



# Changes in Wood Utilization Due to Iron Age Jade Mining in the Western Hexi Corridor: Wood Charcoal Investigations

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Charcoal remains from archeological sites are used not only to reconstruct the historical composition of local woodlands but also to examine the history of the human use of wood. Nevertheless, key questions such as how and why people may have selected particular woody taxa from locations long distances from their habitat have rarely been addressed. In the present study, we analyze charcoal remains from the ancient Jingbaoyer (JBR) jade mine in the Mazong Mountains (Mazong Shan) of Northwest China to explore patterns in the collection and use of wood by Iron Age people. Factors affecting the choice of wood collected at the JBR site are discussed by combining the results of pollen records and charcoal analysis. Our results suggest that tamarisk (*Tamarix* L.), a shrub dominant in the local area, was the main source of wood for JBR miners and was used as firewood depending upon its local availability. The miners may also have used wood from species sourced further away, such as *Pinus* L. and *Picea* L., because of the local scarcity of these trees in such a dry environment. The agropastoralist subsistence system practiced by the JBR miners supports the hypothesis of the collection of wood from distant locales. This study highlights diverse patterns of wood collection in an area scarce in woody plants and provides new evidence for understanding how Iron Age people adapted to extremely arid environments.

**Keywords:** charcoal analysis, wood collection, environment, ancient jade mine, western Hexi Corridor

## INTRODUCTION

Past interactions between humans and environments have been a popular subject of research in disciplines as diverse as geography, archeological, history, and genetics (Cordaux et al., 2004; Kuper and Kröpelin, 2006; Kawahata et al., 2009; Chen et al., 2015; Bevan et al., 2017; Leipe et al., 2019; Chen N.B. et al., 2020; Kennett et al., 2020). As a source of energy and raw material for production, wood is an essential resource in daily life and has played a critical role in

human environmental adaptation throughout history (Martín-Seijo et al., 2015; Medina-Alcaide et al., 2015; Li H. et al., 2017; Masi et al., 2017; Kabukcu, 2018; Liu et al., 2019a,b). Prehistoric humans usually collected locally available wood resources, following the “principle of least effort” (Renfrew and Bahn, 1991; Shackleton and Prins, 1992; Qing et al., 2010; Masi et al., 2017; Bouchaud et al., 2020). However, many studies in different regions of the world have challenged this model that assumes people were more selective in choosing wood for higher social productivity and expressed preferences for certain trees, thus likely requiring the use of wood sourced from trees located long distances from their living areas (Miller, 1985; Marston, 2009; Rubiales et al., 2011; Wang et al., 2011; Deforce et al., 2013; Pichler et al., 2013; An et al., 2014; Tolksdorf et al., 2015). Kabukcu and Chabal (2020) suggested that examining the strategy of wood collection by human communities in the past is inappropriate without considering the environmental contexts and human activity of past wood uses. Therefore, it is of great significance to select study regions exhibiting significant changes in environment and human activities in the past to carry out research on strategies of wood use to yield a nuanced understanding of the relationships among environment, human activity, and wood use strategies.

The western Hexi Corridor (Hexi Zoulang, also known as the Gansu Corridor) is a region that documents significant changes in past environments and human activities in China. It witnessed frequent transitions from agriculture to agropastoralism in human subsistence during the late Neolithic and historic periods (Yang et al., 2019). Human activities here also led to environmental changes, especially variation in woody vegetation, since the late Holocene. Previously published data have shown that wood used in the western Hexi Corridor was derived from local woodlands during the late Neolithic and early historic periods (Figure 1) and that large-scale settlements and metallurgical activities undertaken beginning ca. 2000 BCE accelerated the degradation of woody vegetation in the Hexi Corridor and led to the sparser distribution of trees (Li et al., 2011; Li H. M. et al., 2017; Zhou et al., 2012; Shen et al., 2018; Liu et al., 2019b). In the late Bronze and Iron Ages of the first millennium BCE, both the number of woody taxa and the percentage of xerophytes decreased in the western Hexi Corridor (Shen et al., 2018). However, during this period, people engaged in mining jade (*sensu lato*), an activity that must have been supported by the extensive use of wood resources (Chen G.K. et al., 2020). Given the region’s scarcity of woody vegetation, the way in which miners in this area collected and used wood for daily use needs to be examined.

The focus of our study is the Iron Age Jingbaoyer (JBR) jade mine site in the Mazong Mountains (Mazong Shan) in Northwest China. We used charcoal remains to examine patterns in the miners’ wood use strategy. A combination of charcoal analysis from nearby archeological sites, the results of pollen records from lake sediments, and historical documents was used to explore the impact of the local environment on miners’ strategies for wood collection and use. This study highlights the diverse patterns of prehistoric wood collection in arid environments.

## REGIONAL SETTING AND ARCHEOLOGICAL BACKGROUND

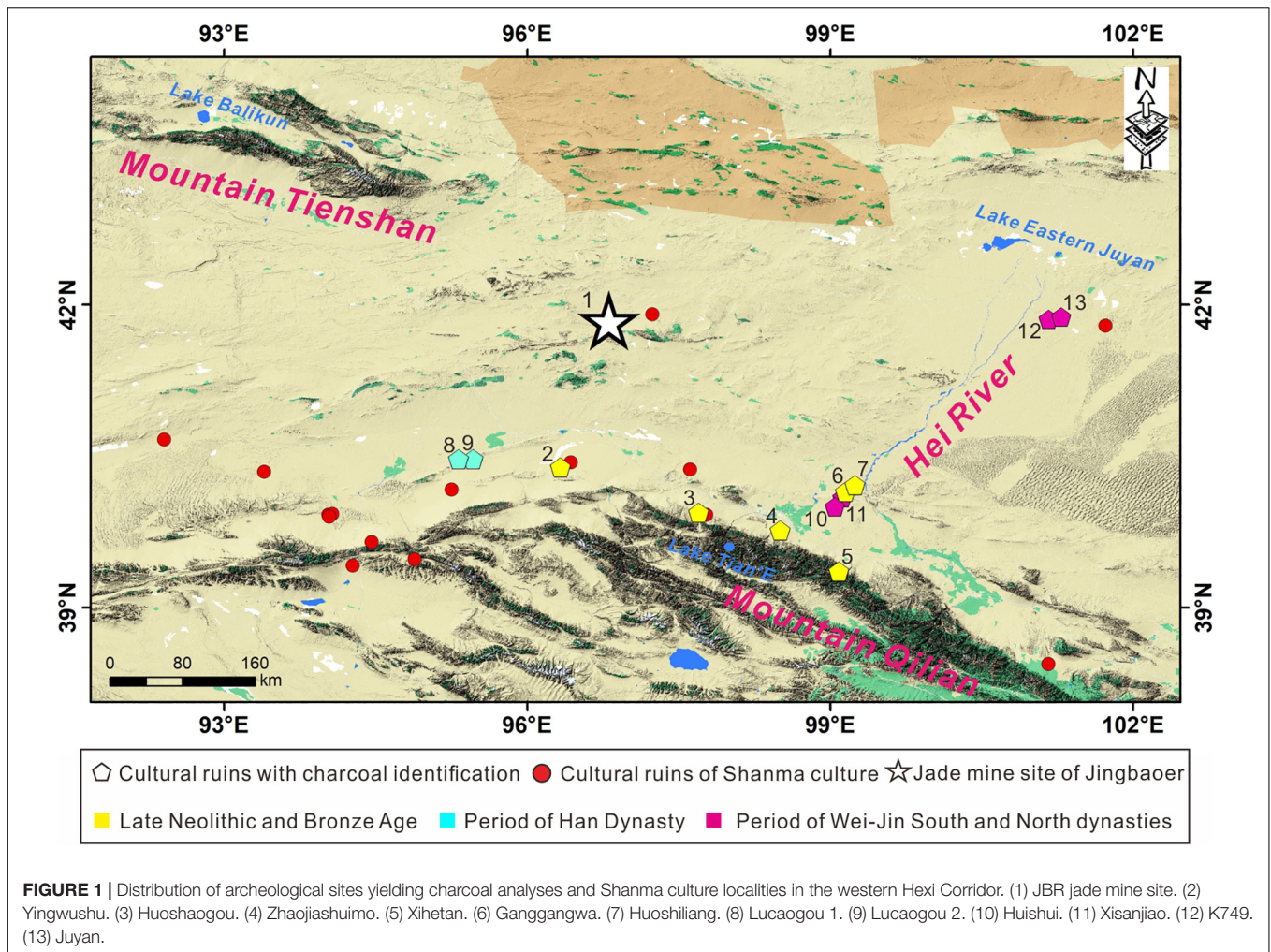
### Present Climate and Woody Vegetation

