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ORIGINAL PAPER

Evolution of Mongolian bronze technology with the rise of the Xiongnu State

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Abstract The emergence of the Xiongnu State in Mongolia reflected a period of increasing foreign influence, especially from China. Metallurgy was likely one of the key cultural components that may have reacted sensitively to this influence. In our ongoing project focusing on metallic objects excavated from the royal Xiongnu tomb at Golmod 2, we found a group of bronze artifacts possessing an important clue as to the general understanding of the contemporary Xiongnu bronze industry. The assemblage in question consists of 21 exotic ornaments, each nearly identical in shape and size and all associated with the horse-drawn wagons interred in the tomb. They were made of copper alloys containing on average 3.8 % arsenic, 3.0 % lead, and 1.3 % tin by weight. This recipe was a continuation of the unique steppe bronze tradition drawing on the copper-arsenic system as dictated by limited access to tin. The addition of lead, however, was a notable departure driven apparently by Xiongnu-Han interaction. This development likely reveals an important facet of the Xiongnu communities seeking a refined adjustment to the bronze recipe. This enhancement likely served to meet the growing demand for exotic items such as those under consideration, whose stylistic characteristics have led to erroneous conclusions as to the political affiliation of their producers.

Keywords Mongolia · Xiongnu · Foreign impact · Bronze · Technological transition

Introduction

The recent excavation of the royal Xiongnu tomb (Erdenebaatar et al. 2015) within the burial site, named Golmod 2 (arrow 1 in Fig. 1), in Mongolia recovered numerous bronze and iron artifacts that may provide a window into the local cultural environment of the time. The majority of these items were functional or ornamental components (Fig. 2) of two-wheeled horse-drawn wagons, one of which was interred in its entirety. It is important to note that the number of bronze axle caps excavated could represent at least a dozen of such wagons. In general, wagons interred in lavish Xiongnu burials have been regarded as a tribute from China (Honeychurch 2014; Miller 2012; Polosmak et al. 2007) given to Xiongnu aristocrats, serving as evidence of important political and economic interactions between the Xiongnu Empire (209 BC–155 AD) and the Han Dynasty (206 BC–220 AD). From this viewpoint, most such wagons should have been imports from China made with little relevance to contemporary Xiongnu craftsmanship. It is difficult to imagine, however, that the Xiongnu community at Golmod 2 depended entirely on foreign imports to meet the need for such a large volume of metallic objects. This concern led us to reconsider the origin of the technological tradition responsible for their manufacture. As an initial step, we launched an

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Fig. 1 Map of Mongolia showing provinces and archaeological sites mentioned in the text. Golmod 2 in the North Khangai (Arkhangai) Province (*1*) and Golmod 1 in the North Khangai (Arkhangai) Province (*2*)

archaeometallurgical project focusing on a particular group of excavated bronze objects (Fig. 3), which were apparently employed as ornaments for the parasol of horse-drawn wagons (Fig. 4). In this study, we intend to characterize the manufacturing methods as determined by the observed alloy composition and microstructure of the specimens, with the specific purpose of discussing the resulting outcome in reference to the traditional steppe and Chinese bronze technologies.

Our project was based on the work by Park et al. (2011) who observed two distinct bronze traditions in use for the production of bronze artifacts recovered from the ancient site at Baga Gazaryn Chuluu (BGC). One of the traditions was basically identical to that dominating the steppe region (Chernykh and Kuzminykh 1989). It is characterized by the use of arsenic (As) as the major alloying element with the frequent addition of small amounts of tin (Sn) but no lead (Pb). By contrast, the other tradition was similar to that of the Qin-Han style technology (Barnard 1961; Bagley 1987; Rawson 1990; So 1995), which relied on the generous use of both tin and lead. They noted that the Qin-Han alloy recipe was identified almost exclusively in objects dating to the Xiongnu period, while the other was confirmed in artifacts from both the pre-Xiongnu and Xiongnu contexts. This connection between alloy composition and artifact chronology was interpreted as a result of intensified Mongolia-China interaction during the dawn of the Xiongnu period. Xiongnu contact with China was also reflected in Qin-Han style imitations made using non-Qin and Han alloys, as well as in traditional steppe artifacts cast following Qin and Han recipes (Park et al. 2011; Khavrin 2011).

