Dynamic Flows of Copper and Copper Alloys across the Prehistoric Eurasian Steppe from 2000 to 300 BCE



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Abstract

The study of ancient Eurasian metallurgy has been suffering from (or preoccupied by) two conventional perspectives. One is that of the diffusion model emphasising the importance of the settled empires of ancient Egypt and Mesopotamia, of south-eastern Europe and of China (Shennan 1986, 1993; Kristiansen 1984). The supremacy of these 'cradles' of early civilisation is marked not only by social hierarchies, but also by technological inventions such as metal production. This view sees the mobile populations of the Eurasian steppe as occupying the "hinterland" of these early settled states in the south, believing that the emergence of metal technologies in the Steppe was the result of the expansions of "advanced" civilisations. The second perspective is rooted in the provenance study which traces metal objects back to their geological sources (Pernicka 2014). It assumes that chemical and isotopic composition of metal is static and only reflects a simple linear relationship between artefacts and specific ore deposits.

Drawing from a legacy database of approximately 9,000 chemical analyses of copper-based artefacts, this thesis rejects the simplicity of both the diffusion and the provenance models. While admitting that the use of metal might have originated from western Asia, the development of metallurgy in the Eurasian steppe should be understood on its own terms. It is constantly re-shaped by vigorous circulation of metal artefacts across mobile communities on a regional or inter-regional scale. This observation is based on the application of a new innovative framework to interpret the patterns of compositional data (Bray *et al.* 2015). This novel method argues that metal can flow, quite literally, from one object to another as it is re-melted, re-mixed and re-cast in different shapes and colours, depending on different social contexts. Thermodynamic modelling and modern experiments have shown that during the copper melt, some volatile elements in copper alloys (e.g. arsenic, antimony, and zinc) are preferentially removed through oxidative loss. Instead, some elements, such as silver, nickel, and gold, tend to be preserved in metals. These predictable patterns of elemental losses provide valuable information to trace the directional flow of metal units between regions/cultures, if we combine chemical data of metal artefacts properly with archaeological context, landscape and chronology.

By using this new methodology, several routes of copper supplies have been identified in the Steppe during different periods. They feature the exchange of metals within regional networks, fuelled by local copper sources. The Urals, central Kazakhstan, the Altai, and the Minusinsk-Tuva regions were the primary copper production centres that developed distinct trace-element chemistry and artefact typology. By contrast, alloying techniques employed by steppe peoples, generally demonstrate the long-distance connections based on two major metallurgical practices: arsenical copper in the western steppe and tin-bronze in the eastern steppe. Copper-arsenic production was concentrated in the Caucasus but the recycling of its arsenical copper became more apparent further away towards the Urals. On the other hand, the invention of tin-bronze metallurgy was triggered by the formation of the Seima-Turbino phenomenon (c. 2100-1800/1700 BC) in the Altai, and this alloying tradition was amplified by the emergence of the Andronovo culture (c. 1700-1400 BC) in the Ural-Kazakh steppe. Tin-bronze

ornaments, in particular, were exchanged between eastern and western mobile communities over a considerable distance, through the mechanism of pastoral seasonal movements.

In conclusion, traditional views of diffusion and provenance theories cannot be uncritically applied to the inception of ancient metallurgy in the Eurasian steppe. Mobile pastoralists developed multi-regional production hubs based on the accessibility of ore resources and the variations in subsistence strategies. Although steppe metalwork revealed some technological borrowings from settled communities, steppe peoples had transformed them into locally adapted products that could fit into their socio-economic systems. That is, when dealing with the issues of Eurasian metallurgy, we should acknowledge the complexity of human engagement with metal and look into subtler differences in cultural context, landscape, and ideology.

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1. Introduction

1.1 Research objectives

This thesis investigates the circulation of ancient copper-based objects across the Eurasian steppe through the lens of chemical composition, as opposed to traditional typological studies that have served as a routine practice for the inter-regional/cultural connections. To achieve this, a large number of published chemical analyses are assembled and integrated into one database, divided by various geographical regions and chronological sequences. The primary focus will be on the history of Eurasian metallurgy dated to between 2000 and 300 BC, particularly in the central and eastern parts of the Steppe. I will employ a new approach, proposed by Bray & Pollard (2012), which is designed to characterise the flows of metal involving the direct exchange of items or recycling/mixing practices within and between metal-using societies (see Chapter 2 for detailed methodology). These dynamics of metalworking preferences, reflected by changing artefact chemistry, play a pivotal role in narrating long-distance exchange and regional variations in metal production.

