Tracing the flows of copper and copper alloys in the Early Iron Age societies of the eastern Eurasian steppe

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Introduction

The Early Iron Age of the Eurasian steppe zone (c. 1000 to 300 BC) is characterized, above all, by connectivity. It is a period in which rapid transmissions of ideas within the pastoral world—marked by the appearance of strikingly similar modes in material culture and stylistic representation from the Danube to Manchuria (Figure 1)—begin to be matched by ever more specific material evidence of contact between these steppe societies and their agricultural neighbours to the south (Rawson 2013; Wu 2013).

Many researchers have sought to explain this increasingly interactive world as an outcome of migration or mobility, associated with rising equestrianism in both economic and martial contexts (e.g. Moskova & Rybakov 1992; Davis-Kimball *et al*. 1995; Chernykh 2014). Others have looked within to find new kinds of social and structural complexity in the societies in the steppe (e.g. Linduff 2004; Bokovenko 2006; Hanks & Linduff 2009; Houle 2010). Whatever the case, a clearer understanding of the patterns and character of interaction is one of the essential goals of archaeological research in this period.

Drawing together existing 'legacy' data on the composition of copper and bronze artefacts from the Early Iron Age of eastern Eurasia, this paper shows how new theoretical and methodological approaches to the study of artefact chemistry (see Bray & Pollard 2012) can begin to contribute to this discussion. Though such data are imperfect in many ways, they reveal structured patterns at a regional scale, providing a framework for the reconstruction of flow (*sensu* Bray *et al*. 2015) in the circulation of copper and tin through contemporary society. By rejecting simple ideas about object and origin, we can begin to trace complex patterns of production and reproduction, mixing, movement, and exchange across space and time, and explore variations in the perception of both metals and metal objects in the societies who made and used them.

Archaeometallurgy in the eastern steppe

Although nominally attributed to the Iron Age, copper, bronze, and occasionally gold, remain a dominant in archaeological metal assemblages for much of this period. These items— including personal weapons and tools, horse harness, mirrors, plaques, pendants, and a range of ornaments (Figure 2)—have been extensively studied in terms of typology and style (e.g. Bunker *et al*. 1997; Wu 2008;). Such traditional discussions frequently use stylistic and typological similarities as markers of 'interaction' and exchange. However, the character of contact is rarely explored in detail and the orientation of exchange often remains a matter of opinion (see Shul'ga in press for a good counter example).

Research into the metalwork of the Eurasian Bronze Age, particularly in the western steppe, has attempted to integrate these traditional modes of archaeological research within a single interpretive system, combining absolute chronology, technological, and chemical analyses (e.g., Chernykh 1992, 2007, 2014; Chernykh and Kuzmynykh 1989). For some reason, this kind of approach has not been extended into the Iron Age. In spite of more than fifty years of research, discussions of metal chemistry in the first millennium have remained solidly independent, locally focussed, and largely disconnected from the primary archaeological narratives.

The earliest significant archaeometallurgical study in the region, led by I.V. Bogdanov-Berezovaya (1963), analysed more than 400 artefacts from the Minusinsk Basin and applied an 1% cut-off to tin and arsenic to classify their chemistry metal into four broad alloy types: clean copper, arsenical copper, arsenical tin bronze, and tin bronze. The observed range of trace elements within each of these alloy types was also discussed. She concluded that arsenical copper production played the primary role in Tagar metallurgy, with tin-bronze as the second largest copper alloy. She also noted that some objects attributed to the Tagar culture contained high quantities of nickel, sometimes up to 2-3%.

Working on the same region in 2007, S.V. Khavrin adopted a more flexible descriptive approach to the raw data on early Iron Age copper and bronze. He concluded that metal production in the region remained focussed on copper with a natural admixture of arsenic and nickel until the middle of the first millenium BC.

Only in later periods did the use of tin-bronze and leaded tin-bronze come into use. Pyatkin (1983) applied a statistical method to the data, using Spearman's rank correlation coefficient, to measure the degree of similarity in the chemistry of bronze horse gear from Arzhan I in Tuva. He concluded that the majority of the material was made from arsenical copper with high nickel and antimony content and some bismuth. Sunchugashev (1969, 1975) adopted a rather different approach to this problem, focussing on the survey and study of potential ancient mining and smelting sites, exemplified by Temir in the Minusinsk and Khovu-Aksy in Tuva. The results showed the extensive exploitation of copper deposits between the 7th and 4th centuries BC. Survey and excavation at the sites identified a wide range of evidence for metallurgical production including slags, casting moulds, crucibles, nozzles, and stone mining and processing tools.

Working on metal assemblages farther to the east, in the Baikal Region, Sergeeva (1981) employed cluster analysis to statistically divide metal chemistry into different groups. Sergeeva also noted that between 1300-700 BC communities living in the Transbaikal utilised both tin-bronze and leaded tin-bronze, and she defined the presence of lead as a unique characteristic of Transbaikalian metallurgy. Communities of the Cisbaikal during the same period produced predominantly clean copper artefacts, though some tin-bronze and arsenical copper artefacts appear in the record around 700-500 BC (Sergeeva 1981: 19-27). A few items of leaded tin-bronze also appeared in Cisbaikal assemblages around this time, which in Sergeeva's opinion, suggests a link with the traditions of the Transbaikal (Sergeeva 1981: 26).
These works certainly provide a good overview of the characteristics of early Iron Age metalwork in eastern Eurasian steppe, and in many cases their general conclusions remain valid. However, these studies follow the conventional provenance perspective to assume that it is possible to correlate metal artefact chemistry directly with geological sources of metal ores. We consider this assumption to be deeply problematic. Technological factors and various human interactions with metal can significantly alter its composition, particularly if they involve re-melting and/or mixing of materials (Bray & Pollard 2012: 856). Understanding the specific distribution and significance of these practices is a necessary and crucial step in any archaeometallurgical analysis.

In this study, we apply a developing methodological approach, which seeks to identify patterns of metal use, re-use, and deposition at a regional scale (Bray *et al.* 2015). To do this, we need to widen the scale of analysis and shift the focus of our interpretations.

An Alternative Chemical Approach

The question of 'provenance,' which has been the dominant theme in archaeometallurgical research over the last 150 years, is based on the assumption that a static chemical connection exists between the composition of the metal and ores from which it was smelted (Junghans *et al*. 1960; Friedman 1966; Liversage 1994; Pernicka 1997). Although this conclusion is potentially valid in certain circumstances, its extension as a universal assumption in archaeological research seriously underestimates the complexity of human relationships with metal in prehistory. As Budd *et al*. (1996) pointed out, metallic ores are limited resources, especially for tin, and recycling or mixing of metal must have been commonplace in ancient societies. Such practices would potentially break any chemical connection between ore source and metal artefact. Indeed, Ixer (1999) argues that ore deposits usually vary so significantly in geochemistry and mineralogy that the *any* attempt to precisely reconstruct this connection is fraught with difficulty.

The method applied here (after Bray and Pollard 2012; Bray *et al.* 2015) is based on both theoretical thermodynamics, industrial observations, and the results of experimental archaeology (Mckerrell & Tylecote 1972; Sabatini 2015; Doonan pers. comm.). It relies on the fact that some common trace elements in copper alloys (e.g., zinc [Zn], arsenic [As], antimony [Sb], and iron [Fe]) under high temperature are preferentially 'lost' through oxidation and volatilization when compared with other more noble elements (e.g., gold [Au], silver [Ag], and nickel [Ni]). Where sufficient densities of data exist, these relative changes in chemical composition can be explored at various scales of analysis, allowing us not only to explore and understand patterns in the chemical data as proxy evidence of metal flow within and between regions in the past, but also to expose different attitudes towards metal and metal objects at the level of the assemblage.