According to the above observation, a significant change in the Mongolian bronze industry was likely initiated by the interregional interaction between the early imperial states of China and Xiongnu. Interesting and challenging questions are then raised regarding the evolution of Mongolian bronze technology in conjunction with the continuing political and cultural interactions with the Chinese states. These questions may not be properly addressed without raising another important question about the extent to which the Xiongnu communities depended on external sources to meet their demand for bronze, particularly the need for exotic prestige items

Fig. 2 Metallic (bronze and iron) artifacts excavated from the Xiongnu royal tomb under consideration. The objects shown consist of functional components of two-wheeled horse-drawn wagons

Fig. 3 General appearance of the bronze objects examined. All except #21 were photographed in a single shot. The magnification mark was drawn in reference to object #12, and the numbers labeling the objects are given in the second column of Table 1

(Barfield 2001) such as those in Fig. 3. We will use the chemical data of the bronze objects under investigation to gain an insight into the general technological environment in which they were produced. The outcome will then be employed to explore the direction of technological developments during the Xiongnu period, particularly in response to the influx of new ideas and materials from China.

Comments on sites and artifacts

The bronze objects examined (Fig. 3) were all excavated from the main tomb of #1 Burial Complex (Fig. 5) of the Xiongnu royal necropolis at Golmod 2 located in the Arkhangai Province. The site is marked in the map (arrow 1 in Fig. 1) along with another Xiongnu site at Golmod 1 in Khairkhan sum of the Arkhangai Province (arrow 2). These two sites, not far away from each other, are burial places for Xiongnu elites, sharing many common features in both construction and layout. Similar Xiongnu tombs were also excavated at Noyon Uul, Duurlig Nars, and Tsaram (Brosseder 2009). The burial complex under consideration is one of those excavated in the Golmod 2 area after it was discovered in 2001 (Allard et al. 2002). The main tomb in the complex has 27 satellite Xiongnu tombs arranged in an arc along its eastern flank, with a single satellite tomb (29) exclusively for a Xiongnu horse placed to the north. It also has a small tomb (28) from the medieval period positioned to the west and another small Xiongnu grave (30) lying between the main tomb and the satellite burial arc. The photo at the top of Fig. 5 shows the landscape surrounding the complex, while the sketch at the bottom illustrates the burial layout (Erdenebaatar et al. 2015: 196). The excavation of this site began with the satellite tombs between 2002 and 2005 as part of the Mongolian-American Khanui Valley Project (Miller et al. 2006). The main tomb, the largest of the Xiongnu burials known to exist, was subsequently excavated in 2011 (Erdenebaatar et al. 2015).

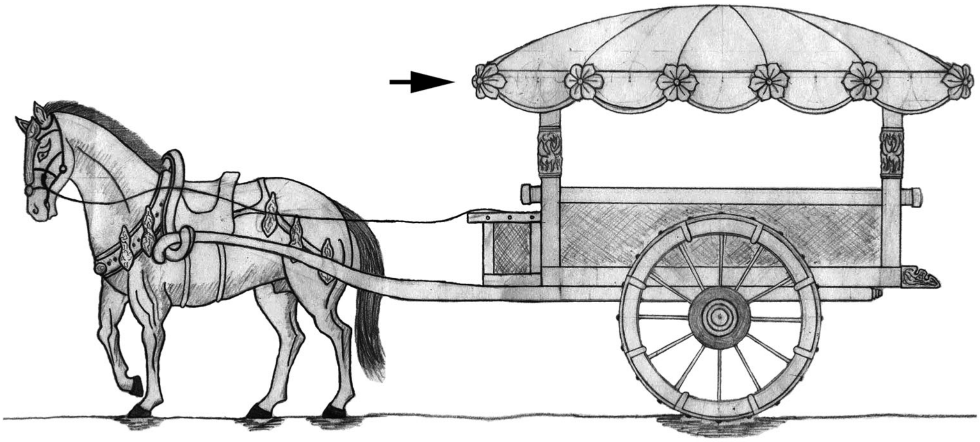

Fig. 4 Sketch of a wagon with a parasol pulled by a single horse. The *arrow* indicates one of the bronze ornaments used such as those shown in Fig. 3 (Erdenebaatar et al. 2015: 122)