Conventional studies on ancient metal aimed to answer two main questions: (1) When and where was the origin of metallurgy, and how did it spread? (2) What technologies were used to produce metal? The first question was initially pursued by archaeologists searching for the chronological sequences of early evidence of metallurgical activities in order to reconstruct the mechanisms (either diffusion or local invention) behind the early development of metallurgy in the Old World (Wertime 1973b; Renfrew 1969). Later on, the introduction of lead isotope analysis popularises the idea of metal provenance – to link artefact chemistry with chemistry of ore sources (Gale and Stos-Gale 1981; Pernicka 2014). The second question involves the detailed survey of the production site and use of experimental data to re-establish the *chaîne opératoire* of metal production, including mining, smelting, casting and relevant ceramic technologies for refractory materials. Such research can be found in the works done by Tylecote (1976), Merkel (1990), Hauptmann (2007) and Martinón-Torres & Rehren (2014), just to name a few.

Presented above are of course valuable studies for the understanding of metal production in the past; however, the provenance approach lacks awareness of multiple

ways in which ancient people exploited metalwork. It simply implies a linear relationship between raw material and final products, but neglects the role played by people who constantly circulated metal in long-distance or regional exchange networks. Metal artefacts may change hands through trade, gift-giving or military plunders between societies. These activities are social or political events that transfer metal goods and associated technological knowledge to a new group of people. The imported items and ideas might be then modified according to indigenous social standards. Therefore, transmission and transformation of metal products and technologies do not follow a simplistic point-to-point communication, as suggested by provenance methodology. Instead, the ultimate form and composition of artefacts are a blend of people's choices in a complex social network.

Pfaffenberger (1992) highlights such anthropological aspect of technology quite neatly. He points out that technologies are largely conditioned by the sociotechnical system in which "complex social structures, nonverbal activity systems, advanced linguistic communication, the ritual coordination of labour, advanced artefact manufacture, the linkage of phenomenally diverse social and non-social actors, and the social use of diverse artefacts" are all integrated into a single vexed network. Simply put, the emergence of new technologies in human society is not driven by human's necessity but by social preferences. Inspired by Pfaffenberger's perspectives, I suggest three ways that people respond to the introduction of new artefacts or ideas: complete acceptance, total rejection or coping with change. Each option is highly associated with given social, economic and political environments. The first instance of full adoption could be the consequence of colonisation such as the circulation of Roman coinage, glass, brooches and ironwork in Britain (e.g. Jackson *et al.* 2015; Sim 2012; Bayley & Butcher 2004). Likewise, direct exchange through developed trading network could also foster the spread of exotic items or technologies in a foreign land. A well-known example is Pazyryk kurgans in the Altai Mountains where Chinese silk, bronze mirrors and lacquer were found alongside Persian woven fabric (Bunker 1991; Rudenko 1970; Cunliffe 2015:236). On the other hand, societies may resist a new item or technique due to their internal social structures. Ancient China is an excellent example to show such reluctance to embrace new ideas. While gold and silver objects were widely used as the symbol of high-status in the Eurasian steppe and Northern Zone of China, the Central Plains of China during the Shang-Zhou period still preferred conventional bronze and

jade items due to its highly hierarchical and ritualised organisation (Rawson 1987; 1995). Finally, people may compromise between two extremes and transform new things into local application as they see fit. Cultures in the Eurasian steppe demonstrate such kind of flexibility in which people would rework foreign metal items to suit indigenous tastes. This character of remodelling foreign artefacts explains why metal recycling, mixing, re-alloying, or re-use are likely to take place in antiquity. In a word, these different local responses to an external stimulation are the entanglement of multiple social and political factors.

In addition to socio-political reasons, natural or cultural landscapes may also determine the movement of objects and technologies between ancient communities. A variety of physical geography gives rise to different natural resources that support prehistoric societies to develop unique "expertise". The circulation of goods and technological ideas becomes possible where there is an uneven distribution of raw material. For instance, western Asia in the late second millennium BC was characterised by the extensive exchange of regional commodities between different kingdoms: gold from Nubia via the Egyptians, tin and lapis lazuli from central Asia via Elam, copper from Alashiya, Iron from the Hatti, and Baltic amber trade operated by the Mycenaean kings (Cunliffe 2015:156). Of course, this trading system could not take place alone without specific political environments in which the gift exchange was a means to reconcile the tension between great powers. Furthermore, people are also capable of creating the cultural landscape as a venue to convey new ideas and objects. In studying the Bronze Age of southwest Norway, Nordenborg Myhre (2004) argues that the construction of grave monuments and rock art created a meeting place where new artefacts and social systems came into existence.

Due to these versatile mechanisms for technological adoption, transmission and transformation, it is difficult to imagine that the life history of metal only follows a simple linear trajectory from its birthplace (ore sources) to the final destination (tombs, settlements or hoards). Instead, I agree with the view of Bray *et al.* (2015) that the journey between these two ends is a key to understand the complex human relationship with metal and metal artefacts in the past. Therefore, this thesis sets out to specifically address how ancient metallurgy can be understood as the interplay between objects (typology), natural landscapes (resources) and organisations (social networks). It is hoped that these characters of ancient metalwork can be well manifested by changing

artefact chemistry that underpins how people actually used metal: melting and casting, smithing, recycling and alloying/re-alloying. The Eurasian steppe provides an excellent opportunity to examine such human participation in metal production. The next section will address why this region serves as a unique candidate for the intended goals of this thesis.