Although described more fully elsewhere (Bray *et al.* 2015), it is worth outlining the main steps in the analytical process, the first of which is characterise the copper itself. For unalloyed artefacts, this is straightforward, but even where the copper has been intentionally alloyed with tin, lead, or zinc, we can give some estimate of the underlying copper composition by stripping out these elements and renormalizing the result. This calculation relies on the assumption that the remaining trace elements are associated with the copper itself rather than any of the added alloying components. Although this assumption is not always valid—the deliberate addition of lead, for example, may result in elevated silver content in objects—the methodology is sufficiently sensitive to identify the resulting anomalous patterns and sufficiently flexible to allow us to treat these alloying practices accordingly.

The modified data are classified into sixteen copper types based on presence or absence of certain trace elements (Table 1). Because we are drawing on chemical data from a variety of sources, the cut-off value for presence/absence (0.1 wt% in this instance) is a pragmatic compromise, which allows us to include as much of the available data as possible into the analysis. To test the robustness of the conclusions built on the basis of this analysis, this value is routinely changed during the interpretive process to assess the significance of any changes to the patterns described.

The next step is to classify alloy types, to do this, we use an arbitrary 1% cut off value to distinguish the presence/absence of deliberately added elements (tin, lead and zinc). This theoretically leads to an eight-fold classification: copper, leaded copper, tin-bronze, leaded tin-bronze, brass, leaded brass, gunmetal, and leaded gunmetal. However, for this period and region, only the first four of these categories are relevant.

These preliminary organisational steps, enable us to examine regional patterns in the composition of metal assemblages and to explore not only the movement or flow of metal differences in the way metals are used and re-used in society (Bray *et al.* 2015). The composition of metal within these flows can be altered by a number of processes: oxidative loss and volatilization, mixing with copper from different sources, and deliberate alloying. Each copper group does not necessarily relate to a single source, and over the course of its 'lifetime' a unit of metal may pass between different groups. The stepwise process of assigning a group, then examining the distribution and median levels of key elements allows us to untangle aspects of this life-history.

Early Iron Age copper metalwork in eastern Eurasia

A database of 1900 chemical entries (1371 of which have trace elements) has been collected for the purpose of this paper (Appendix 1 & 2). The data collated in this paper covers areas of the Altai, Tuva, Minusinsk Basin, Cisbaikal, Transbaikal, and Xinjiang which were occupied by predominantly pastoralist societies throughout the Early Iron Age. By way of comparison, we also include analyses of metal from contemporary semi-sedentary societies of northern and northwestern China, and the agricultural world of the Central Plains.

This chemical data was obtained from a variety sources and represents the use of an almost equally a wide range of analytical techniques. As a result, it is important to consider questions of comparability and reproducibility in our analysis. Fortunately, a large-scale, inter-laboratory investigation of this issue was carried out by Northover and Rychner (1998). They concluded that most of the data obtained showed general agreement irrespective of the analytical technique employed; these can, therefore, be used interchangeably with appropriate caution. Moreover, to minimise any resulting errors, we do not deal with absolute compositional values of isolated objects but rather focus on the chemical trends within the dataset.

Unfortunately, there is no universally accepted chronology for the pastoralist cultures of the Early Iron Age across these areas, and we are often reliant on reference dates from key monuments to establish a relative chronology for analysed artefacts. Among these critical monuments are the kurgans around Arzhan in Tuva, which provide a series of well-dated reference assemblages (especially for items of horse harness and animal-style ornaments) between the ninth and mid-seventh centuries calBC (Alekseev *et al*. 2001; Zaiteseva *et al*. 2007) (Figure 3). Contemporary with these finds are the early Tagar complexes in the Minusinsk Basin (Svyatko *et al*. 2009), the early 'nomadic' cultures of the Altai (Moskova & Rybakov 1992: 164), and the early Slab-Grave cultures of the Transbaikal (Tsybiktarov 1998)— although the precise chronological position of the latter is still a matter of debate. While we have provisionally accepted the published chronological interpretations associated with the analyses (e.g. Sergeeva 1981; Khavrin 2008), we hope that further archaeometallurgical research, integrated with reliable radiocarbon dates, will provide better chronologies for comparison in the future.

Classification of copper groups

Table 3 summarises the distribution of the sixteen copper groups in each of the geographical regions defined in this study. Where more than 10% of the analysed objects from a region belong to any single group, the corresponding cells are shaded to highlight major regional patterns.

'Clean' copper (G1) and 'arsenic-only' copper (G2) are both present in almost all regions; 'arsenic-antimony' (G6) and 'nickel-bearing' copper (G11 and G14) are restricted to the steppe, while argentiferous copper (G9 and G12) are primarily Chinese (the silver in these cases is probably brought in with the lead during alloying) (Figure 4).

The distribution of 'Clean' copper (G1) is most abundant in the Altai, Minusinsk Basin, and Cisbaikal, along the northern edge of Altai-Sayan Mountains. 'Arsenic-only' copper (G2) is common in most areas, but dominant in the metalwork from the Altai, accounting for almost 60% of the analysed objects, and suggesting significant primary production. The proportion of G2 copper within the local asssemblages diminishes with distance from the Altai.. Although central Chinese objects also show a high proportion of G2 , their arsenic content tends to be low, and most of them also belong to ritual vessels, radically different in technology and style, from the metalwork of the steppe. The emergence of G2 copper in central China probably belongs to another metallurgical network as yet incompletely defined (Liu *et al.* forthcoming).

The distribution of G6 'arsenic-antimony' copper, though interesting, does not reveal any clear patterns. Although the Lake Baikal regions contain a higher percentage (55%) than those in the west, we cannot rule out the possibility that other sources in other regions were also contributing to this pattern. Instead of linear directional exchange, the distribution of this copper type may help to highlight the complexity of the system and would be a potentially interesting focus for future research.

Nickel-bearing copper (G11 and G14) appears to be restricted to the steppe, and Tuva and the Minusinsk Basin are both excellent candidates as the source regions for these types of copper. The presence of metal of this type in the Transbaikal is potentially significant, but as it is relatively rare within the assemblage, its contribution to wider flow of metal is not yet clear.

Some copper types suggest possible long-distance relationships between the steppe and China. For example, G12, silver-bearing copper typical of metalwork in China, also occurs in the Transbaikal, but is absent in other areas. Additionally, highly mixed G16 metal is found in both northern China and the Transbaikal.

Reconstructing flows of metal

Our chemical model predicts that elements vulnerable to oxidative loss (e.g. arsenic and antimony) will diminish during recycling events. Therefore, a decrease in the average levels of these elements at an assemblage level can be regarded as indicators for the dominant direction of metal flow between regions. By observing the profiles of these elements, we can begin identify patterns of primary and secondary production.

Figure 5a shows the profile of arsenic in G2 'arsenic-only metal' for each region. In the Altai we see two pronounced peaks between 0.5–1% and 1.5–2%. Over 50% of the Altai G2 copper objects fall within one of these two bands. In this respect, the Altai region is quite different from the other areas. Such high arsenic levels imply easy access to high-arsenic copper ores.