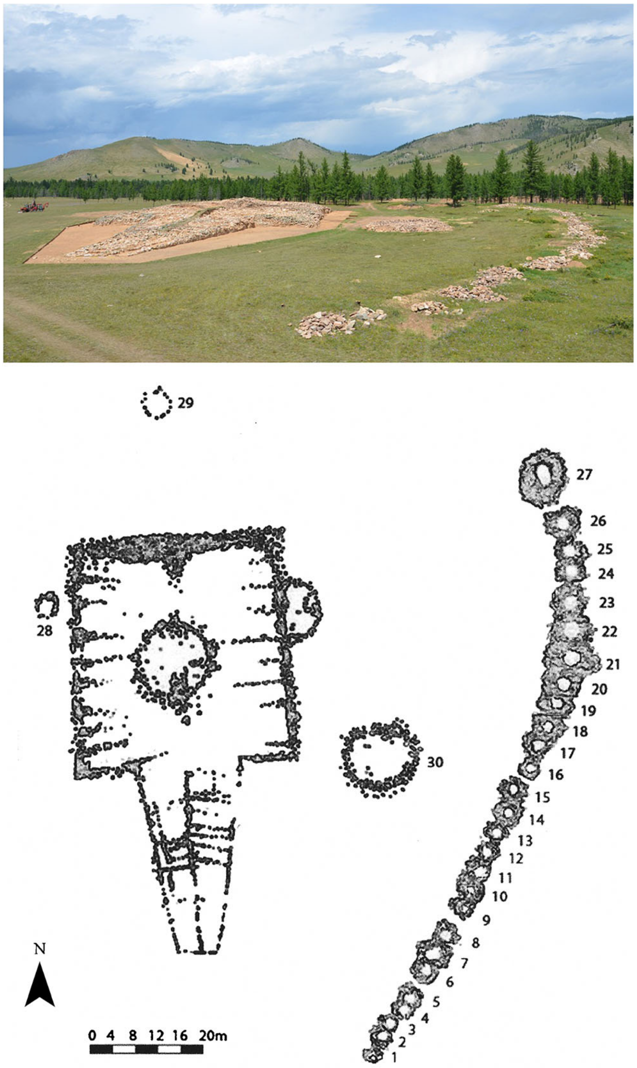

Fig. 5 Tomb complex. This shows the surrounding landscape (*top*) and the arrangement of the main tomb and satellite burials (*bottom*)

The main tomb held numerous bronze and iron objects along with many other valued items, providing a unique opportunity to gain insight into the material culture dominating the region at the time. The bronze and iron objects are of particular importance because of their large volume (Figs. 2 and 3), which is of almost an industrial scale and does not seem to support the theory viewing them primarily as the result of foreign imports. With the exception of various large-scale bronze vessels of typical steppe style (Erdenebaatar et al. 2015: 184), most of the artifacts were apparently parts used in lavishly adorned horse-drawn wagons, which have generally been regarded as imports from China. In order to address this inconsistency, we performed a preliminary investigation (Eregzen et al. 2013) on some select bronze objects. It was surprising to note that most of the objects examined, especially the larger ones, were produced with alloy recipes similar to that of the steppe bronze tradition. To test this result, we focused on artifacts large in both scale and quantity, as well as stylistically of foreign origin. The objects shown in Fig. 3 were found to meet these requirements and selected for investigation. They are almost identical in shape and size, resembling a flower with six petals emanating from a hollow stem, which is similar in style to those found in China (see Plate 92 in Umehara 1937). A thin gold (Au) layer was observed on the surface of the test specimens from objects #1, 2, 9, 11, 18, 19, and 20, indicating that they were produced as gilt bronze. In the other specimens, however, no such layer was found to remain, although it is not certain if they were coated but subsequently lost the gold layer or were not coated at all. Given their large quantity, the artifacts under consideration are expected to provide information that may better represent the general technological tradition involved. The weight of object #12, which is relatively well preserved and better maintained in terms of original shaping, was approximately 720 g.

