang and Tibet since ancient times. The conditions along this road, which is 2140 kilometers long, are extremely harsh, with an average altitude of more than 4500 meters and includes 16 icy mountain passes and glaciers as obstacles (Tian 2011). Wang (2009) records that this route was operational with ancient post stations during the Qing Dynasty, so it is conceivable that connections started as early as 3500 BP. The presence of *Bromus* cf. *ramosus* might favour hypothesis 2, as *B. ramosus* is a very temperate grass, known from high elevation through Central Asia, northern Pakistan, Kashmir and the Himalayas and Tibet, generally above 2900 meters (Cope 1982; Liu et al 2006). If its easterly distribution is anthropogenic, then this fits better with a dispersal via the Inner Asian Mountain corridor.

Some geographical patterns of barley genetic groups (haplotypes) have been discussed and highlight a distinctive grouping of within Eastern Eurasian barley, that is the Tibetan *qingke* barleys (Zeng et al. 2018). In their analysis Lister *et al.* (2018) found a population associated with the lower elevations of the Indian subcontinent, distinct from Tibetan, Himalayan, and some Central Asia mountain barleys. Lister *et al.* (2018) conclude with four distinct dispersal hypotheses, including two barley routes into the Himalayas and Tibet from the west, which match our two hypotheses for the origins of the Gepa serul barley.

What needs to be emphasized is the contrast between migration and trade in the two hypotheses. In hypothesis 1 we would envision barley farmers gradually migrating up river valleys over generations allowing for experimentation with barley through which seasonal adaptations evolved. In hypothesis 2, the route is largely uninhabitable, so this would represent movement of barley (contaminated by *Bromus*) through long-distance trade, and assume that seasonal adaptations had originated in the mountains of the northern Iranian plateau, such as the Kopet Dag or the Hindu-Kush. These hypotheses have different predictions. In hypothesis 1 we should be able to identify precursor cultural assemblages to Gepa Serul from prior centuries to the southwest in India. By contrast, hypothesis 2 leads to expectation of evidence for contemporary trade with cultural contexts across the mountains of Central Asia.

Other lines of evidence suggest continuities of pre-agricultural populations at Gepa serul with long distance trade. The only female skull of phase I of Gepa serul discovered exhibits close affinities with the East Asian Mongoloid population and the "Ancient Northwestern type", displaying a subtle European genetic influence (Chen et al. 2023). Furthermore, preliminary technological analyses of the artifacts unearthed at the Gepa serul site reveal a possibility that Faience beads originated from Egypt (Cao S. et al. 2021), while the provenance of bronze artifacts could be associated with the northern part of the Mustang region in Nepal, particularly in proximity to Sam Dzong (Cao K. et al. 2021). Such data favour hypothesis 2, which supports a key role for long distance trade in moving crop varieties adapted to high altitude.

Conclusion

The Gepa serul cemetery, has produced the earliest evidence of naked six-rowed barley in Tibet dating back to the Tibetan Metal Age, in the 15th century BC (~3500 BP). This highlights that the Ngari plateau (~4000 m.), was much connected to a wider world in Asian mountain regions. Trade and interaction between peoples across central Eurasia have been seen as early examples of globalization and one which delivered new forms of crop utilization and agricultural innovation (e.g. Spengler *et al.* 2014; Stevens *et al.* 2016; Wang *et al.* 2019), but equally new crop varieties and cropping systems facilitated the expansion of farming cultures into new ecological zones. The Tibetan Plateau, however, is more often seen as a barrier to expansion, in contrast to the Inner Asian Mountain Corridor or steppe route. The Gepa serul barley finds points to a pathway of barley diffusion from the west, which might have involved either the expansion of farming populations from the Southwest (the Indus region) upwards to higher elevations from or trade from the Inner Asian Mountain Corridor via the Pamirs. These two hypotheses both imply agriculture overcoming the challenges of high elevation but imply very different social processes, one of farmer expansions and the other of trade. These hypotheses have different predictions of future archaeological evidence to be pursued through further work in in mountains regions of Central Asia, Pakistan, and India, as well as in Tibet, to better understand the networks of cultural connection across Middle Holocene Asia.