G2 metal in other regions tends to fall into the low-arsenic range (<0.5%). This pattern could be explained as the result of routine re-casting of the Altai G2 metal into new objects or locally appropriate forms. Figure 5b compares the median arsenic level across the regional assemblages. In the Altai, it is around 1.5%, far higher than that in other regions.

Of course, many other primary production centres would have existed beyond the Altai region during the Early Iron Age. These certainly contribute to the patterns we observe in the data. Interestingly, even with the relatively limited data, some potential candidates show up clearly. One such example is the nickel-bearing copper (G11 and G14) which appear concentrated in the Tuva and Minusinsk Basin. The profile of arsenic in G11 illustrates the general similarity of metal in both regions, with a common peak at 1-2% arsenic (Figure 6a). Arsenic levels in G14 metal also show a maximum at the same level (Figure 6b). This may suggest a shared 'repertoire' of nickeliferous metalwork in both Tuva and Minusinsk.

This conclusion fits well with the available archaeological evidence of mining and metalworking activities in these regions, which have emphasised the importance of primary production in the Tuva and Minusinsk Basin; several Early Iron Age mining, smelting, and casting sites have been discovered near the copper-nickel-cobalt deposits at Khovu-Aksy in eastern Tuva (Sunchugashev 1969: 44). Likewise, the chemical analysis of copper ingots from Temir, a Tagar casting site in Minusinsk, show arsenic greater than 1% and nickel around 0.1 to 0.6% (Sunchugashev 1975: 124-125). This evidence shows that, when sufficient data is available, our chemical approach can serve as an independent tool to predict likely areas of primary production area for particular copper groups. This is particularly important when there is no direct archaeological evidence of primary production is available.

Distribution of alloy types

Examining the alloy types used by different pastoralist groups can also provide valuable information regarding the circulation of alloying materials (tin or lead), whether as ore, metal, or within finished objects. Regions with access to such resources are likely to produce high proportions of tin bronze or leaded tin bronze in their assemblages. In order to determine the alloy type, we set the cut-off value at 1% for the significant presence/absence of tin and lead. This classification criterion is intended to highlight the characteristic history of theses copper-based alloys rather provide any window into the the actual mechanical properties of the metal itself.

Table 3 shows the percentage of each alloy type in each region, revealing two separate traditions of metallurgical practice in the Early Iron Age of eastern Eurasia. The first is the steppe-style use of unalloyed copper and tin bronze. This stands in sharp contrast to the strong tradition of leaded tin bronze seen in central China and among some of its neighbours, the bronze-producing communities in northern China and the Hexi Corridor, though it is not yet clear how much of this latter material is recycled or acquired from Chinese sources (see Cao 2014).

Plotting distributions for each alloy type on a map can further highlight the spatial relationships between different areas (Figure 7). In the Altai, tin bronze production dominates that seen other steppe regions, and nearly 60% of the Altai objects from this period were alloyed with tin. This proportion drops steadily as we move eastwards away from the Altai. Assemblages from the Minusinsk Basin and Xinjiang still contain quite high proportions of tin bronze, while in the Cisbaikal the proportion falls sharply. Interestingly, the use of tin bronze in Tuva is also quite low, though this is potentially a function of the particular character of the analytical sample from this region. Also of interest is the signifcant proportion of tin bronze in the assemblages of the Transbaikal, which may reflect the exploitation of local cassiterite deposits near the Upper Onon River (Wolf 1982: 262).

The Baikal Region is also noteworthy for the presence of leaded copper and bronze objects (Cu-Pb and Cu-Sn-Pb). As noted above the addition of lead appears to be closely connected with China and may suggest the use of leaded metal, acquired from China and its neighbours, in these regions. Again, this would fit well with other lines of archaeological evidence (e.g. Hommel *et al.* 2013).

In order to develop a better picture of the use of tin and lead, it is important to look at the profiles of these elements in the regional assemblages. In the primary production regions, where ancient metalworkers had ready access to tin resources, they were able intentionally produce tin bronze/leaded tin bronze within more or less controlled compositional ranges (Figure 8). Central Chinese metalwork, for example, shows a unimodal distribution of tin between 7% and 19%. Such a broad tin distribution might be due to diverse types of bronze artefacts which require different levels of tin. Objects from the Altai and Xinjiang do not show such prominent peaks. However, we can still regard both areas as tin bronze production centres due to the frequent occurrence of high-tin objects. The Altai region has a faint peak between 10% and 13% tin, followed by Xinjiang with a peak between 7% and 10% tin. The similarity of the tin distributions in both regions may indicate that tin bronze production in Altai and Xinjiang were closely associated and tin resources or high tin bronzes were either readily available or freely circulated in both regions.

In other areas, with limited access to local tin resources, we would expect a different pattern. Such ‘non-primary tin bronze use’ would be characterized by a predominance of low-tin artefacts, perhaps primarily produced by recycling and recombining tin bronzes acquired through exchange or other forms of contact. Since the majority of objects from the Transbaikal, Cisbaikal, Minusinsk Basin, and Tuva contain considerably less than 7% tin, we would argue that all of these areas fall into this latter category. Of course, on its own, this pattern could be interpreted as local tradition of low-tin bronze production, but if we combine this with data on arsenic levels, this seems increasingly unlikely. Arsenic, as discussed earlier in this paper can be used as a marker of recycling, and if tin bronzes from one region were routinely re-melted in another, we would expect an overall decrease in arsenic between their assemblages. Figure 9, shows median arsenic levels in regional bronze (tin>=1%) assemblages across the eastern steppe, illustratesprecisely this pattern. Away from the Altai, which we consider to be a major source of tin and tin bronze, the falloff seen into other regional assemblages in the steppe can be most plausibly explained as the result of re-melting imported tin bronzes in combination with local unalloyed copper, resulting in objects with both relatively low tin and arsenic values.

Typology and Chemistry

Thus far, the discussion has considered all types of copper alloy objects together at a regional scale. However, where sample numbers permit, it is possible to begin to target individual artefact types and consider how they fit within or differ from the general trends. To demonstrate this, we have extracted data for the most iconic and widely distributed steppe artefacts of this period: single-bladed knives and cauldrons.

Knives from the Minusinsk Basin and the Baikal Region allow for this kind of comparative study. As shown in Table 4, these knives mainly consist of G2 ‘arsenic only’ copper and tin bronze. However, while we see a pattern of diminishing arsenic in the overall assemblages from these regions, the arsenic distribution in knives appears relatively stable. This implies that many of these knives were moving directly between regions, whether through exchange or population movements, without entering the recycling chain (Figure 10a). The similar profile of tin (between 1 and 7%) may suggest that some were even transported directly between Minusinsk and the Transbaikal (Figure 10b). Consequently, the circulation of metal in eastern Eurasia involved both general exchange and recycling of metal (e.g., Altai G2 tin bronze) and direct movement or exchange (e.g., single-bladed knives) to form a complex metallurgical network. Such patterns are clearly worthy of further study. Compositional data on cauldrons, though relatively limited, may also show interesting evidence of technological transmission. In the Minusinsk Basin, the chemistry of cauldrons generally follows the same copper groups as single-bladed knives (G2, G6, G11 and G14). However, the alloy types used are distinctive; mostly unalloyed copper with a few leaded tin bronze and leaded copper examples. The preference for pure copper in the production of cauldrons is also attested in Xinjiang (see Mei 2002), suggesting a possible relationship in technological choice. Furthermore, these copper cauldrons often bear traces of casting seams, evidence of 'piece-mould' production. This method was characteristic of bronze vessel production in China, and its appearance in the eastern steppe further consolidates proposed links between these two areas (So and Bunker 1995: 108).