Microstructure and alloy composition

Small specimens were taken from the objects and then prepared following standard metallographic procedures of mounting, polishing, and etching with a solution of 100 ml methyl alcohol, 30 ml hydrochloric acid, and 10 g ferric chloride. Their microstructures were examined using an optical microscope and a scanning electron microscope (SEM). The chemical composition was measured using the energy dispersive X-ray spectrometer (EDS) included with the SEM instrument and reported in weight fraction to within 0.1 %. The average composition of each specimen was inferred from the EDS spectrum taken in a raster mode from a corrosion-free area of approximately 0.65 × 0.45 mm, except in cases where restrictions arising from specimen size or corrosion necessitated a smaller area.

Alloy composition

The average chemical composition per specimen taken from each object in Fig. 3 is summarized in Table 1, in descending order according to arsenic level. The most prominent feature evident in this data set is the presence of arsenic in all the objects examined and its key role in most of them as the major alloying element. Another significant fact is that the arsenic level varies considerably from 1.2 to 8.9 % and averages 3.8 %. Tin was also added but the amount was limited, ranging from 0 to 3.5 % with the average determined to be 1.3 %. The insignificant tin concentration of 1.0 % or less observed in nearly half of the specimens examined must have been the result of an addition that was not intended. By contrast, a lead concentration of 3.0 % and above (Craddock 1979) in more than half of the items indicates that they were manufactured in a technological environment where lead addition was in

Table 1 Chemical composition of the bronze objects shown in Fig. 2, with the data arranged based on arsenic content in descending order

No	Object no. in Fig. 2	Chemical composition by weight %				Comments
		As	Pb	Sn	Fe	
High As and little Sn without added Pb						
1	16	8.9	0.7	–[a]	2.3	Speiss precipitates
2	12	7.4	–	–	2.3	Speiss precipitates
3	9	7.0	1.5	0.5	1.5	Speiss precipitates; Gilt
4	4	5.9	0.4	1	3.1	Speiss precipitates
Group average		7.3	0.7	0.4	2.3	
Medium As and low Sn with added Pb						
5	7	5.2	3.0	0.9	2.3	Speiss precipitates
6	2	5.1	5.8	2.2	–	Gilt
7	17	4.6	3.0	0.6	–	
8	6	4.2	1.8	0.4	–	
9	11	4.1	2.6	1.3	0.4	Gilt
10	14	4.1	2.5	–	–	
11	19	3.9	3.8	0.7	–	Gilt
12	3	2.9	2.2	1.3	–	
13	10	2.8	5.0	0.7	–	
Group average		4.1	3.3	0.9	0.3	
Low As and notable Sn with added Pb						
14	1	2.3	4.0	1.6	–	Gilt
15	18	2.2	3.0	2.0	–	Gilt
16	8	2.0	3.0	2.2	–	
17	21	1.8	3.6	2.2	–	Artifact fragmented
18	5	1.7	4.7	2.9	–	
19	20	1.6	2.8	3.5	–	Gilt
20	15	1.5	4.2	2.3	–	
21	13	1.2	5.1	1.6	–	
Group average		1.8	3.8	2.3	–	
Average		3.8	3.0	1.3		

[a] None detected

practice. The amount of added lead, however, is relatively low and never exceeds 5.8 %.

Another fact of significance noted in the data of Table 1 is that the decrease in arsenic content is largely in keeping with the increase in the lead and tin levels. For instance, both the lead and tin concentrations of the first four objects are negligible and well below 1.0 % on average. The rest of the objects, however, contain 1.8 % or greater lead with the average set at 3.5 %. By contrast, evidence of tin addition, though limited, is noted only in the bottom eight objects where the tin level ranges from 1.6 to 3.5 % with an average reading of 2.3 %. The strong compositional correlation between arsenic and the other two alloying elements suggests at least three different alloy recipes in practice for the objects under consideration. The items in Table 1 are therefore classified into three groups consisting of the high, medium, or low arsenic levels. This classification emphasizes the key role of arsenic in determining the alloy methods. However, it should also be noted that the medium arsenic group features the addition of only lead in a notable amount, while the low arsenic group is characterized by the addition of both lead and tin. The significant iron level, which must have been derived from an inadvertent addition, is another factor that distinguishes the high arsenic group from the others. Such high iron content is intimately associated with the presence of speiss precipitates observed only in the high arsenic group, which will be discussed in detail in the next section.