The western Hexi Corridor is located in China’s arid zone (Figure 1). According to data from the Jiuquan meteorological station located in the western Hexi Corridor, the mean annual temperature is 3.9–9.3°C. A remarkable decrease in annual precipitation is notable from the south to the north. The annual precipitation in the Qilian Mountains is 300 mm, and those at Jiuquan and the Mazong Mountains are 84 and 39 mm, respectively. However, annual evaporation amounts to approximately 2,000–4,000 mm.

Woody vegetation in the area displays a prominent spatial difference owing to spatial changes in regional precipitation (China Forest Editorial Committee, 1997). Conifers such as *Picea crassifolia* Kom., *Sabina przewalskii* Kom., *Picea wilsonii* Mast., and *Pinus tabulaeformis* Carr. are distributed mainly in the Qilian Mountains, with broadleaved trees also present, including *Ulmus pumila* L., *Betula* L., and *Salix* L. Dry-tolerant shrubs, such as *Calligonum* L., *Hippophae* L., *Sarcozygium* Bunge., and *Tamarix* L., dominate the piedmont region, and broadleaved trees such as *Populus* L. mainly grow along the area’s principal rivers. The Mazong Shan are located in the northern part of the western Hexi Corridor, where woody vegetation is much less diverse than in other areas of the western Hexi Corridor and the wood assemblage is similar to that of the gallery forest along the main river (China Forest Editorial Committee, 1997). Farther north, the Gobi Desert contains few woody plants.

### Composition of Woody Plant Communities During the Late Prehistoric and Historic Periods and the JBR Jade Mine Site

The archeological sites from which charcoal has been analyzed are distributed near the Qilian Mountains, along the Hei and Shule Rivers (Figure 1). These sites are dated from the Neolithic to the historic period, spanning roughly 2300 BCE–589 CE, including the Machang (2300–2000 BCE), Xichengyi (2000–1700 BCE), Siba (1700–1400 BCE), and Shanma (1000–100 BCE) cultures; the Han dynasty (202 BCE–220 CE); and the period of the Southern and Northern Wei-Jin dynasties (220–589 CE) (Li H. M. et al., 2017; Shen et al., 2018; Liu et al., 2019b). These results show remarkable spatial differences in the composition and distribution of local woody plants in this area during the late Neolithic and Iron Age. Evidence of coniferous trees, such as *Picea* L., *S. przewalskii* Kom., and *Pinus* L., was mostly discovered in archeological sites located near the Qilian Mountains; broadleaved trees with high relative percentages or frequencies were found in archeological contexts along the main rivers. The relative percentage of shrubs was much higher in the northern Hexi Corridor than that of arboreal taxa. This situation in the western Hexi Corridor that emerged since the late Neolithic suggests that the distribution of woody plants gradually decreased from the Qilian Mountains to the Gobi Desert in the north and



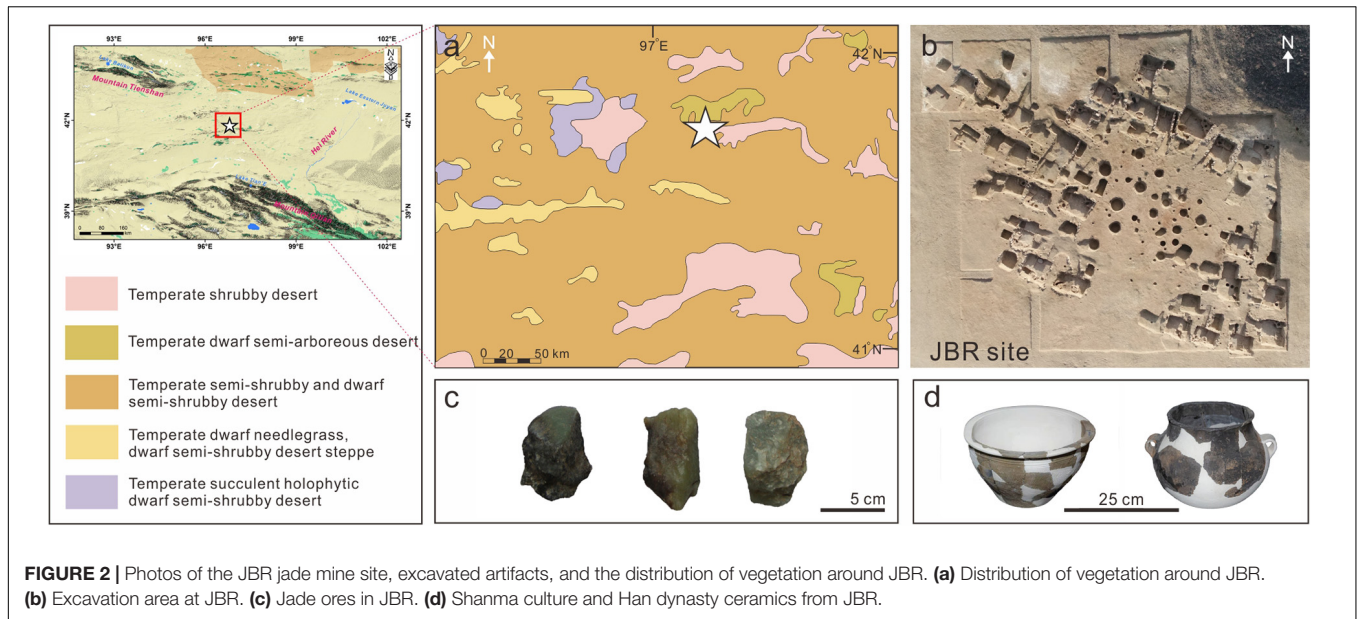
the landscape featured coniferous forests, mixed vegetation, and oasis woodlands in succession, a scenario which is consistent with the composition and distribution of local woody plants at present.