Certainly, the focal point of this discourse is to emphasize the pivotal and eminent geographical significance of Western Tibet in the contextual frameworks of proto-globalization, glocalization, or networking (Hodos 2017; Jones et al. 2016). The evidence for arrival from thew west, whether immigrant food producers, or via trade indicates that this long antedates the historical ascendancy of Tubo in the Yarlung River Valley in central Tibet, or the kingdom of "Zhang Zhung" in western Tibet (Huo 1997). Instead, the Bronze Age cultural networks provided a context for adaptation of crops like to high altitudes in the mountains of southeastern Central Asia nor northwestern South Asia and their transfer to highest frontiers of Old World agriculture, allowing for cultivation and long-term settlement on which later polities were built.

Acknowledgments We thank Prof. Li Yongxian (Sichuan University), Prof. Xin Jia (Nanjing Normal University), Ganggang Guo (Institute of Crop Sciences, Beijing) and Prof. Liu Xinyi (Washington University, St Louis) for their kind guidance and suggestions on the related issues of Tibet!

Funding statement This research was supported by China Ministry of Education Grant #D18004 (“Project 111”).

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Figure Captions

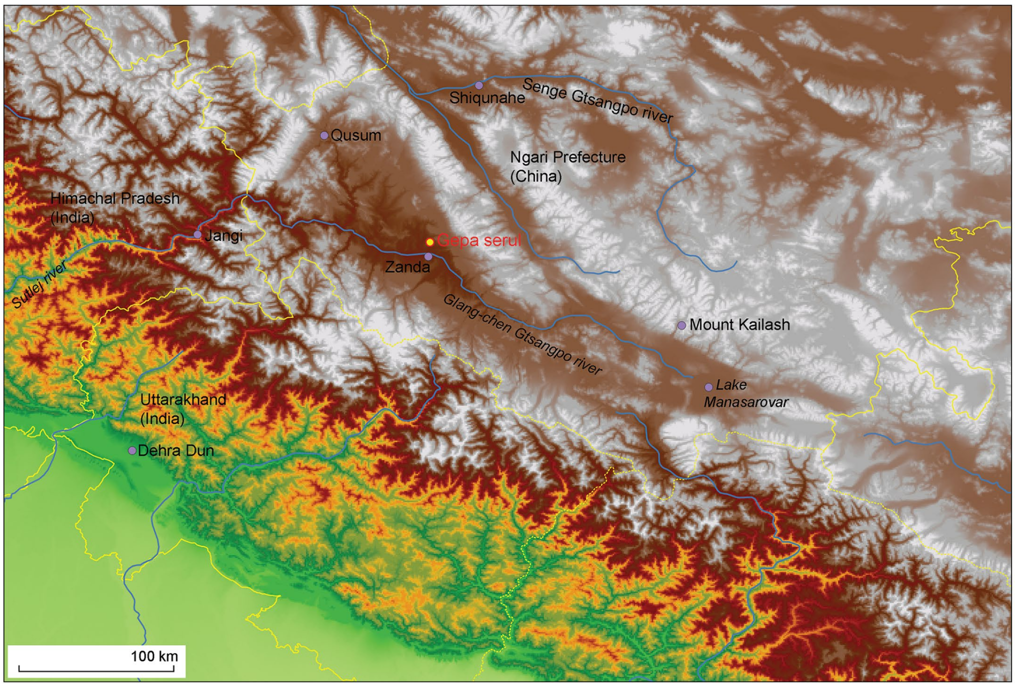

Figure 1. The location and overview of Gepa serul in relation to southwestern Tibet and adjacent India, selected places and rivers indicated.