It is generally accepted that arsenic alloying in antiquity was achieved through the careful use of As-bearing ores in the smelting of copper (Lechtman 1999). Recently, however, Rehren et al. (2012) proposed the possibility of adding a special high arsenic material termed speiss either to oxide-based copper ores during smelting or directly to molten copper metal in alloy making. In all the methods proposed, the arsenic content is indirectly controlled as opposed to the direct alloying of tin and lead in which the component materials are predetermined and then added in elemental form. As such, the amount of arsenic included in an object is difficult to control exactly and subject to inevitable variation. It is important to note that this variability becomes even more pronounced by the loss of arsenic occurring in the subsequent remelting operations for casting, alloying, or recycling (Park and Eregzen 2015). In this respect, the high arsenic objects with their negligible lead and tin contents have special significance in that they may represent fresh copper-arsenic materials that were given no further treatments for the addition of other alloying elements. Their high iron concentration, rarely attained in objects treated with significant remelting, provides supplementary evidence that they were made of fresh arsenical copper with no further treatments applied (see next section). The high arsenic group as seen in Table 1 contains arsenic of approximately 5.9 to 8.9 %, but the lead and tin concentration are not high enough to suggest that they were the result of a deliberate addition from a separate process. These data should then serve as a reference approximating the composition of freshly made copper-arsenic alloys in terms of their arsenic level and the amount of other elements incorporated inadvertently through the use of impure copper ores or recycled copper metals.

By contrast, the addition of lead and tin, whether together or separately, should be done in a process involving remelting. This in turn may cause a substantial loss of arsenic. The medium arsenic specimens containing notable lead are then expected to have had their arsenic content lowered as compared with those made of fresh arsenical copper. This expectation is confirmed in their reduced arsenic level ranging from 2.8 to 5.2 %, as seen in Table 1. This value amounts to a depletion of arsenic by around 3.0 % in comparison to that of the high arsenic group, which must have occurred during the treatment given in order to raise the average lead content to 3.3 %. The iron level which is below the detection limit in most of the objects, together with the general absence of speiss precipitates, further supports the notion that the medium arsenic objects were made of arsenical copper that was treated in a process involving remelting.

The low arsenic specimens must also have had their arsenic concentration reduced during the remelting treatments in order for lead and tin to be added. Their significantly lower arsenic level as compared with that of the medium arsenic group, however, cannot be fully explained by the effect of remelting and needs further explanation. There is no reason to believe that the treatments given to them were any different and yielded excessive arsenic depletion. Rather, it is more likely that the low arsenic level was inherited primarily from the raw copper material supplied for making the specific alloys, whether from smelting or from recycled scraps. The data in Table 1 indicate that the tin addition of 1.6 % and above was made only in objects with an arsenic concentration below 2.3 %, with the only exception being object #2. This suggests that at least two kinds of distinctly different raw materials were available; one with sufficient arsenic that would not necessarily require reinforcement by tin and the other in need of tin addition to supplement its low arsenic content. The arsenic level clearly distinguishable between them suggests that they were likely produced in at least two distinct engineering processes. One could infer from Table 1 that the high arsenic material was used either with or without the addition of lead resulting in high or medium arsenic objects, respectively, while the other, with the tin addition, was predominately alloyed with a notable amount of lead.

Microstructure

The microstructures of all the specimens examined were similar and found to consist of the α phase of the Cu-As or Cu-As-Sn system forming the background, which was dotted with various small-scale precipitates. A typical structure is presented in an optical micrograph (Fig. 6) taken from the specimen of object #16 where numerous bright and grey precipitates are scattered in the α background along with some large-scale pores located in the dark areas. The presence of some precipitates is clarified in the SEM micrograph (Fig. 7), magnifying the area marked by the arrow near the left edge of the optical micrograph. The EDS spectrum (Fig. 8) shows that the particle at arrow 1, which is one of the numerous bright particles scattered over Fig. 6, is composed of iron-copper arsenide, i.e., speiss. Those at arrows 2 and 3 were also identified from similar EDS analyses to be particles of copper-iron sulfide and almost pure lead, respectively. This specimen is shown in Table 1 to have been made of copper alloys containing approximately 8.9 % As, 2.3 % Fe, and 0.7 % Pb without tin. A small amount of sulfur was also detected but not reported. It is believed that this was due to an inadvertent addition and has