The JBR ancient jade mine is located in the Mazong Mountains, where woody vegetation is much less diverse than in other areas of the western Hexi Corridor (Figures 2a,b). The site measures 5,400 m north–south and 1,400–1,850 m east–west, consisting of a defensive area, the mine itself, and a workshop precinct, and is considered one of the earliest jade mining sites thus far discovered in China (Gansu Provincial Institute of Cultural Relics and Archaeology, 2016). Recent archeological excavations have investigated a total of 33 houses, 31 military installations, and more than 290 mining pits. Most of the houses included remains of ash pits, hearths, worktops, and artifacts, including ceramics, objects made of jade, bronze projectile points, and various iron objects (Figures 2c,d; Gansu Provincial Institute of Cultural Relics and Archaeology, 2016). Carbonized plant remains were also recovered at JBR, including those of foxtail millet, broomcorn millet, wheat, and barley (Yang, 2017). Excavated ceramics suggest that they are the remains of the Shanma culture and the Han dynasty, ranging from the middle-to-late Warring States period and the early Han dynasty (ca.

400–100 BCE), an era in which people used iron tools extensively in China (Bai, 2005).

## Paleoeconomy During the Late Neolithic and Iron Age

Archeological investigations have revealed large-scale human settlements in the western Hexi Corridor beginning in the third millennium BCE (Dong et al., 2018). The Neolithic Majiayao culture (ca. 3300–2000 BCE) adopted a settled lifestyle and was principally engaged in cultivating millet and raising pigs, ovicaprids (sheep and goats), cattle, and dogs in the western Hexi Corridor. This strategy subsequently changed to semi-settled agropastoral production, based on the cultivation of millet, wheat, and barley, and included the utilization of ovicaprids, pigs, cattle, and dogs by the Xichengyi (ca. 2000–1700 BCE) and Siba (ca. 1700–1400 BCE) cultures (Yang et al., 2019). During the Iron Age, the Shanma culture (ca. 1000–100 BCE) occupied the western Hexi Corridor (Xie, 2002). Archeobotanical evidence suggests this culture was still engaged in crop cultivation, with barley, wheat, and millets forming the basis of their subsistence (Yang, 2017). Carbonized remains of these crops were also



recovered from the JBR site (Yang, 2017). However, the faunal composition and strategies for feeding livestock in the Shanma culture were obviously oriented toward mobile pastoralism. Zooarcheological evidence reveals that dogs, ovicaprids, horses, cattle, and camels were maintained by the Shanma people, but with the notable absence of pigs (Yang et al., 2019). Livestock better suited as long-distance transport animals were widely used by the Iron Age inhabitants of the western Hexi Corridor, as recorded in historical texts such as the *Shiji (Records of the Grand Historian)* and *Hanshu (Book of Han or History of the Former Han)*. Shanma culture artifacts unearthed at JBR indicate that the miners there may have also relied on agropastoral subsistence.