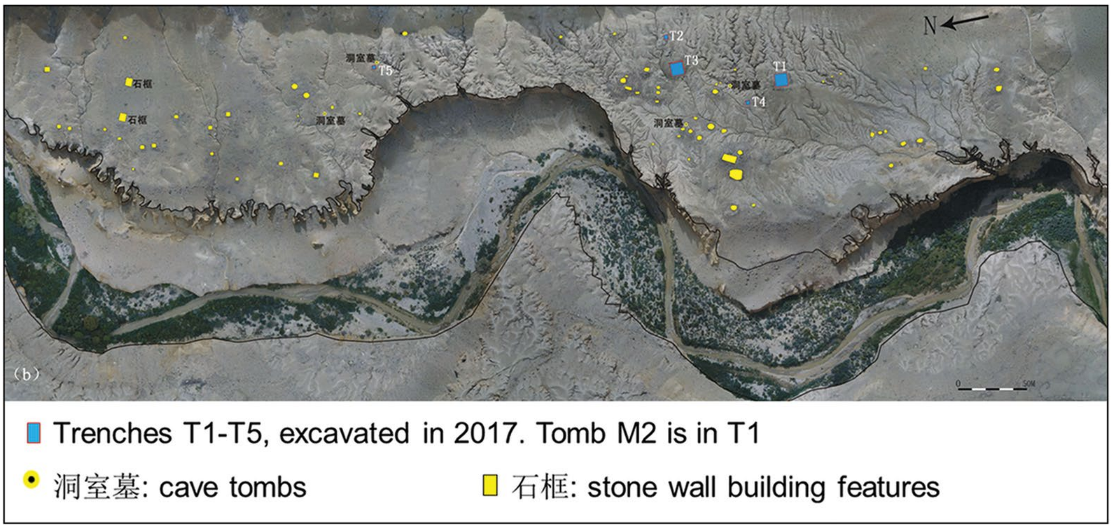

Figure 2. Overview of the Gepa serul site. Yellow dots indicate archaeological features, blue boxes indicated excavation areas in 2017. Note: East is to the top.

Figure 3. Setting of the Gepa Serul excavations, viewed from northwest to southeast across Sangda brook. Excavation camp is in the middle of the photo.

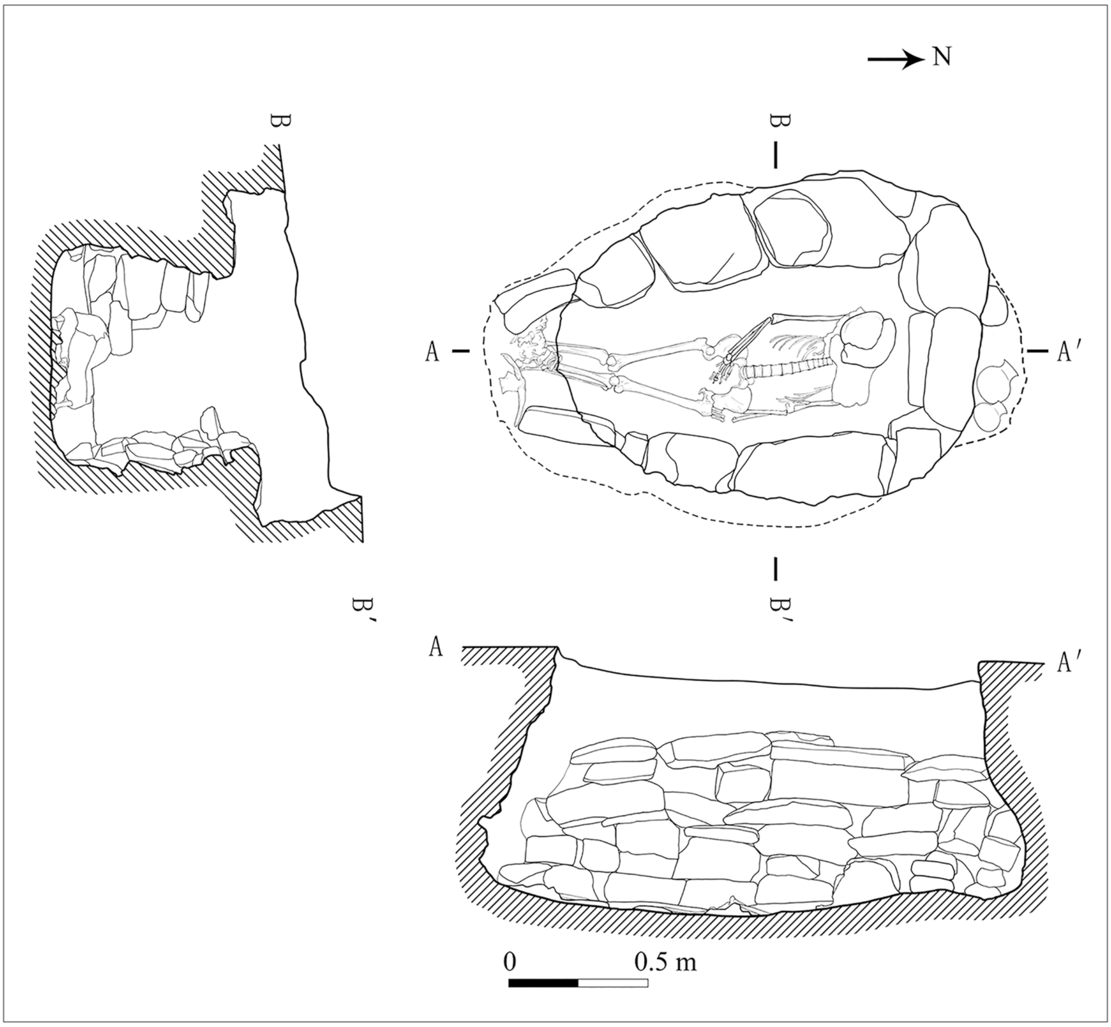

Figure 4. Plan and sections of tomb M2. Ceramic containing charred plants remains in the niche at the northern end of the grave.