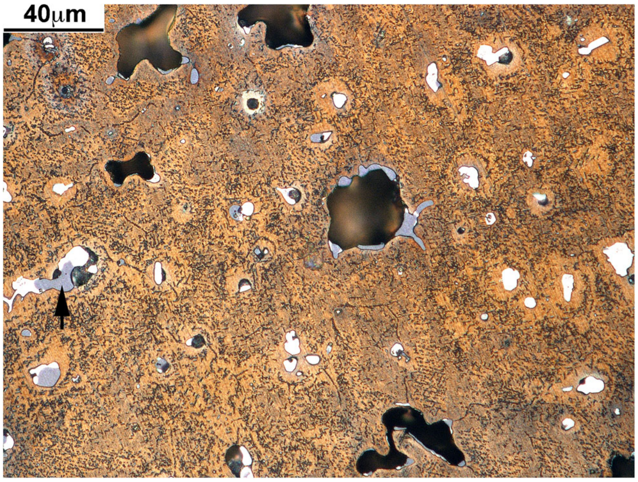

Fig. 6 Optical micrograph taken from the specimen of object #16. The background consists of the α phase of the Cu-As system; the numerous bright and grey particles represent iron-copper arsenide and copper-iron sulfide, respectively; the *large dark areas* are cavity porosities

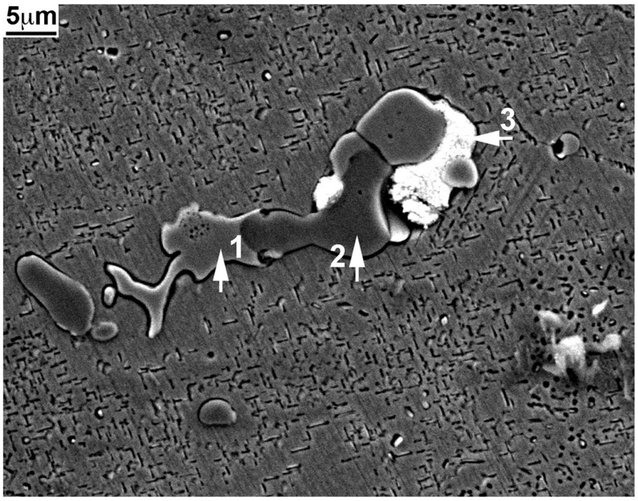

Fig. 7 SEM micrograph magnifying the area *marked by the arrow* near the left edge of Fig. 6. *Arrows 1*, *2*, and *3* indicate the presence of iron-copper arsenide, copper-iron sulfide, and almost pure lead particles, respectively

little effect on the alloy properties. The α background of the specimen, which is in a well-annealed state with no notable evidence of mechanical working applied, indicates that the object was fabricated exclusively by casting at relatively slow cooling rates.

Speiss precipitates were consistently found in specimens belonging to the high arsenic group in Table 1, but not in any of those of the other groups with the single exception of object #7. This observation parallels the result obtained by Park and Eregzen (2015) in their remelting experiments with an arsenical copper object containing a notable amount of iron along with numerous speiss precipitates. Their work confirmed that brief remelting could cause arsenical copper to suffer a complete loss of iron and speiss particles, if any, as well as a notable depletion of arsenic. Our data, in line with their result, supports the idea that the compositional difference between the high and medium arsenic groups resulted from different treatments applied to fresh arsenical copper prior to its use in making a final product.