1.2 Why the Eurasian steppe?

Before the European Age of Discovery that initiated maritime routes to the East, overland movement across the Eurasian steppe played a pivotal role in exchanging goods, technologies, and ideas between the East and West. Whether it was the invention of chariot technology during the Bronze Age, the widespread horse riding during the Iron Age, the "Silk Road" during the medieval period, or political upheaval brought by Mongolians or Turks, material culture of the steppe communities constantly shaped the ancient world of Eurasia (Beckwith 2009).

The unique ecological character of the Steppe stimulates cross-regional/cultural exchange in antiquity (Christian 2000: 6). As Curtin points out, trade usually takes place across contrasting ecological divisions with greater intensity than it does in more homogenous environments (Curtin 1984:16). The incentive to trade lies in different "expertise" based on different resource endowments. While steppe communities can offer livestock with their meat, milk and wool/leather (the so-called "secondary products revolution" proposed by Sherratt 1981), agricultural societies can satisfy steppe herders' need for grain and/or textile (though it remains questionable whether cultivated crops in the steppe were initially used for ritual practices or daily food, see Frachetti *et al.* 2010). As the Steppe is an intermediate zone between northern forest foragers and southern settled farmers, the unique geographical position of the Steppe makes the mobile pastoralists a bridge linking different ecological zones of the Eurasia continent into a single system (Christian 2000:1).

The abundant natural resources in the Steppe give another impetus for the long-distance exchange. The vast grassland is an ideal environment for horse raising. The earliest evidence for horse domestication comes from the communities living in the Pontic-Caspian steppe around 4800 BC (Anthony 2007:201). According to Anthony, horses initially served as the source for winter meat, but in the fourth millennium, some horses were ridden at the Botai site of northern Kazakhstan. Although the date when horse

riding began is still hotly debated, there is no doubt that the knowledge of horse domestication was first achieved by the mobile pastoralists. The use of horses for transportation ensures steppe people's contacts and influence over an enormous geographical extent.

Another advantage of the Steppe is its rich metallic deposits. Interestingly, two of the most "advanced" ancient civilisations – Mesopotamia in the West and early China in the East – actually lack any appreciable mineral resources, yet they developed enormous copper-based production both in quality and in quantity. Obtaining copper is not so much of a problem because copper deposits are reachable in the regional trading network. However, it is certainly a challenge to get hold of tin as tin deposits are confined to specific geographical locations. That is why in studying the origins of tin in antiquity, both western and Chinese scholars asked the same question: where is the tin? (Charles 1975; Wen 1983). Mountainous areas in the Steppe provide this much needed raw material that could potentially support the large-scale tin-bronze production in the settled areas. Recent archaeological surveys have uncovered several ancient tin mines in the Altai and central Asia, dating back to 1700-1500 cal. BC (Parzinger *et al.* 2003; Gorelik *et al.* 2013). Tin, as a sought-after resource, was potentially a precious commodity in the long-distance trade that intensified economic, ritual, social, and political changes that swept across Eurasia.

1.3 Geographical settings

The Eurasian steppe, or simply the Steppe, usually refers to the vast treeless area between the taiga zone and mid-latitude deserts in the Eurasian continent (Figure 1.1). Grasslands extend as a continuous belt from the northern shores of the Black Sea to western Siberia and become scattered in the Altai Mountains due to the presence of mountainous terrain. The temperate steppe, from the west to east, is subdivided into several zones: the Pontic-Caspian steppe in the East European plain, the Kazakh steppe in the western Siberian lowland, steppe areas in the river valleys of southern Siberia and Transbaikal, and the grasslands in Mongolia and Manchuria. Patchy alpine meadows are developed in the southern Urals, the Altai-Sayan Mountains, the Caucasus, and the mountains of southern Kazakhstan and central Asia. The broader definition of the Eurasian steppe may include the forest-steppe zone in the north and the dry steppe adjacent to the desert zone in the south. The forest-steppe landscape stretches from the

Carpathian foothills to the Altai, and becomes fragmented further east in the Minusinsk Basin and Baikal region. The dry steppe is mainly distributed from the Lower Volga to the Upper Irtysh, covering a large part of central Kazakhstan.

The Eurasian steppe is characterised by a typical continental climate with bitter winters and warm summers and low annual precipitation (254-508 mm). Hence, drought is a constant companion. Despite this extreme climate, the immense grasslands in this area offer promising conditions for cattle and horse breeding. The relatively smooth relief also facilitates the movement of goods and people by the means of horse riding or caravans.