Discussion and Conclusion

The provisional directional flows of metal described in this paper are summarised in Figure 11. G2 'arsenic-only copper' was primarily produced in the Altai and filtered into the Minusinsk Basin and on into the Baikal Region. A similar flow of tin from the Altai, and possibly also from Xinjiang, is also apparent—probably in the form of finished tin bronze products, reworked and recombined with other copper sources in the Minusinsk Basin and beyond. Only in the Transbaikal do we see the potential exploitation of other primary sources of tin. Simultaneously, nickel-bearing copper (G 11 and G14), deeply rooted in Tuvinian and Minusinsk metalwork, reached as far as Transbaikal, where the presence of G12 (silver-containing copper) also suggests other connections with the south. Interestingly, though G2 metal produced in the Altai flowed into the Minusinsk, no corresponding flow of G11 and G14 metal in the opposite direction was identified. This apparent eastward drift in the flow in copper and tin resources during the first few centuries of the first millennium BC is intriguing and warrants further investigation, both in the context of subsequent developments and in relation to the extensive metallurgical network which emerged during the Final Bronze Age. The coincident distribution of Karasuk-related bronze single-bladed knives, in particular, suggests that the patterns of flow in the Early Iron Age built directly upon the 'modalities of exchange' established in the preceding period (Legrand 2004:15; Molodin *et al*. 2009; Gorelik *et al*. 2013). Likewise, another metal trading network, through the Mongolian steppe to central China, was also established during the Final Bronze Age (Cao 2014).

What seems clear from our initial analysis is that the structure of metallurgy and metal exchange among pastoral communities of the steppe is both complex and dynamic. It is tempting to attribute some of the 'mobility' seen in metal as markers of the routine seasonal movements and intercommunal contact, which is broadly characteristic of steppe societies. Certainly many of the patterns we see were shaped by short-distance, multi-stage exchange relationships of this kind, combined with significant local re-production. However, indications of more extensive transfers, and even the direct movement of finished objects over considerable distances seems clear.

Perhaps certain objects had sufficient social significance to escape the basic currents of metal circulation, in which re-working and re-melting was commonplace, changing hands multiple times in their original form. Perhaps they were deeply personal, and closely bound to the people for whom, or by whom, they were made. New data, combined with detailed typological work and other lines of evidence, should allow us to target and unpick these patterns of movement and exchange; again, such questions provide potentially fruitful avenues for research.

Of course, as this paper has been reliant on 'legacy data' in its reconstruction of flow within the metallurgical network of the Early Iron Age, it inevitably faces the challenges of insufficient information, sampling bias, and chronological uncertainty. In the absence of significant bodies of data on metal composition from key regions of Northern China, Mongolia, Xinjiang, and Kazakhstan all the patterns we describe are to some extent incomplete and the existence of alternate pathways of circulation and additional foci of primary production seems certain. Data collection in all these regions is an active focus of our on-going research.

Chronology is also a significant problem. Reliable series of radiocarbon dates for this period are only available for limited number of sites in the Tuva, Minusinsk Basin, and central China, and the majority of the Early Iron Age cultures have only broad and ambiguous chronological boundaries. This alone makes the comparison of synchronous events very challenging. Since we know that some metal objects remained in circulation for significant periods, absolute chronology must also be very carefully paired with typology. For many sites, this pairing is currently difficult to achieve.

Perhaps the most significant problem we face is the general lack of data, which limits our ability to work in detail on relationships between typology and composition. This work is crucial, as it is only through this combination of archaeological and chemical studies of metal that we can hope to find explanations for the structure in the data. Ultimately, both the patterns we have described and the questions we have left unanswered can only be tested and clarified through further research. For us, in spite of all the challenges, this seems an exciting prospect.

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Figure Captions

Figure 1. Map showing defined geographical regions within the Eurasian steppe

Figure 2. Examples of steppe-style bronze artefacts during the Early Iron Age (redrawn after Moskova & Rybakov 1992 & Wu 2008).

Figure 3. Archaeological chronologies (dates modified after Moskova & Rybakov 1992; Alekseev *et al*. 2001; Zaiteseva *et al.* 2007; Wu 2008; Svyatko *et al*. 2009).

Figure 4. Distribution of copper groups across eastern Eurasia.

Figure 5. (a) Distribution of arsenic in G2 artefacts. (b) Comparison of median arsenic levels.

Figure 6. Arsenic profile in (a) G11 artefacts (b) G14 artefacts.

Figure 7. Distribution of alloy types across eastern Eurasia.

Figure 8. Distribution of tin within the copper-alloy objects.

Figure 9. Comparison of the median arsenic levels in G2 bronze artefacts (tin≥1%).

Figure 10. (a) Distribution of arsenic in G2 single-bladed knives. (b) Distribution of tin in G2 single-bladed knives.

Figure 11. Schematic map showing the reconstructed flow of metal in the early Iron Age of eastern Eurasia (c. 900-650 BC).

16 copper groups based on the presence or absence of elements							
G1	G2	G3	G4	G5	G6	G7	G8
NNNN	YNNN	NYNN	NNYN	NNNY	YYNN	NYYN	NNYY
G9	G10	G11	G12	G13	G14	G15	G16
YNYN	NYNY	YNNY	YYYN	NYYY	YYNY	YNYY	YYYY
sequence: As/Sb/Ag/Ni							
N when the element <0.1 wt%; Y when the element ≥0.1 wt%							

Table 1. Classification of copper groups.

900 to 650 BC	Steppe					Chinese	
	Cisbaikal	Transbaikal	Minusinsk	Tuva	Altai	N.China	C.China
G1	25.0%	7.3%	11.2%	4.9%	20.1%	2.0%	12.8%
G2 As	23.8%	23.6%	24.9%	11.1%	**59.7%**	11.8%	**30%**
G6 AsSb	27.4%	24.2%	20.0%	13.2%	10.8%	2.0%	7.3%
G9 AsAg	8.3%	5.5%	1.4%	0%	0%	19.6%	17.9%
G11 AsNi	0%	3.0%	15.3%	**30.6%**	4.3%	2.0%	1.1%
G12 AsSbAg	8.3%	11.9%	2.1%	0.0%	1.4%	19.6%	28.0%
G14 AsSbNi	1.2%	10.9%	19.8%	**31.3%**	0.7%	0%	0%
G15 AsAgNi	0%	1.8%	2.1%	1.4%	0%	21.6%	0%
G16 AsSbAgNi	1.2%	10.3%	1.8%	0.7%	0.7%	17.6%	0%
Total n	84	165	570	144	139	51	218

10-30% >30% **G1&G2: steppe/China. G6&G11&G14: steppe. G9&G12: China. N=1371**

Table 2. Summary of copper groups in analysed objects.

900 to 650 B.C.	Cu	Cu-Sn	Cu-Sn-Pb	Cu-Pb	Total N
Cisbaikal	**54.8%**	26.2%	15.5%	3.6%	84
Transbaikal	19.4%	**53.9%**	19.4%	7.3%	165
Minusinsk	**48.5%**	**40%**	8.8%	2.6%	532
Tuva	**94.4%**	4.2%	0%	1.4%	144
Altai	16.5%	**59.7%**	21.6%	2.2%	139
Xinjiang	**46.8%**	**48.4%**	4.8%	0%	62
Hexi Corridor	7.1%	7.1%	**64.3%**	21.4%	14
N. China	20%	32.7%	**45.5%**	1.8%	55
C. China	4.1%	24.4%	**69.8%**	2.3%	705
:10-40%	:>40%	**Sn≥1%**	**Sn & Pb≥1%**	**Pb≥1%**	**1900**

Table 3. Summary of alloy types in analysed objects.