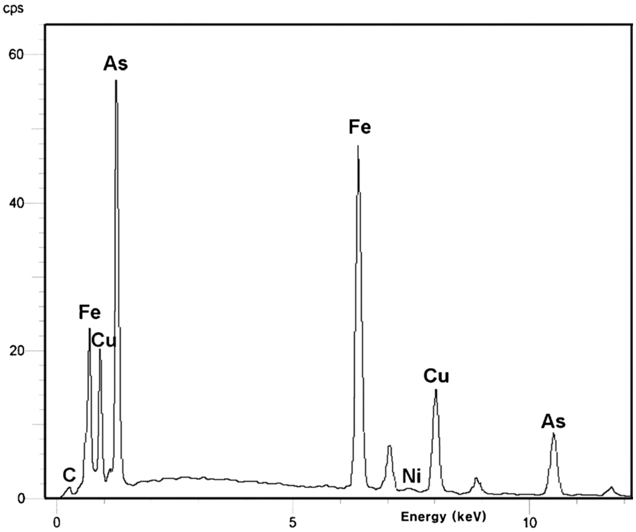

Fig. 8 EDS spectrum taken from *arrow 1* in Fig. 7

Radiocarbon dating

Pieces of degraded or burnt wood were frequently found inside the hollow stems of certain bronze objects excavated. Others contained organic materials such as leather and cloth attached to their surface. Three such wood specimens and a piece of leather were sent for radiocarbon measurements to the University of Arizona's NSF-Arizona AMS Facility for ^{14}C analysis. The results are summarized in Table 2 where the calendar date was calculated using Calib Rev 6.1.0 (Reimer et al. 2009) in conjunction with the extended ^{14}C database (Stuiver and Reimer 1993). Note that measurements #1 and 2 were made using the same wood specimen from object #12 at two different precision levels, while measurements #4 and 5 were done on two different specimens, wood and leather, associated with a single bronze object not examined in this study. The 1σ ^{14}C age, given in years before present (year BP) as of 1950, varies significantly from 3341±43 in #4 to 2008±37 in #5. The age of specimen #4 is clearly too old for some unknown reason and cannot be used to infer the actual age of the site under consideration. The data in measurements #1, 2, and 4 from the wood specimens are however in good agreement but show notable deviation from the age of the leather in #5. If the uncertainty associated with the old wood effect is taken into account, the data from this leather specimen may best represent the actual date, which ranges from the first century BC to the first century AD. This date falls within the range proposed for other Xiongnu elite burials such as those at Golmod 1, Tsaram, Duurlig Nars, and Noyon Uul (Brosseder 2009).

Discussion

The compositional data presented in Table 1 indicate that the objects under consideration were made in a technological environment where the production of arsenical copper played a key role as the primary raw material. They can be classified into three groups of high, medium, and low arsenic content, with their arsenic level varying significantly from 1.2 to 8.9 %. This classification and observed tin content suggest the circulation of at least two distinct arsenical copper alloys used as raw materials for bronze making during that period. One of them is seen in Table 1 to contain sufficient arsenic such that no further addition of tin was considered necessary to improve any material properties such as the melting points,

Table 2 Results of the AMS radiocarbon measurements on wood and leather specimens excavated from the tomb under consideration

No.	Lab Code	Material		δ^{13}C (‰)	1σ ^{14}C age (year BP)	95.4 % (2σ) Cal. age ranges
1	AA101070	Burnt wood	Standard	−25.2	2070±36	186 BC-AD 3 (100 %)
2			High precision	−25.2	2099±28	194 BC-48 BC (100 %)
3	AA104115	Degraded wood		−24.3	3341±43	1739 BC-1706 BC (7.7 %) 1697 BC-1520 BC (92.3 %)
4	AA106394	Degraded wood		−23.5	2060±42	186 BC-AD 25 (99.9 %) AD 25 (0.1 %)
5	AA106395	Leather		−16.9	2008±37	109 BC-AD 75 (100 %)

The measurements were made in the University of Arizona's NSF-Arizona AMS Facility for ^{14}C analysis

fluidity, or strengths of the alloys. According to the composition of the high arsenic group, this material was employed with no further treatment applied for control of the alloy chemistry. By contrast, the tin content that is significant in the low arsenic group suggests that the tin addition was made exclusively to materials whose arsenic level was known to be distinctly low. The amount of added tin is very limited, however, revealing a serious effort to minimize tin consumption. As for the medium arsenic group, its unique chemistry may be taken as evidence for the circulation of another arsenical copper produced exclusively for use in the specific alloying of lead without tin. This possibility can be rejected, however, given the loss of arsenic that may occur during the remelting operation necessary for the addition of lead. It is likely therefore that the difference in alloy composition between the high and medium arsenic groups originated not from the difference in raw materials but rather from the remelting treatment applied only to the latter. The absence of speiss precipitates in the medium arsenic group as opposed to their consistent presence in the high arsenic group also supports this interpretation.