The major transit rivers— the Dnieper, Don, Volga, Ural, Tobol, Ishim, Ob, Irtysh, and Yenisei – are northbound, which have served as the main waterways of the north-south communication in antiquity. However, rivers in the Asian part flow north into the ice-covered Arctic and are frozen at least three months of a year. This causes a serious obstacle to transportation. In these regions, overland movement across the pathways of frozen river surfaces is widely utilised.

Many mountains are within or close to the steppe landscape. The Pamir, with the highest elevation of 7,620 metres, is the most remarkable landmark of the mountain terrain, whence radiates other ranges. The east of the Pamir contains a series of high ranges, such as Tian Shan, Altai-Sayan Mountains, the Hangai ranges and the Yin Mountains. The west of the Pamir develops towards the Caucasus Mountains between the Black Sea and Caspian Sea, the Alborz ranges in northern Iran, and the Hindu Kush running along the boundary between Pakistan and Afghanistan. The Ural mountain ridge, extending about 3,000 km and 100-400 km wide, forms a natural boundary between Europe and Asia.

The character of mountain landscapes shapes and strongly influences the lifestyle of steppe inhabitants. Contrary to a traditional view that mountains generally lead to physical barrier to the communication between societies, mountain corridors actually provide great opportunities for inter-regional interactions. High-altitude meadows attract herders from various parts of the Steppe and in such a way they are in contact with each other. Mountains also contain precious resources for human societies. The melted snow provides much needed water for irrigation systems in the oasis agriculture

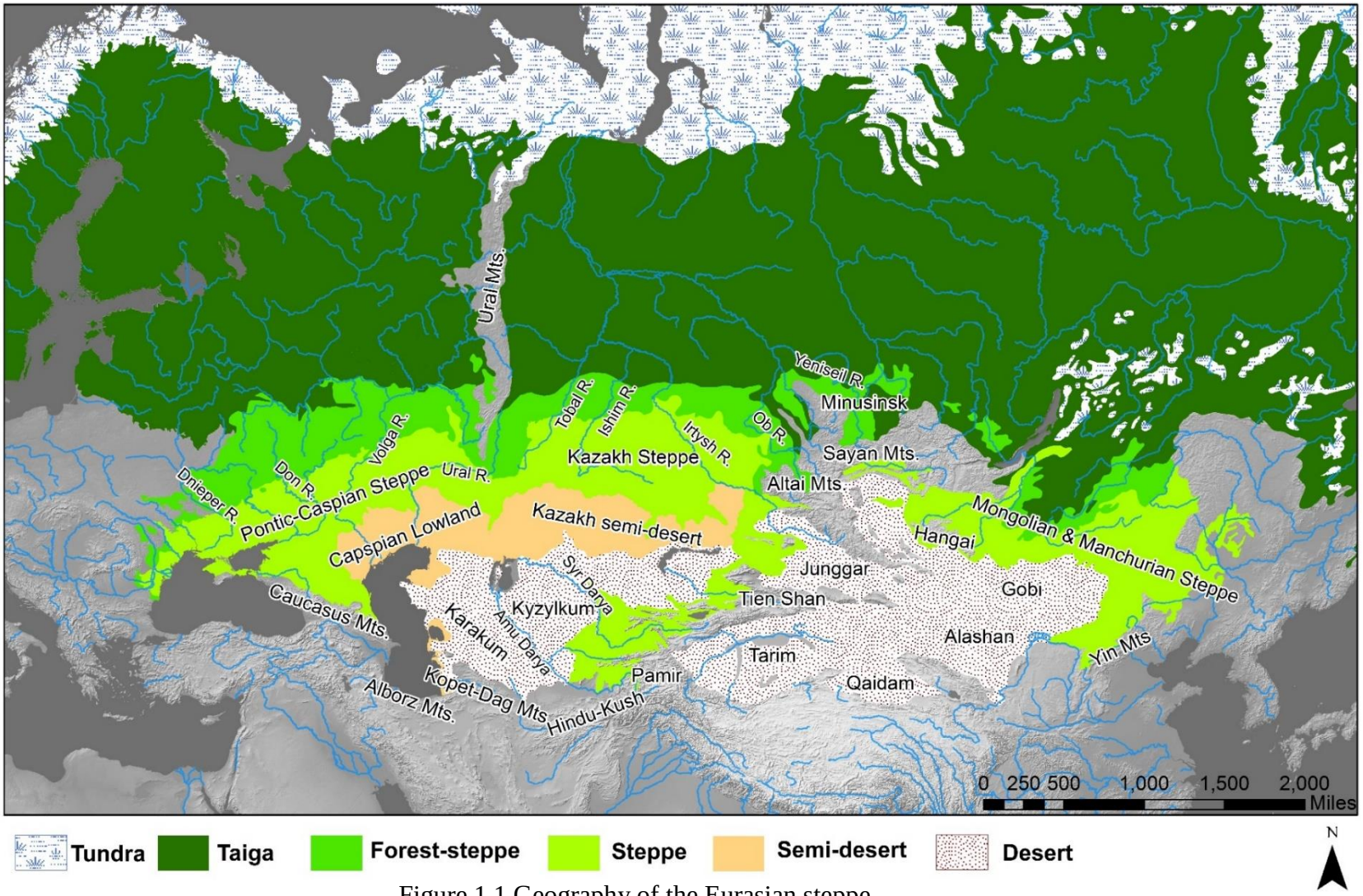


Figure 1.1 Geography of the Eurasian steppe.