900-650 BC	***Single-bladed knife***			***Cauldron***
Copper Group	**Cis-Baikal**	**Trans-Baikal**	**Minusinsk**	**Minusinsk**
G1	28.6%	4.0%	8.7%	28.0%
G2 As	42.9%	32.0%	36.5%	32.0%
G6 AsSb	7.1%	20.0%	22.2%	16.0%
G9 AsAg	7.1%	5.3%	1.6%	0.0%
G11 AsNi	0.0%	4.0%	16.7%	0.0%
G12 AsSbAg	7.1%	8.0%	0.8%	0.0%
G14 AsSbNi	0.0%	13.3%	19.8%	24.0%
G15 AsAgNi	0.0%	1.3%	0.0%	0.0%
G16 AsSbAgNi	0.0%	10.7%	0.8%	0.0%
Copper Alloy	**Cis-Baikal**	**Trans-Baikal**	**Minusinsk**	**Minusinsk**
Cu	50.0%	11.8%	25.5%	68.0%
Cu-Sn	50.0%	71.1%	60.8%	4.0%
Cu-Sn-Pb	0.0%	15.8%	12.4%	12.0%
Cu-Pb	0.0%	1.3%	1.3%	16.0%
Total	16	76	153	25

Table 4. Summary of copper and alloy types in object typology

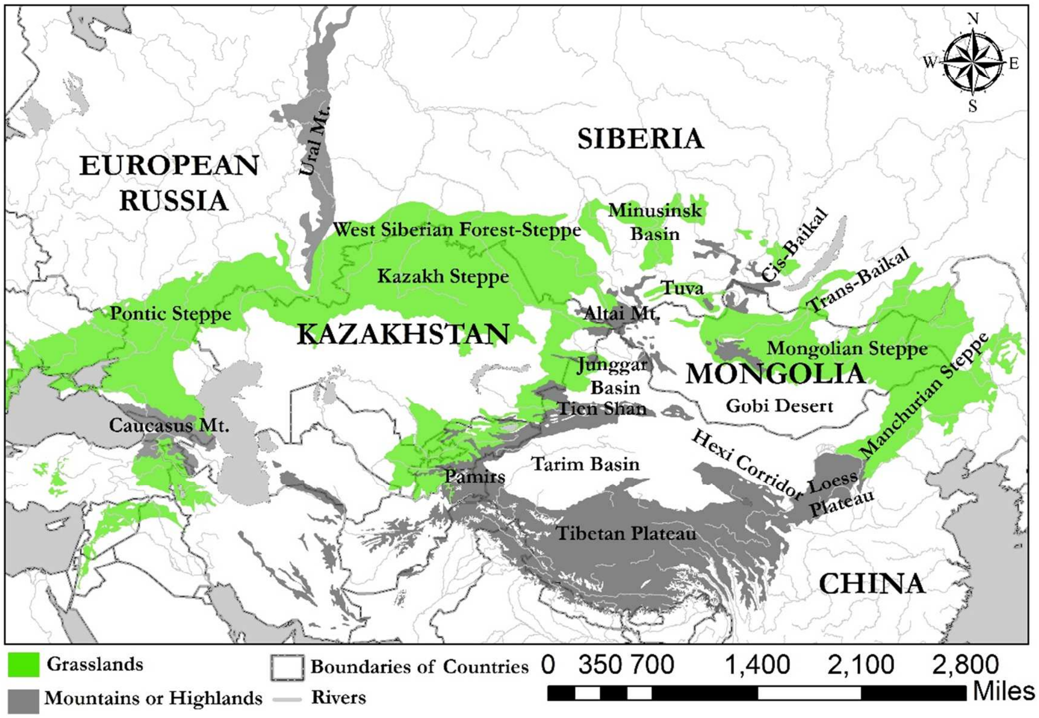


Figure. 1

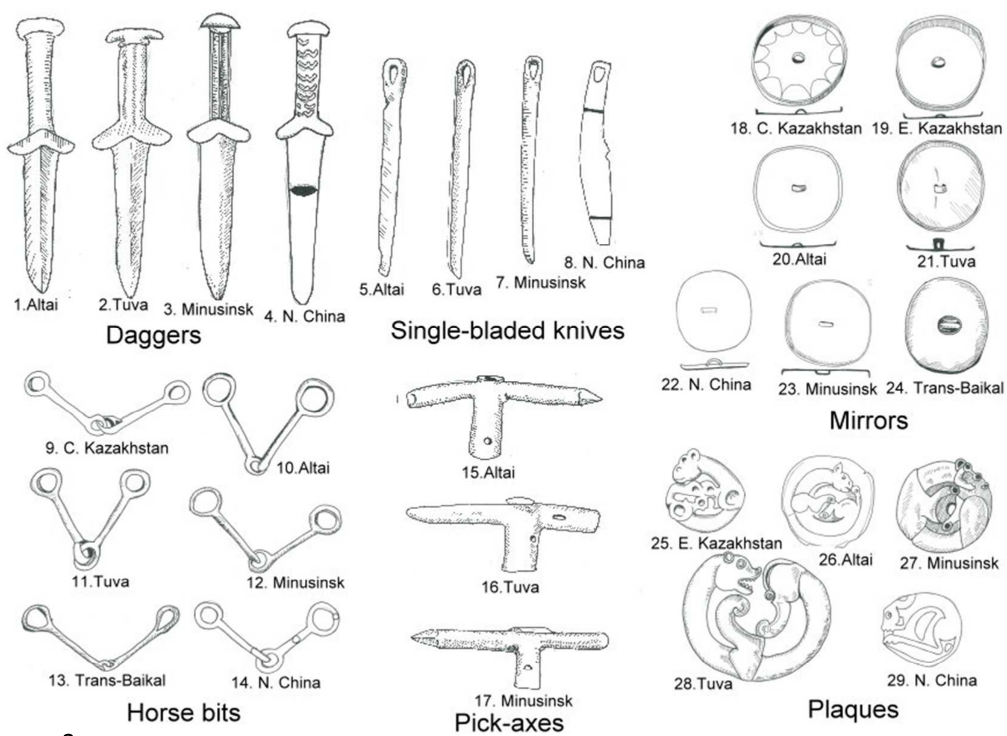
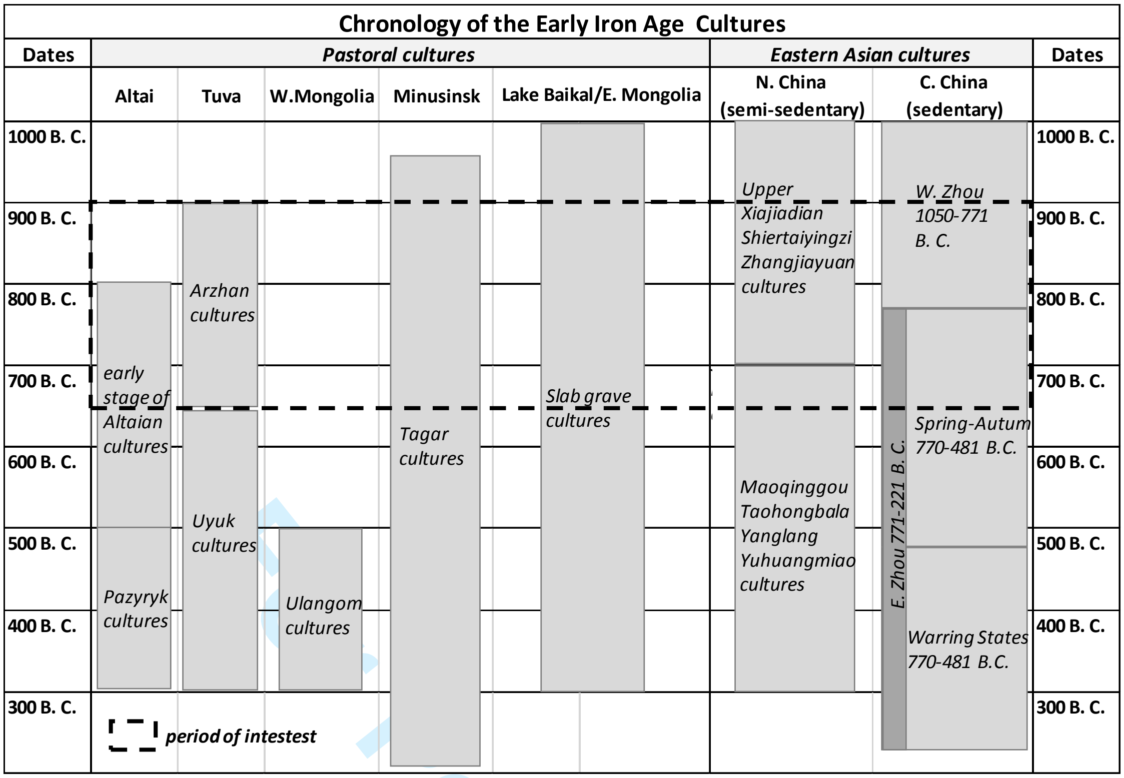