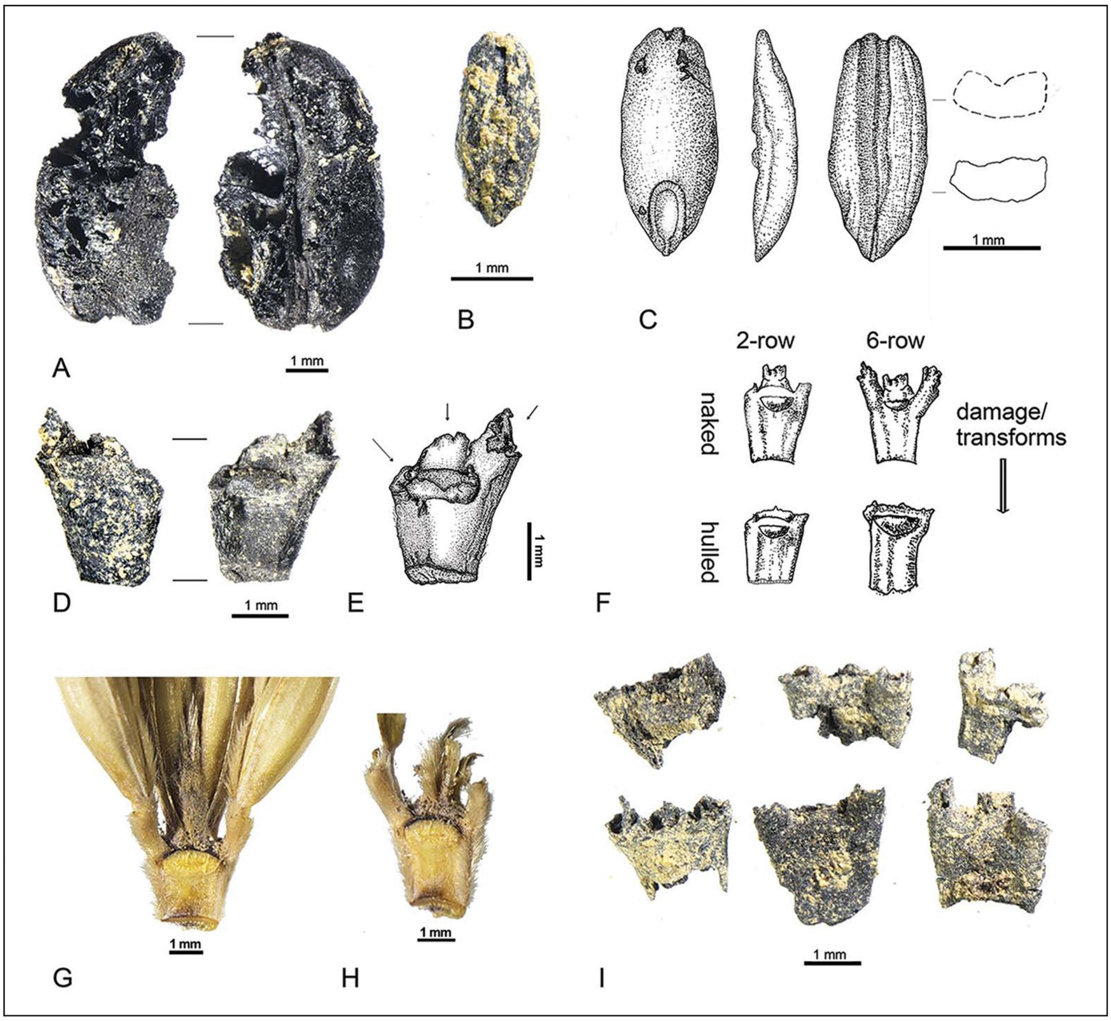

Figure 5. Archaeobotanical remains from Gepa serul M2, with relevant comparative material. **A**. Dorsal and ventral view of barley grain; **B**. Ventral view of weedy brome grass grain (*Bromus* cf. *ramosus*); **C**. Drawing of *Bromus* cf. *ramosus* in C; **D**. Two views of barley rachis segment; **E**. Drawing of adaxial view of barley rachis with arrows indicating floret bases indicative of 6-row, naked barley; **F**. Sketches comparing by the 4 potential types of barley rachis; **G**. Photograph of Tibetan *qingke* 6-row, naked barley rachis and spikelet base; **H**. Photograph of Tibetan *qingke* 6-row naked barley with florets removed; **I**. additional examples of barley rachis from Gepa serul M2.