in the desert, timber can be obtained as fuel or construction materials, and metallic deposits, such as copper, tin and gold, are desired by both indigenous and foreign prospectors. For example, from the economic point of view, major tin deposits in the Eurasian steppe are restricted to mountain ranges of the central Asia and Altai (Figure 1.2). They were also the primary exploitable tin mines during the Bronze Age.

Arid environments are widespread in the south of the Eurasian steppe. A belt of mid-latitude deserts is formed from the Caspian lowland to the Gobi desert in southern Mongolia and Northwest China. In addition to Xinjiang and Mongolia, an enormous desert landscape occurs in the Kyzyl-Kum and Karakum deserts of central Asia.

Although this ecological zone is unfavourable for the human inhabitation, the sporadic oases among deserts are the cradle of flourishing agro-pastoralist communities, especially in the regions of Amu Darya and Syr Darya which served as important trade centres of the Silk Road.

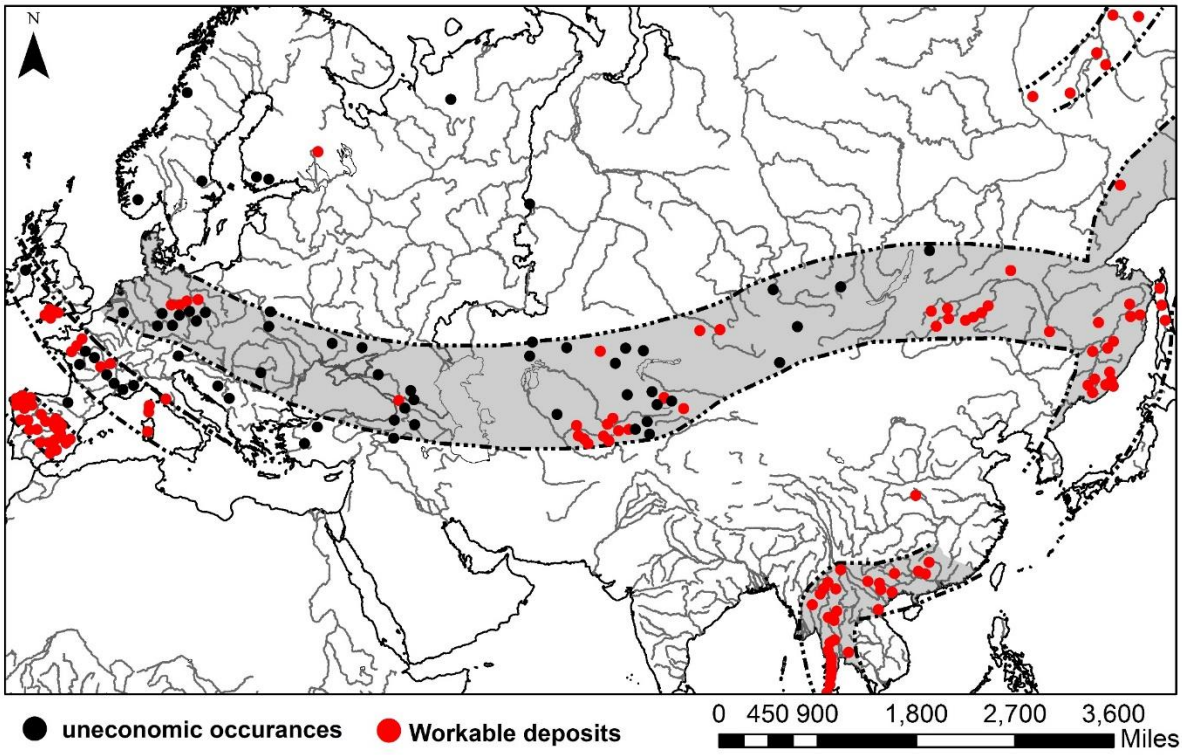


Figure 1.2 Tin belt of the Eurasian continent. Modified from de Jesus (1978).

1.4 The "significance" of metal

The inception of metallurgy is considered fundamental in the formation of complex societies in prehistory (eg. Tylecote 1987; Maddin 1988; Yener 2000). Metal production boosts local and long-distance exchange, stimulates the flow of new

technologies, and sets the scene for the emerging elite societies through wealth accumulation (Chapman 2003).