Figure. 2



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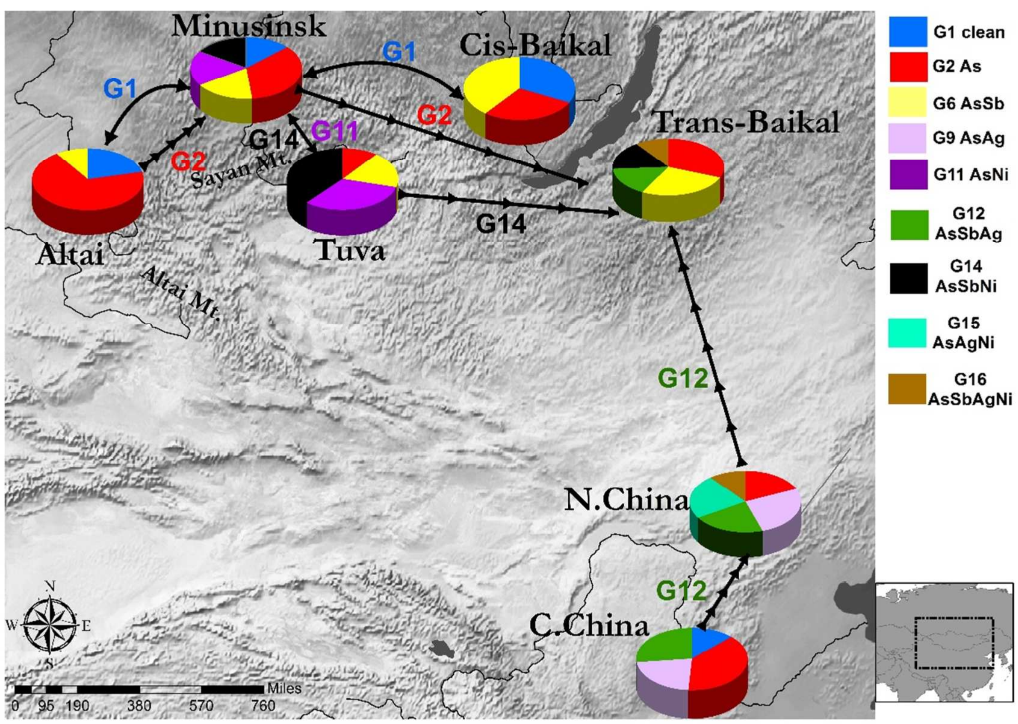


Figure. 4

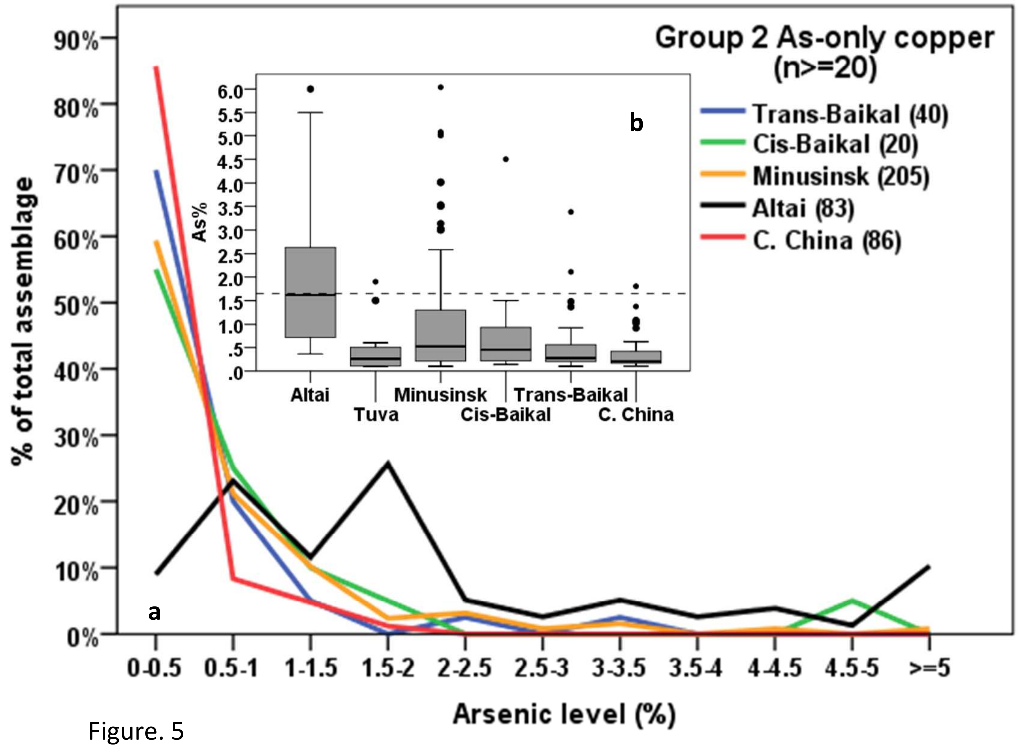
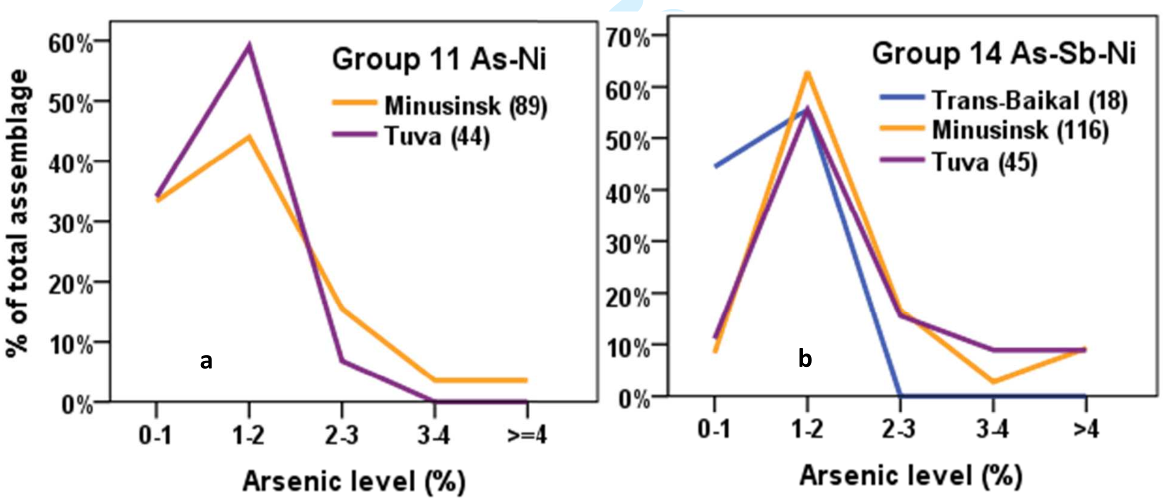