The bronze tradition as inferred from the above observation is identical in nearly every aspect to the technology that was practiced in the steppe region including the Xiongnu territory. Notable similarities include the dominance of arsenic as an alloying element, occasional use of limited tin, and the total alloy content being determined at 10 % or below. All of these features are in strong contrast, however, to those characterizing the bronze tradition that had long been established in China by the time the objects under consideration were being made. Therefore, based on the reliable evidence currently available (Barnard 1961; Bagley 1987; Chernykh and Kuzminykh 1989; Khavrin 2011; Park et al. 2011; Rawson 1990; So 1995), they were most certainly products of Xiongnu communities that were made following the traditional steppe bronze recipe. This conclusion is surprising in view of their exotic appearance (Umehara 1937) which is rarely observed in objects of steppe origin. In fact, their unique forms and styles as well as their affiliation with Chinese style wagons give the misleading impression that the objects were products from Han workshops. The analytical results, however, make it clear that they were imitations of Han style artifacts manufactured following the steppe technology.

The substantial lead added in all the objects belonging to the medium and low arsenic groups, however, must have been a departure from the known steppe recipe although it is not impossible to find evidence for occasional use of lead before the Xiongnu period (Park et al. 2011). Given the style and purpose of the objects as well as the key role of lead in Chinese bronze, the lead addition intended in the majority of the artifacts examined was likely encouraged by an ever-increasing influence from China through Xiongnu interaction with the Han Dynasty. The lead content that is negligible in the high arsenic group, however, suggests that experiments with lead and arsenical copper were still under way at the time. This relative lack of lead in objects with more arsenic, despite the possible Han influence, may have been associated with the depletion of valuable arsenic from the parent copper alloys during the remelting treatment for lead addition. This loss must have been perceived as a serious disadvantage, particularly in the Xiongnu bronze industry which relied heavily on arsenical copper as a raw material. As such, the consistent use of lead in such alloys was likely discouraged.

The attempt to exploit the beneficial effect of lead in bronze, as inferred from the data in Table 1, may have been the beginning of a notable transition in Mongolian bronze technology. According to the above discussion, however, the regular use of lead in bronze for its effects on reduced melting points, enhanced fluidity and lower material costs was apparently just beginning in Mongolia at the time. However, its impact remained limited primarily due to a heavy reliance on arsenical copper likely stemming from a shortage of available tin in Mongolia.

Conclusion

Twenty-one bronze objects excavated from the royal Xiongnu tomb of the first BC to AD first century located at Golmod 2 in Mongolia were examined for their alloy composition and microstructure. These consisted of exotic ornaments affiliated with multiple Chinese style wagons interred in the burial. The composition data show that the objects were made of alloys based on the Cu-As system, though frequently with the addition of either lead alone or both lead and tin. The establishment of this particular alloy recipe reflects the lack of tin long endemic to Mongolia, which is also evident in the above data. It is important to note that this tin deficiency placed a limitation on the amount of lead to be added, keeping its potential benefit from being fully exploited.

The bronze technology associated with the objects under consideration may therefore be characterized by the heavy reliance on arsenical copper, limited access to tin, and the total alloy content being determined mostly at a low value of 10 % or below. This particular alloy recipe is nearly identical to that of the pre-Xiongnu period as reported by Park et al. (2011), indicating that the earlier steppe bronze tradition was mostly carried forward to the Xiongnu State. The regular use of lead was a notable deviation, however, though its impact was limited. This constituted a minor adjustment most likely in response to the growing demand for exotic items, particularly those from China. The objects examined confirm this premise by providing an example of such foreign items produced in Mongolia. It is evident therefore that Xiongnu bronze production was not impacted by foreign influence as much as previously suggested as inferred from the exotic forms and styles of certain status items recovered. In fact, many of these items may have been domestically produced instead, yet erroneously regarded as imports, thereby inaccurately supporting the notion of Xiongnu dependency on foreign states.

According to the above observation, however, the Xiongnu bronze industry still maintained most key features of the earlier steppe tradition and remained self-sufficient in terms of material resources and technological aspects. Moreover, they could meet their own needs for traditional steppe items as well as those of foreign origins. It is significant to note that a similar conclusion was drawn from studying the iron technology of the Xiongnu State (Park et al. 2010). which was based on the production of bloomery iron as opposed to the Chinese style of cast iron technology. Evidently, achievements by the Xiongnu in terms of material culture, bronze and iron production, were substantially underestimated in arguments centered around their pastoral nomadic economy. Thus, revision may be needed to theories that overemphasized the impact of foreign influences on the rise of the Xiongnu State.

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