However, this top–down perspective is recently challenged by various scholars. As Thornton and Roberts (2009:182) point out, most metal-using societies show a significant delay between the first use of metal and the full-blown standardised metal "industry". They also argue for multiple facets of development in which craft-specialised elite-driven metal production coexists with more domestic settings of production on a regional scale. Put simply, the initial adoption of metallurgy does not necessarily result in a big leap from a simple society (such as tribes and chiefdom) to a complex one (state), nor does the development of metallurgy require "advanced" socio-political organisations. For instance, the Early Bronze Age of central Europe was marked by an increasing number of metal objects, which was traditionally considered as a sign for major socio-economic changes (Strahm 1995). Nonetheless, Bartelheim's research (2009) demonstrates that the distribution of settlements concentrated in the regions favourable for crop cultivation rather than in the proximities of important rich mineral deposits. According to him, the introduction of metal did not change the economic structures. Agriculture still served as the basis for the economy arising from the Early Neolithic. Farming created the most wealth during the Early Bronze Age, which in turn made the exchange and production of metal possible (Hayden 1992). The emerging metal usage was an effect rather than a cause for social and economic development.

As a result, I argue that the introduction of new metal artefacts and metallurgy is only possible under certain cultural and socio-economic preconditions. As Smith (1981) pointed out, people did not need metal; they wanted metal. This human desire stems from a combination of factors (political, socio-economic, cultural, ritual or aesthetic considerations). Physical superiority of metal, in my view, is often the least reason for the domestication of metallurgy. After all, at the beginning use of metal, lithic material was more common for everyday tasks, and the use of stone tools persisted as late as the Iron Age (Rosen 1996). Also, the early metal artefacts tended to be decorative and early metal tools were not always made to improve mechanical properties (Pigott 1999, 2011).

With regard to the importance of metal in the Eurasian steppe, it was not until the late-third and early-second millennium BC that we encounter an increasing scale of metal

production in ore mining, smelting and casting among the Abasehvo-Sintashta complex (see Chapter 4). Furthermore, this era was marked by a sudden rise of tin-bronze metallurgy in the eastern steppe (the Altai), with advanced bronze-casting techniques (the Seima-Turbino metalwork, see Chapter 4). This change in metal organisation was concurrent with alterations of settlement patterns, elaborate burial monuments, the occurrence of new technologies (chariot) and abundant animal sacrifices. The rapid appearance of smelting and alloying techniques in the Steppe poses a question of whether the introduction of metal and the relevant knowledge were of foreign or local origins. In order to understand how metallurgy came about in the Steppe, it is necessary to review the contention between the diffusion and independent invention of metallurgy.

1.5 Diffusion versus independent invention of metallurgy

The emergence of early metallurgy has been a heated debate among archaeologists over several decades. Investigations into this puzzle have led to two opposing perspectives: diffusion versus local invention. While this thesis primarily deals with the movement of metal rather than the search for its origins, a review of the controversy over the diffusion or local invention of metallurgy can facilitate our understanding of the nature of metallurgy and its influence on human history.

1.5.1 Diffusion of Metallurgy

V. Gordon Childe specifically emphasised the role of metallurgical technology in the formation of an elite class and complex societies (Childe 1930 & 1944; Wailes 1996). He systematically examined the similarity of metal object typologies across Eurasia and argued for the spread of metallurgy from the Near East to the rest of the Old World (Childe 1939). This viewpoint was consistently revisited by various eminent scholars such as Wertime, Smith, Muhly and Chernykh.

Wertime (1964, 1973a, 1973b, and 1973c) contended that any major technological breakthrough requires a complex logic rather than mere happenstance. According to him, any innovation is built upon pre-existing knowledge or experiences accumulating for a certain amount of time. Only after certain conditions have been fulfilled, can a new invention then become accessible. In his view, a new technology comes into existence as a reflection of other relational techniques. Therefore, the history of metallurgy is an interlocking and sequential evolution. Humans first learned to use monometallic or native copper based on preceding experience in working on lithic

material (Wertime 1973b: 880). With the aid of fire and cold water, prehistoric peoples were able to fracture the native metal for the further cold-hammering or annealing (Ibid. 880). In about the fifth millennium BC, the improving furnace technology, related to the pottery kiln, introduced metal artisans to the world of copper casting and smelting (Ibid. 880). Along with recurrent casting of native copper and smelting of polymetallic ores, people realised that impurities of arsenic, antimony or bismuth could facilitate the castability and malleability of metal (Ibid. 881). This led to the initial use of arsenical copper, which was subsequently replaced by the tin-bronze. Ultimately, extracting copper ores from the sulphide zone foresaw the coming of Iron Age (Ibid. 882). Smelting in the polymetallic settings often resulted in the fluxing of impurities. Metallic iron with content often existed in copper slags, which gradually caught metallurgists' attention and eventually led to the inception of an iron-producing industry (Ibid. 885).