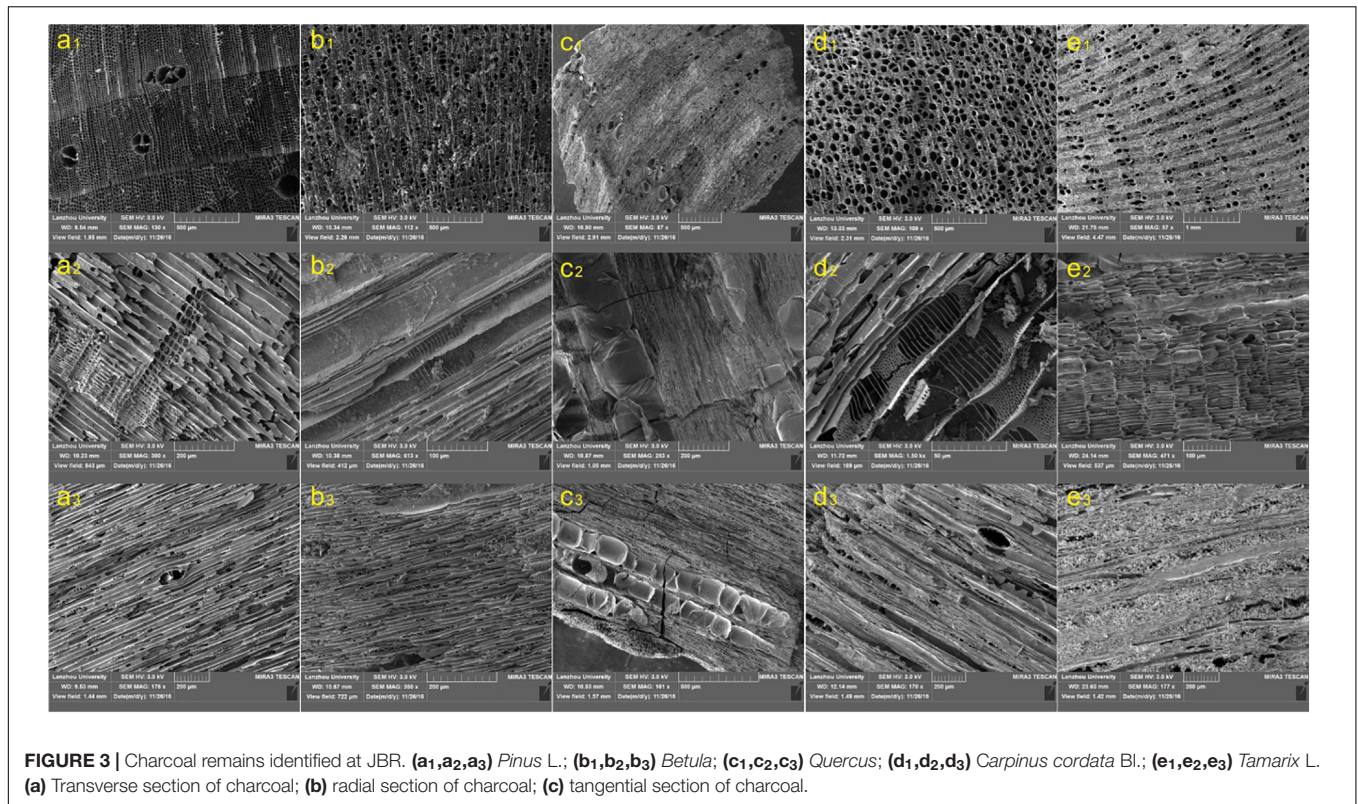
## MATERIALS AND METHODS

Charcoal analysis was employed at JBR to explore how people inhabiting this arid zone collected and used woody plants during the Iron Age. Considering the diverse behavioral implications of the charcoal remains unearthed from different cultural contexts at the site, soil samples were collected from each feature, including 24 houses, eight ash pits, and 11 hearths. Flotation was used to collect charcoal. Soil samples were bucket-washed through an 80-mesh sieve (aperture size, 0.2 mm) to aggregate carbonized plant remains, which were dried in the shade and then sorted. We chose pieces of charcoal with a diameter of  $\geq 2$  mm using sieves with apertures of 4, 2, 1, 0.7, and 0.35 mm. The species of charcoal remains were determined according to descriptions of corresponding wood taxa in the *Zhongguo Mucai Zhi (Wood Records of China)* (Cheng et al., 1992). Microscopic features were examined, and taxonomic species determined using a metallurgical microscope in the MOE Key Laboratory of Western China's Environmental Systems at Lanzhou University. Calculation of relative percentages and frequencies was carried out to explore patterns of wood use at JBR.

To compare differences in the woody plant assemblage between JBR and other sites in the western Hexi Corridor oasis zone and examine the sources of wood used by the JBR miners, the results of charcoal analysis, including percentages of trees and shrubs and those of different arboreal taxa from JBR and other oasis archeological sites in the western Hexi Corridor, were examined using principal component analysis (PCA). PCA makes each new variable (called the principal component) a linear combination of the original variables. Its aim is to compress the original hyperspace into a new principal component space of reduced dimensionality, while retaining as much of the data variation as possible, and to conveniently allow direct comparison of similarities or differences among sample groups. This statistical method has been widely used in discussions of past human–land interactions (e.g., Cui et al., 2015; Zhang et al., 2017). In this study, the R environment software was used to analyze our data (R Core Team, 2019, R version 3.6.3).

## RESULTS

Through flotation, 1,940 pieces of charcoal were identified from 87 JBR soil samples, including 1,412 pieces of charcoal from 65 soil samples from houses, 238 pieces from 12 hearth soil samples, and 290 pieces from 10 ash pit soil samples (**Supplementary Table 1**). A total of 14 woody taxa, including conifers, broadleaved trees, and shrubs, were identified. The coniferous taxa included only *Picea* L. and *Pinus* L.; the deciduous trees were represented by *Quercus*, *Betula*, *Carpinus cordata* Bl., *Acer* L., *Populus*, and *Salix*; and the shrubs included *Tamarix* L., *Caragana sinica* (Buc'hoz) Rehder., and *Elaeagnus angustifolia* L. Three specimens that could not be taxonomically identified were labeled Unknown 1, Unknown 2, and Unknown 3. Microstructural characteristics of these unknown taxa suggest that they may represent broadleaved woody plants. Scanning



**FIGURE 3** | Charcoal remains identified at JBR. (a<sub>1</sub>,a<sub>2</sub>,a<sub>3</sub>) *Pinus* L.; (b<sub>1</sub>,b<sub>2</sub>,b<sub>3</sub>) *Betula*; (c<sub>1</sub>,c<sub>2</sub>,c<sub>3</sub>) *Quercus*; (d<sub>1</sub>,d<sub>2</sub>,d<sub>3</sub>) *Carpinus cordata* Bl.; (e<sub>1</sub>,e<sub>2</sub>,e<sub>3</sub>) *Tamarix* L. (a) Transverse section of charcoal; (b) radial section of charcoal; (c) tangential section of charcoal.

electron microscopy (SEM) photos of some of the carbonized woody plants are shown in **Figure 3**. The specific identification results of charcoal remains recovered from houses, hearths, and ash pits are as follows.

A total of 65 soil samples were collected from 24 houses, and 1,412 pieces of charcoal were identified. Among them, 12 different species were identified, namely, *Picea* L., *Pinus* L., *Quercus*, *Betula*, *C. cordata* Bl., *Acer* L., *Populus*, *Salix*, *Tamarix* L., *C. sinica* (Buc'hoz) Rehder., *E. angustifolia* L., and Unknown 3. Twelve soil samples collected from 10 hearths yielded 238 pieces of charcoal representing nine woody plant taxa. Compared with analytical results from excavated houses, *Quercus*, *Acer* L., *E. angustifolia* L., and Unknown 3 were not identified in the hearth samples. Only one piece (Unknown 2) was discovered. A total of 290 pieces of charcoal from 10 soil samples representing eight ash pits were identified, including 11 taxa. The ash pit samples did not include *Acer* L., Unknown 2, and Unknown 3, and only three pieces of Unknown 1 were discovered there. The relative percentages and frequencies of the arboreal taxa identified in different cultural units at JBR are presented in **Table 1** and **Figures 4, 5**.

A score plot of the first two principal components for the data is shown in **Figure 6**. The data are derived from the results of charcoal analysis in archeological sites located in the western Hexi Corridor oasis and the JBR jade mining site. Independent PCAs were carried out, including percentages of trees and shrubs in **Figure 6A** and those of different arboreal taxa in **Figure 6B**. There is no obvious cluster identified in terms of the percentages of trees and shrubs in the results of charcoal analysis between the

oasis archeological sites and the JBR site (**Figure 6A**). However, two main clusters were identified, respectively, in terms of the percentages of different tree taxa in the results of charcoal analysis between the oasis archeological sites and the JBR site (**Figure 6B**). The results of the percentages of different arboreal taxa identified through charcoal analysis from six oasis archeological sites appear as a cluster characterized by negative Dim1 values. Only the analytical results of the JBR site appear as another cluster, characterized by positive Dim1 values.

## DISCUSSION

### Use of Wood at the JBR Jade Mine During the Iron Age

Wood has long played a significant role in human livelihoods and social organization as a raw material for construction, cooking, fire making, heating, and artifact production (Rubiales et al., 2011; Salavert and Dufraisse, 2014; Wang et al., 2014a,b; Medina-Alcaide et al., 2015; Kabukcu, 2018). Charcoal remains derived from cultural features with clear functional attributes are the result of conscious choice and can reflect information on wood use and the patterns of its collection in the past (Li et al., 2012; Marcos and Ortega, 2014; Wang et al., 2014a; Rhode, 2016; Hazell et al., 2017; Kováčik and Cummings, 2017; Mafferra, 2017; Mota and Scheel-Ybert, 2019; Kabukcu and Chabal, 2020). *Tamarix* L. was the most abundant taxon in houses, hearths, and ash pits at JBR. Because the tamarisk shrub usually grows on alluvial and silty plains in arid and semi-arid areas of Northwest China,

TABLE 1 | Relative percentages and frequencies of woody taxa identified at the Iron Age JBR jade mine site in the western Hexi Corridor.