Figure. 5



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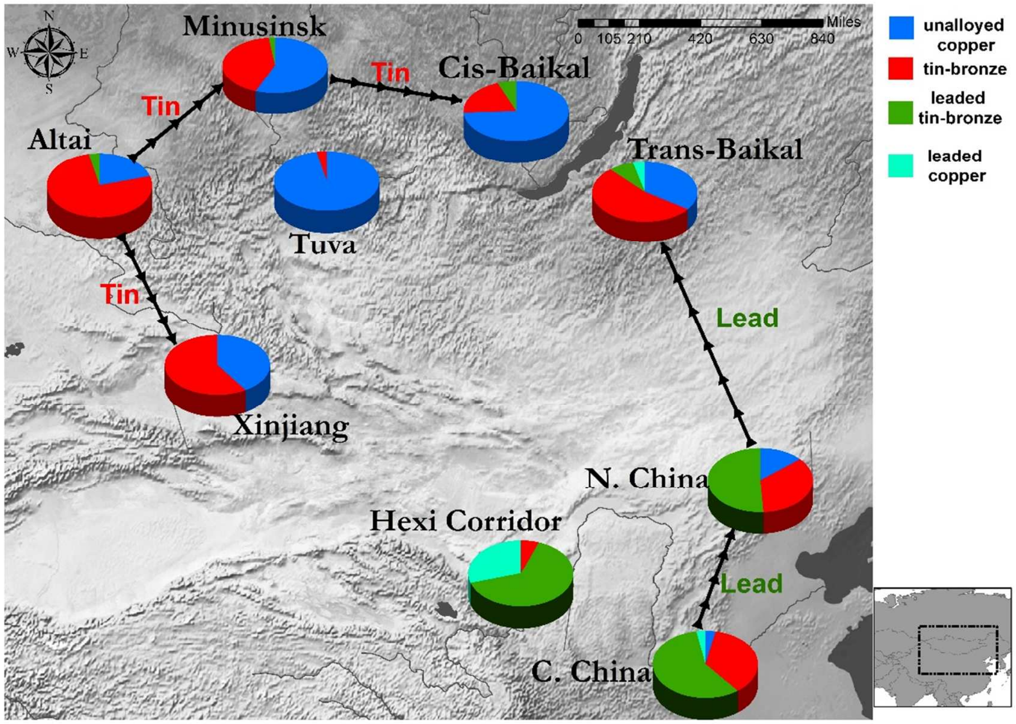