Because the history of metallurgy in western Asia documents a complete set of technological transformations, Wertime (1973b: 885-886) proposed that the adoption of early metal was a process of diffusion from western Asia to other secondary centres as ancient metalworkers travelled to seek raw material.

Cherynkh (1992; 2009b) advanced this diffusionist and sequential concept by mapping the adoption of early metal in the Old World (Figure 1.3). Chronologically, the dissemination of copper-based metallurgy follows a general trend from western Asia to the rest of the Eurasian continent. From the ninth to sixth millennia BC, decorative or utilitarian items made from native copper sporadically appeared in the monuments of Anatolia, northern Mesopotamia, the Levant and Iran. During the fifth millennium BC, a sudden shift from native copper production to copper smelting and casting took place not only in western Asia but also in the Carpatho-Balkan, Moldavia, Trans-Caucasus and southern central Asia. In the following fourth millennium BC, metallurgy was spread over temperate Europe and the western Eurasian steppe. Throughout the third millennium BC, arsenical copper became the most prevalent metal in many regions of Eurasia, then followed by the adoption of tin-bronze in the second millennium BC when the distribution of metallurgy practically covered the most of the Old World. Figure 1.4 demonstrates the pace of metallurgical adoption in a chronological order.

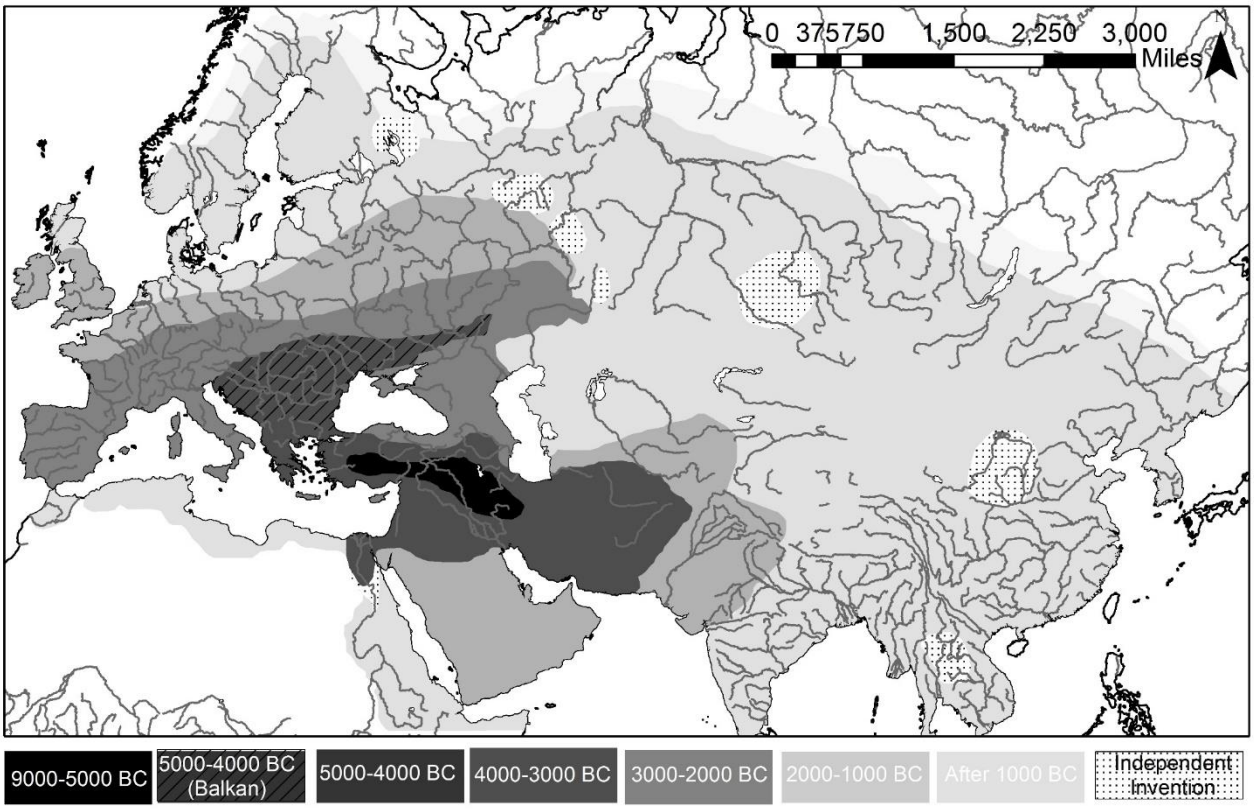


Figure 1.3 Diffusion of the copper-based metallurgy. Modified from Chernykh 2013.