	<i>Picea L.</i>	<i>Pinus L.</i>	<i>Quercus</i>	<i>Betula</i>	<i>Carpinus cordata Bl.</i>	<i>Acer L.</i>	<i>Populus</i>	<i>Salix</i>	<i>Tamarix L.</i>	<i>Elaeagnus angustifolia L.</i>	<i>Caragana sinica (Buc'hoz) Rehder</i>	Unknown 1	Unknown 2	Unknown 3
Relative percentage	2.97%	0.50%	1.06%	3.26%	0.85%	0.07%	1.70%	1.20%	82.44%	0.28%	5.45%	0.00%	0.00%	0.21%
Hearths	4.62%	2.52%	0.00%	10.08%	0.42%	0.00%	2.94%	7.56%	70.59%	0.00%	0.84%	0.00%	0.42%	0.00%
Ash pits	23.45%	2.41%	12.41%	3.10%	1.03%	0.00%	4.14%	3.10%	48.28%	0.34%	0.69%	1.03%	0.00%	0.00%
Houses	32.31%	9.23%	7.69%	35.38%	13.85%	1.54%	10.77%	16.92%	98.46%	6.15%	16.92%	0.00%	0.00%	1.54%
Hearths	50.00%	25.00%	0.00%	41.67%	8.33%	0.00%	16.67%	33.33%	100.00%	0.00%	16.67%	0.00%	8.33%	0.00%
Ash pits	70.00%	20.00%	20.00%	60.00%	30.00%	0.00%	20.00%	40.00%	100.00%	10.00%	20.00%	30.00%	0.00%	0.00%

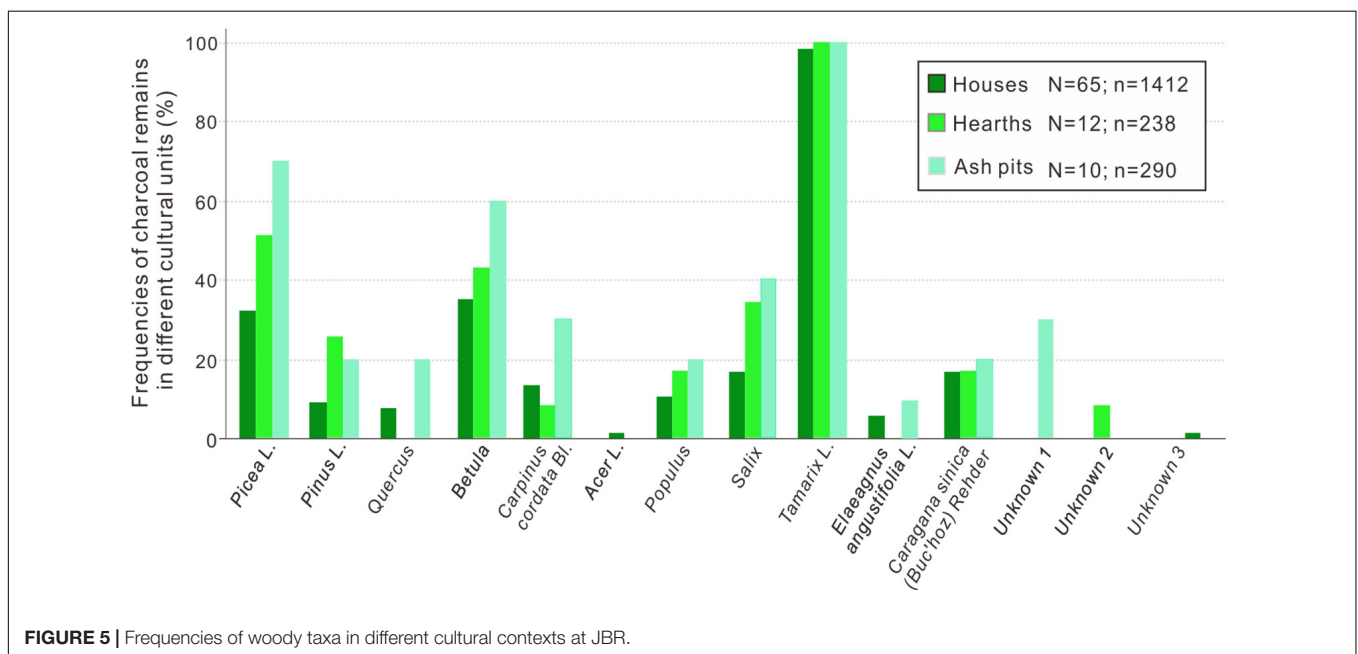
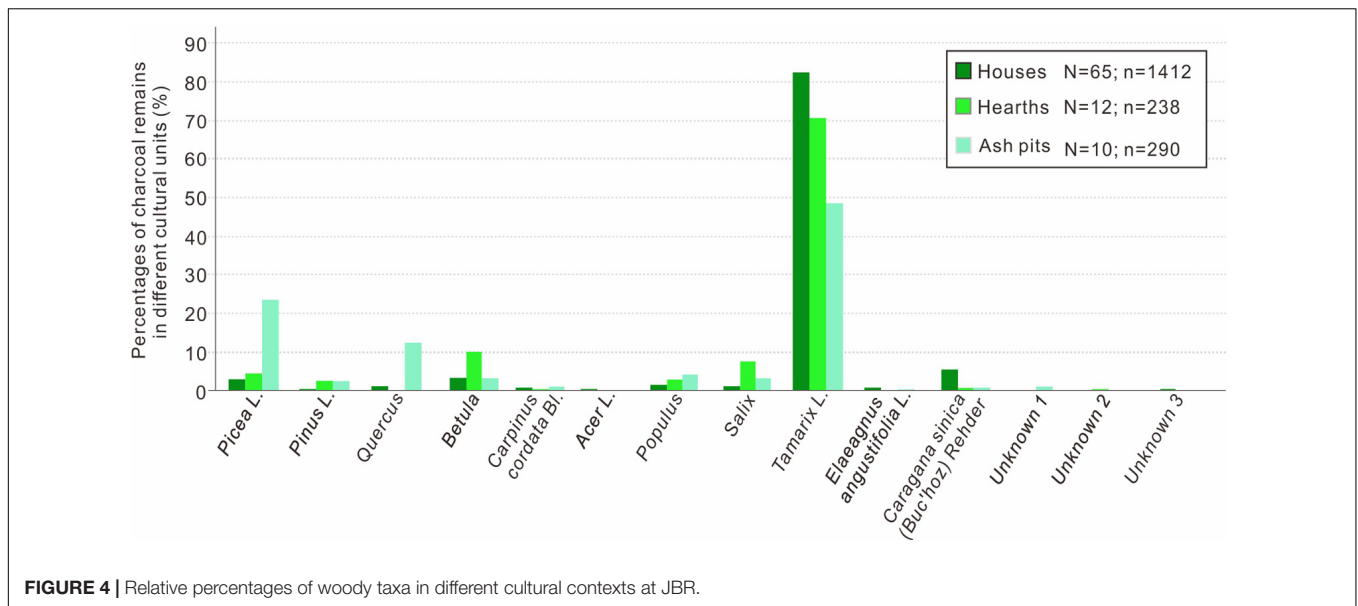
its branches are ideal for making agricultural implements and fences, as well as for fuel. Archeobotanical evidence suggests the universal use of *Tamarix L.* in archeological sites in the western Hexi Corridor during both prehistoric and early historical periods (Li et al., 2011; Wang et al., 2014a; Liu et al., 2019a,b). The highest relative percentage and frequency of *Tamarix L.* occurred in hearths and ash pits, indicating that it was at least used as firewood at JBR (Figures 4, 5). The shrubby *C. sinica* (Buc'hoz) Rehder and *E. angustifolia L.* are widely distributed in arid areas and were also used at JBR. However, the lower relative percentages and frequencies of these two taxa in house and ash pit samples and the absence of *E. angustifolia L.* in hearths indicate that they were probably not used as fuel, perhaps due to their relatively high economic value (Flora of China Editorial Committee, 2004).