Figure. 7

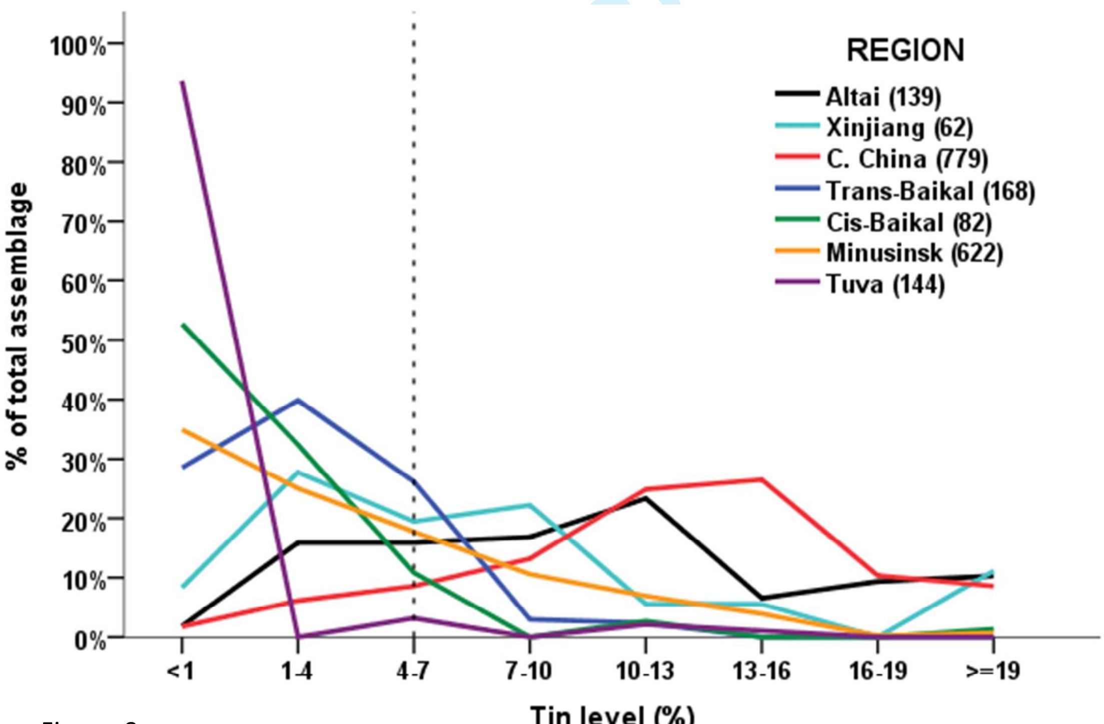

Figure. 8

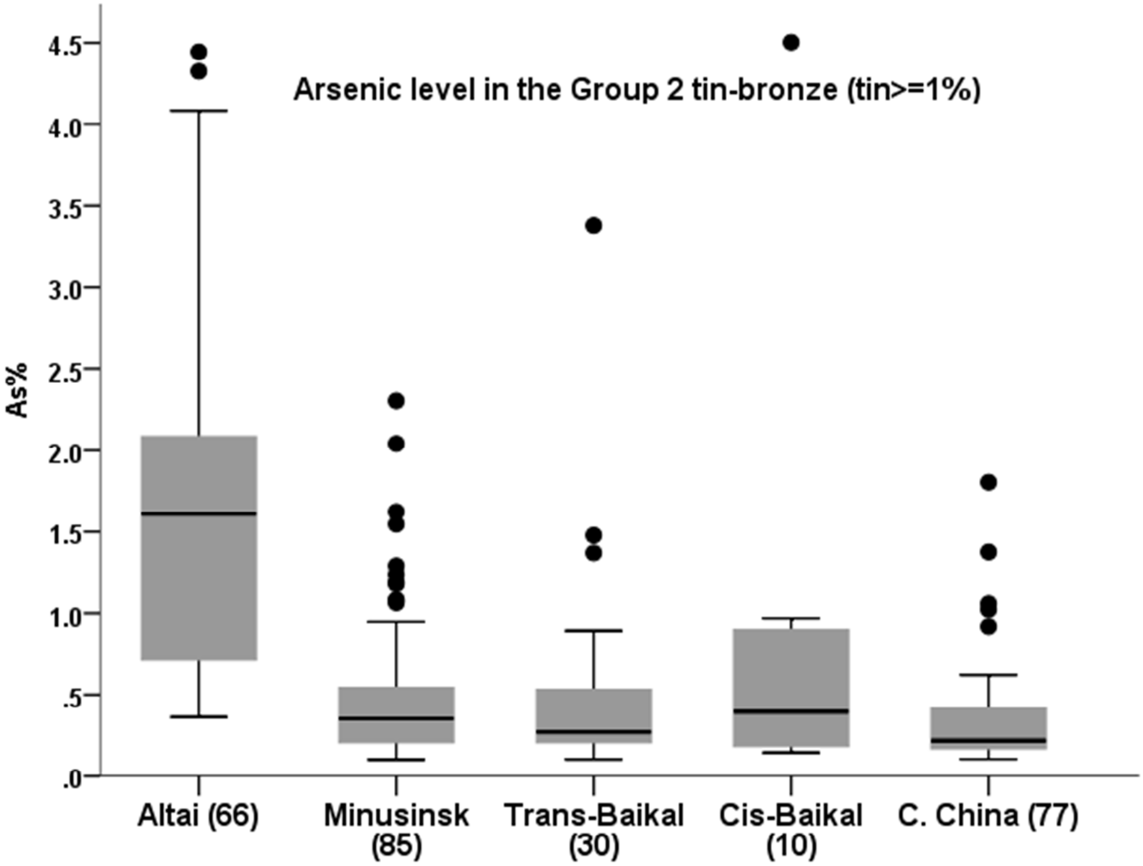

Figure. 9

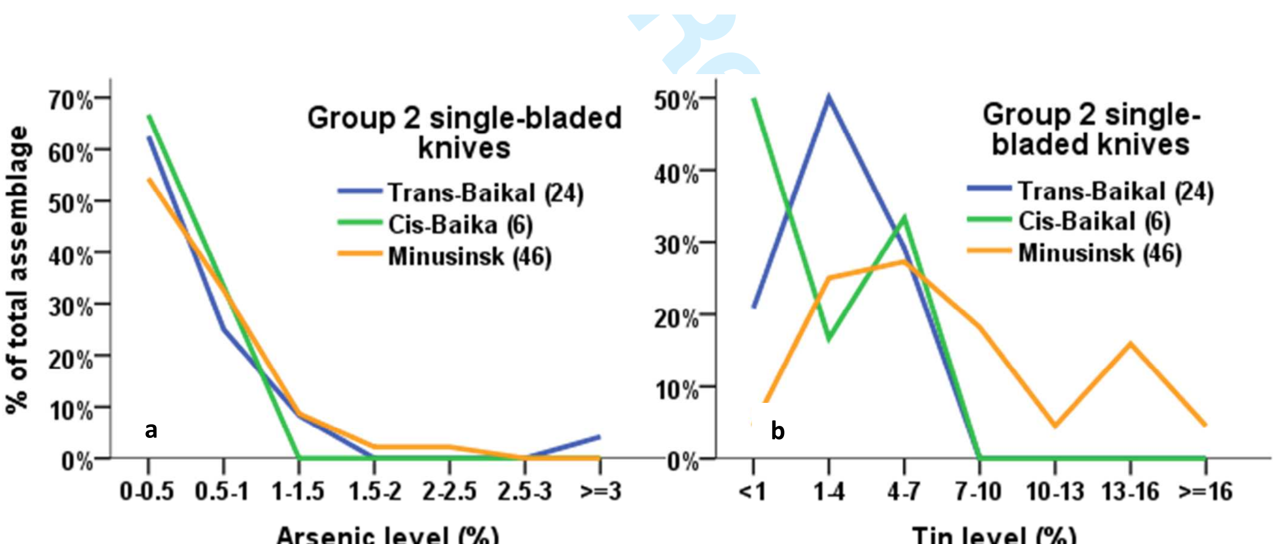

Figure. 10

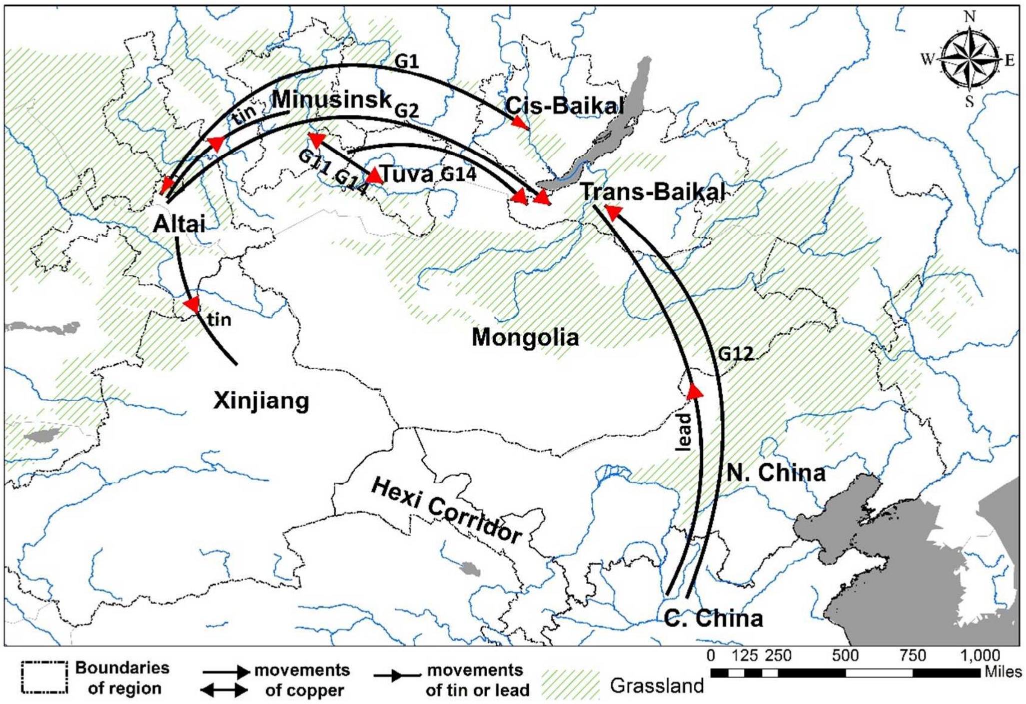
G1
Minusinsk
tin
G2
Cis-Baikal
G11 G14
Tuva
G14
Trans-Baikal
Altai
tin
Mongolia
G12
Xinjiang
lead
N. China
Hexi Corridor
C. China
N
W
E
S
Boundaries of region
movements of copper
movements of tin or lead
Grassland
0 125 250 500 750 1,000
Miles

Figure. 11

Appendix 2: Sources of Chemical Data

Central China

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Xinjiang

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Tuva

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Altai

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