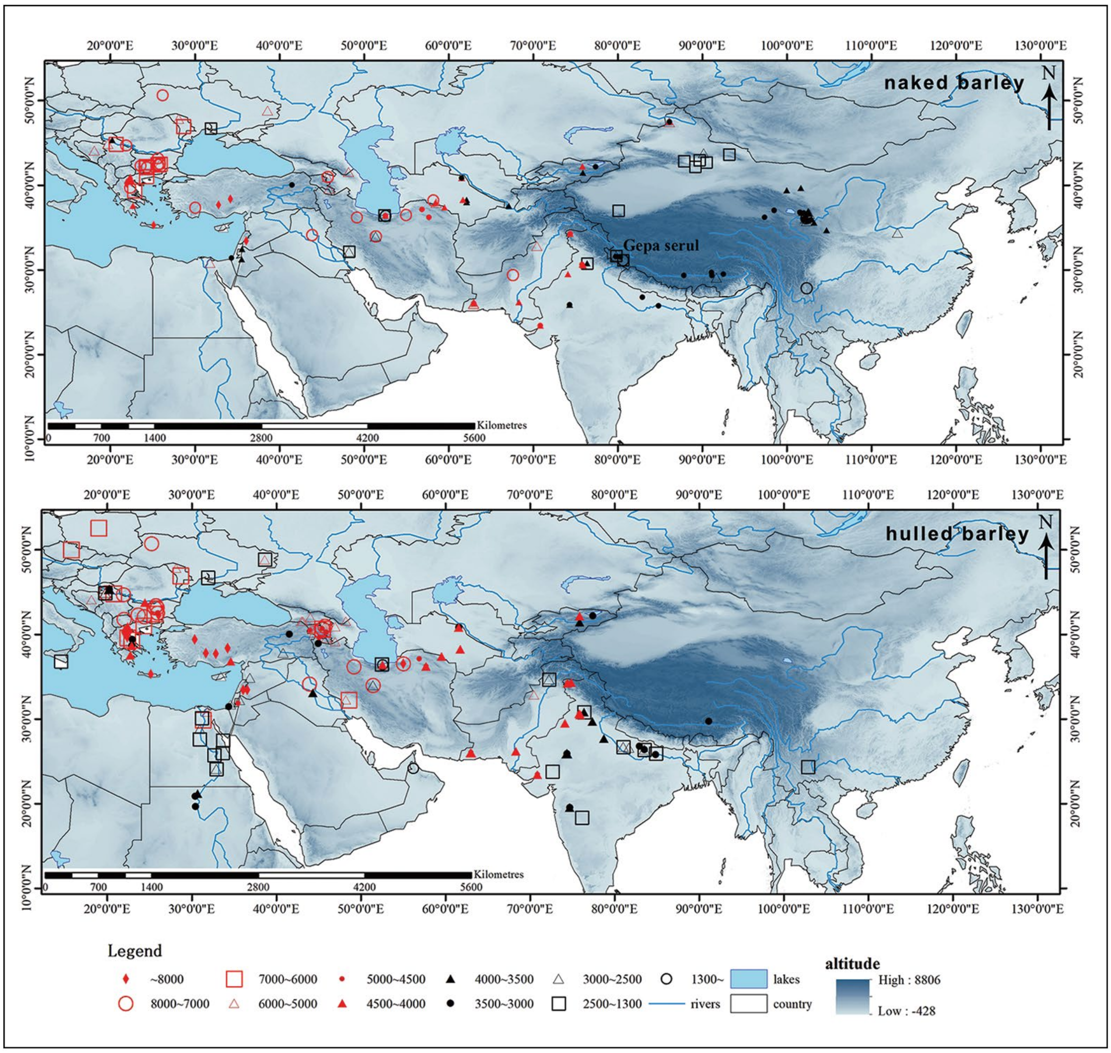

Figure 6. Geographical distribution of archaeological naked and hulled barley, across Asia. Above, map of naked barley remains (including or predominantly of six-row); shaded region in China includes many reports of suggested naked barley where morphological details have not been rigorously reported. Below, map of hulled barley reports across Asia