In addition to shrubs, some arboreal taxa were also identified. Despite low relative percentages, their higher frequencies indicate that trees were also used by Iron Age miners. All the arboreal taxa except *Acer L.* were found in both hearths and ash pits, suggesting that they were used as fuel. Remains of maple (*Acer L.*) were found only in houses. Due to the absence of post holes in habitation structures, the potential use of *Acer L.* as a building material for house construction requires further investigation.

The use of wood in the Hexi Corridor has a long history. The expansion of millet cultivation in the third millennium BCE promoted wood use for residential construction, as fuel in ceramic kilns, and, later, for smelting (Xie, 2002; Li et al., 2011; Yang et al., 2016; Zhang et al., 2017; Dong et al., 2018). Based on the results of charcoal analysis in archeological sites, it is clear that the wood taxa used by people were not diverse and generally did not exceed five categories in each ancient site located in the western Hexi Corridor (Li et al., 2011; Shen et al., 2018). The relatively simple composition of woody taxa used is likely the result of the gradual emergence of a cold-and-dry climate as well as increasing social complexification since the late Neolithic (Li et al., 2011; Zhou et al., 2012). However, our results suggest that the JBR jade mine site preserves a remarkably diverse range of woody taxa, considerably different from that of other archeological sites in the western Hexi Corridor (Figures 4, 5). Therefore, we asked where the JBR miners collected their wood.

## Strategy of Wood Collection at the JBR Jade Mine Site and Its Relation to the Iron Age Environment of Northwest China

Preferences in the choice and use of firewood by early human groups have attracted more and more attention in archeobotanical research. The “principle of least effort” that supposedly determined early wood collection strategies has been challenged by many case studies suggesting that selective choices in the collection of woody plants from trees located long distances from people’s living areas due to certain environmental factors were common (Rubiales et al., 2011; Wang et al., 2011; Deforce et al., 2013; Pichler et al., 2013; An et al., 2014; Tolksdorf et al., 2015). Our results indicate that *Tamarix L.* appears in all

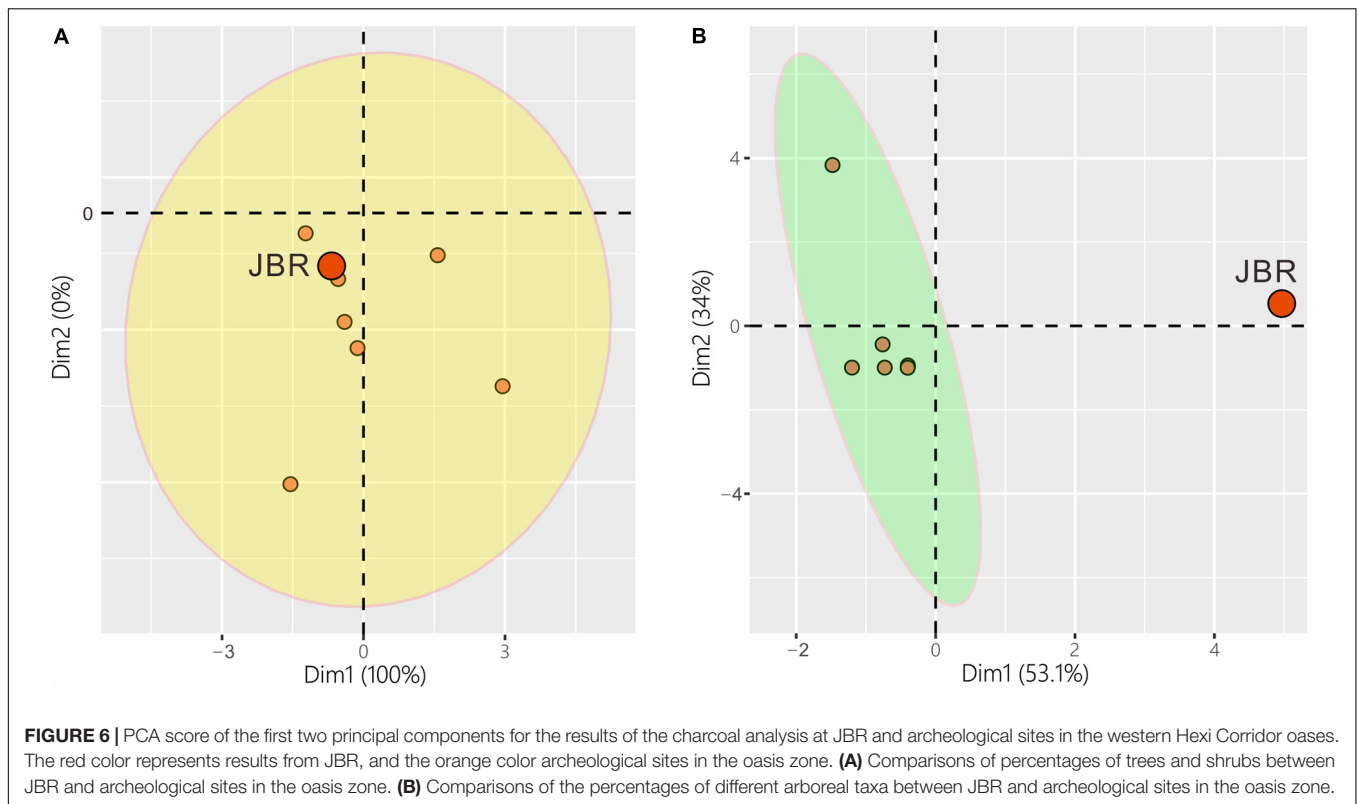


samples and maintains high percentages in the houses, hearths, and ash pits, which may be closely related to the ecology and environment at JBR.

The Mazong Mountains, where the JBR site is located, lie in the northern expanse of the western Hexi Corridor and have harbored an oasis woodland ecology since the late Holocene due to low annual precipitation, confirming the deduction based upon PCA that yields a similar composition of woody plants in the Mazong Mountains and the oasis gallery forests bordering rivers in the western Hexi Corridor (Figure 6A). *Tamarix* L. as well as *C. sinica* (Buc'hoz) Rehder and *E. angustifolia* L. shrubs usually grow on alluvial and silty plains in arid and semi-arid areas and often in oases along the main rivers in the western Hexi

Corridor (China Forest Editorial Committee, 1997). Thus, it can be concluded that the shrubs used by miners at JBR may have been collected in the vicinity of the site.

On the other hand, the number and composition of arboreal taxa at JBR are significantly different from those in the western Hexi Corridor oases (Figure 6B). We compared the use of wood at JBR with archeological sites in the western Hexi Corridor, including the percentages of trees and shrubs as well as the number of arboreal taxa identified. Figure 7 reveals that no more than five taxa of woody plants were discovered at each site in the western Hexi Corridor since the late Holocene (Shen et al., 2018). A clear contrast can be seen with JBR where at least eight tree taxa were identified (Figure 7). The



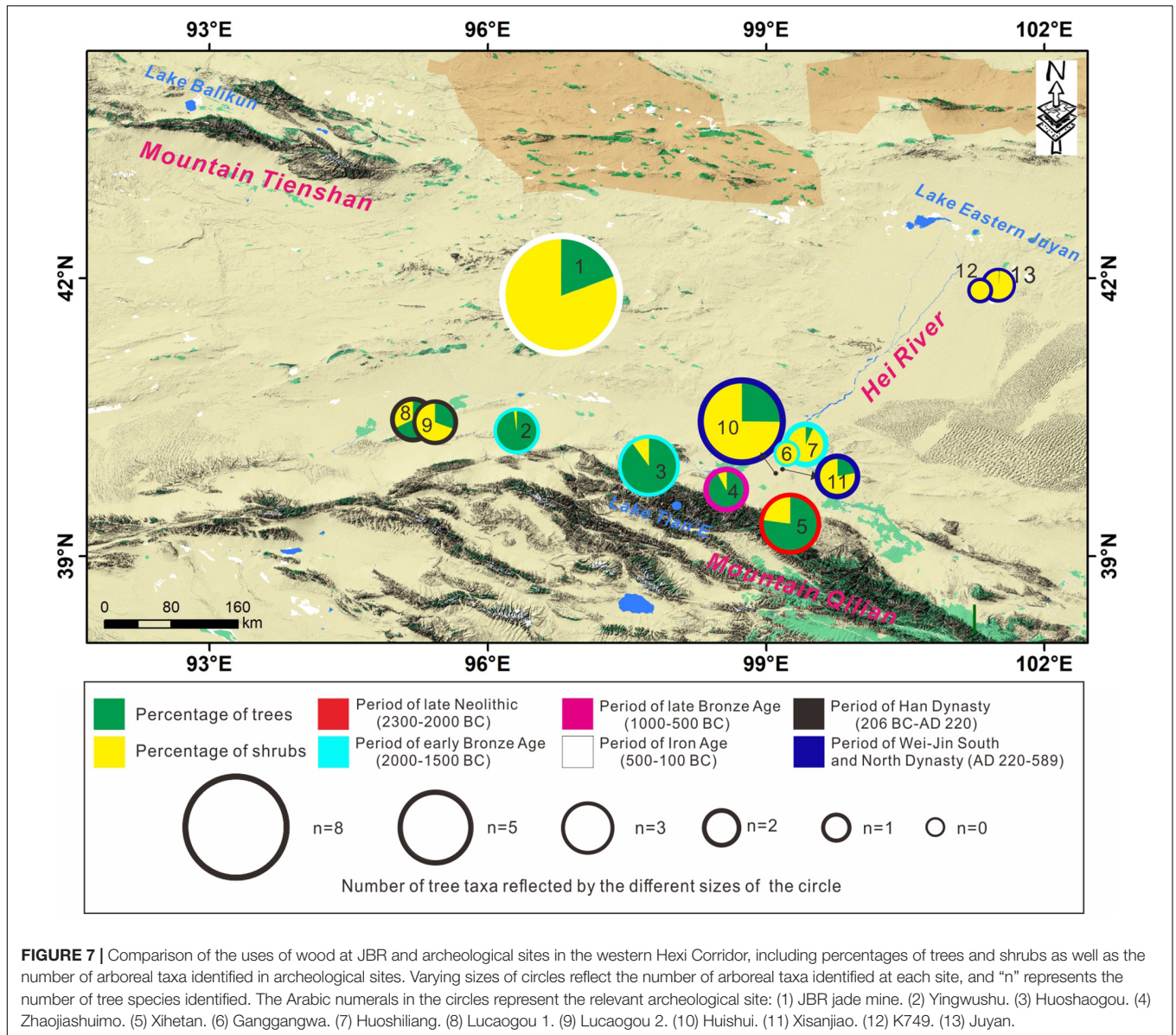
percentages of trees and shrubs identified at JBR were similar with those in the western Hexi Corridor oases (Figure 7), while the assemblage of arboreal taxa reflected a different forest composition. The composition of tree taxa revealed by our charcoal analysis reflects a mixed forest and a relatively cold and humid environment around the JBR site. However, low annual precipitation in the Mazong Shan did not support the growth of arboreal taxa, especially *Picea* L. and *Pinus* L., and this also conflicted with the assumed dominant use of *Tamarix* L. by the miners. Therefore, the tree taxa discovered at JBR were likely distributed only sparsely in the Mazong Mountains during the Iron Age (Figure 7). Based on extant paleoenvironmental records, the Hexi Corridor experienced obvious degradation of woody vegetation and desertification since the late Holocene, both due to the drier climate and human metallurgical activities (Zhou et al., 2012). The use of diverse woody plants by people in the Hexi Corridor decreased during the late Bronze Age (Shen et al., 2018). By the Iron Age, the number of arboreal taxa was no more than five in all known archeological sites, indicating that the diversity and distribution of woody plants may have been far less than those during the Bronze Age. However, the pre-industrial exploitation of jade must have been supported by large amounts of wood resources. Compared with shrubs, trees are more suitable for the sort of construction associated with mining jade, housing and military installations, and durable toolmaking. The local arid ecology likely constrained the diversity of tree communities in the Iron Age; thus, the trees used by the JBR miners were probably not collected in the immediate vicinity of the site due to this prevailing arid

environment. Therefore, it is important to ask where the trees used at JBR came from.

### Wood Collection Far From Living Areas and Its Relationship to the Subsistence Strategy of the JBR Jade Miners

Constraints imposed by the dry environment on the arboreal community identified in our research suggest that the trees used by the JBR miners were not collected locally. To examine the possible source of those trees, understanding the regional vegetation and its historical changes plays a critical role (Pickarski et al., 2015; Schiferl et al., 2017; Xu et al., 2017; Lézine et al., 2019; Park et al., 2019; Zhao et al., 2020). Pollen analysis of natural sediments has recently been used to outline the evolution of vegetation and explore the relationship between human activities and environmental changes in the past (Hou et al., 2015; Huang et al., 2017, 2018; Pini et al., 2017; Cheng et al., 2018; Novenko et al., 2018; Qiu et al., 2020). Palynological analysis of lacustrine cores from the western Hexi Corridor, that of Lake Tian'e in the western Qilian Range in particular, reveals the presence of *Picea* L. and *Betula* in the late Bronze and Iron Ages (Zhang et al., 2018). *Picea* L., *Pinus* L., *Betula*, *Salix*, and *Ulmus* appeared during the same period in the pollen records from Eastern Lake Juyan (also known as Sogo Nuur) on the lower reach of the Heihe River and Lake Balikun in the eastern Tianshan Mountains (Herzschuh et al., 2004; Tao et al., 2010). In the eastern Hexi Corridor, the presence of *Picea* L., *Pinus*, and *Sabina* also in the late Bronze and Iron Ages has been noted in pollen profiles from the Sanjiaocheng





section, and such broadleaved trees as *Betula*, *Quercus*, *Corylus*, and *Ulmus* have been identified there (Chen et al., 2006). The pollen records from lakes and stratigraphic sections seem to suggest a diverse arboreal community in mountain areas in the Hexi Corridor. Most tree taxa identified at JBR were also observed in pollen records from these lakes and sedimentary sections, indicating that trees destined for the jade mine were collected from surrounding mountainous areas located far from habitation areas.

Our results indicate that wood used at JBR was collected at some significant distance from the site's living areas, which is at variance with other archeological sites in the Hexi Corridor and, more broadly, eastern China (Wang et al., 2013; Li et al., 2014; Li H. M. et al., 2017; Yan et al., 2017; Shen et al., 2018; Liu et al., 2019a,b). Archeological evidence suggests that a critical transformation occurred in

the pattern of wood collection in the past, from dead wood collected in the Paleolithic to fresh wood utilized in the Neolithic (Rubiales et al., 2011; Wang et al., 2016; Allué et al., 2017; Vidal-Matutano et al., 2017; Mota and Scheel-Ybert, 2019). This transformation in wood acquisition was presumably closely related to changes in people's subsistence strategies and their increasingly sophisticated technologies. These differences occurred at JBR also owing to changes in subsistence strategies that took place during the late Bronze Age and Iron Age.

Larger-scale human settlements in the western Hexi Corridor can be traced back to the third millennium BCE (Dong et al., 2018). Suitable climatic conditions promoted the westward diffusion of the Neolithic Majiayao culture (ca. 3000–2000 BCE), and an agricultural economy based on millet cultivation was established in the Hexi Corridor at this time (Dong et al., 2013).

With the gradual enhancement of cultural exchange between the East and the West during the second millennium BCE, domesticated wheat and barley, sheep, and metallurgical technology were introduced to the Hexi Corridor, where they transformed human subsistence strategies in the region from reliance on agriculture to agropastoralism (Yang et al., 2019). During this period, people mainly settled in oases and used shrubs such as *Tamarix* L. as fuel for metallurgical activities like smelting (Li et al., 2011). When the physical and chemical properties of the main coniferous and broadleaved trees or shrubby taxa are compared, the caloric value of conifers is significantly higher than that of broadleaved arboreal species and shrubs, making them more suitable for metallurgical activities. However, conifers were only widely used by people who settled near mountainous areas (Figure 7). This is likely related to the fact that large livestock species, such as horses, cattle, and camels which can be used to transport resources over long distances, were not yet widely used during this period. In the late first millennium BCE, a prevailing cold-and-dry climate led to less intense patterns of human settlement but promoted the establishment of agropastoralism across Eurasia (Kuz'mina, 2008). Archeological evidence suggests a rapid growth of agropastoralism along the Great Wall of China, including the Hexi Corridor (Han, 2008; Yang et al., 2019). Bones of pigs (*Sus scrofa domesticus*) are absent from archeological sites of this period in the Hexi Corridor, where they appear to have been replaced by grazing livestock, such as horses, cattle, sheep, and camels, indicating the establishment of agropastoralism (Yang et al., 2019). Horses and camels can be used for long-distance transportation, an advantage that can significantly expand the resource catchment area for people to exploit and obtain resources for production and daily life, including wood (Wu, 2002; Guo, 2012; Li et al., 2020). Recent data reveal that agropastoralism was much more common in the western Hexi Corridor during the Iron Age, e.g., the Shanma culture (Yang et al., 2019); thus, it is logical to assume that the JBR miners or other local people used traction animals to transport wood over long distances.

## CONCLUSION

This study analyzed charcoal remains from an ancient jade mining site at JBR, Gansu, to explore the history of wood use in the western Hexi Corridor during the Iron Age. By combining these results with pollen records obtained from nearby lakes and sedimentary sections, we identified the pattern of wood collection at this site and the ways in which it was different from that of other broadly contemporary archeological sites in the Hexi

Corridor. Our results indicate that *Tamarix* L. was the principal source of firewood for Iron Age miners at JBR. Some arboreal taxa were also used as fuel but were not collected locally due to the extremely arid environment of the Mazong Range that did not support the growth of such trees. The pollen records indicate that tree taxa present at the site were likely collected from mountainous areas far from the site. The pattern of wood collection exhibited by the JBR miners was closely related to their pastoral subsistence mode. This study provides information on the diversity and particularity of wood collection and use in arid areas in the past and reflects on important local environmental impacts on human adaptations.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

## AUTHOR CONTRIBUTIONS

HCZ and GKC conceived this study. FWL undertook the identification of charcoal remains and wrote the manuscript. YSY and SJZ discussed the data. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2021.636534/full#supplementary-material>

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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