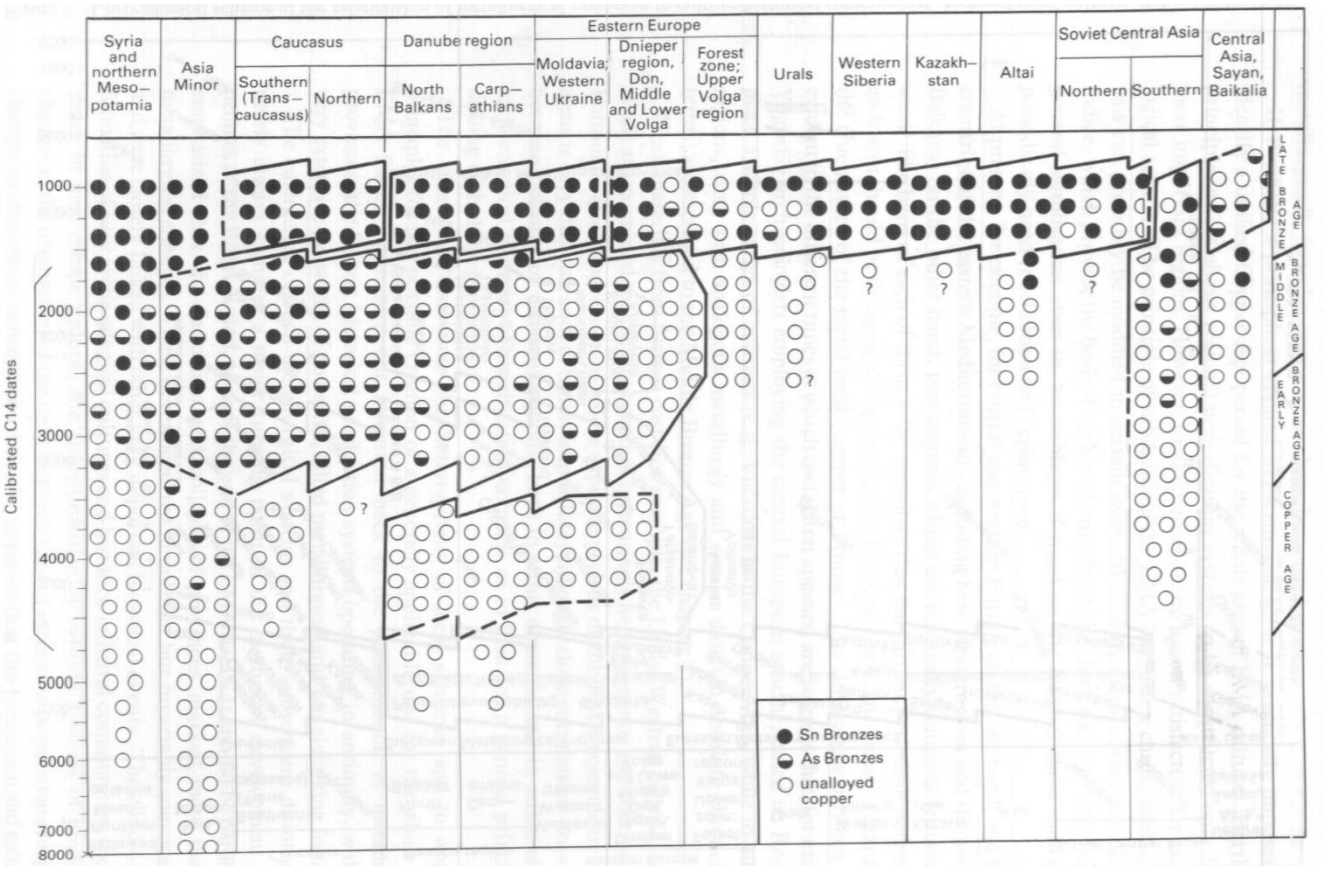


Figure 1.4 Adoption of copper and bronze metallurgy in Eurasia. From Chernykh (1992:14).

1.5.2 Local invention of metallurgy

The diffusionist model has been challenged by many examples of early metal-using communities that contradict a linear and evolutionary development of metallurgical technology. For instance, Renfrew (1969 &1973) believed that independent invention of metallurgy took place in Copper Age south-east Europe (c. the 5th to 4th millennium BC). As opposed to the conventional view that Balkan metallurgy was transmitted from the Near East through the Anatolian and Aegean regions, Renfrew utilised radiocarbon dates to argue that the early metallurgical sites in the Balkan were actually older than similar monuments in western Asia. Therefore, metallurgy, like Neolithic agriculture, had multiple origins rather than a single birthplace (Harlan 1971).

Autonomous development of metallurgy also occurred in areas remote from the Near East. In search for the origin of metal technology in China, Noel Barnard (Barnard 1961, 1983, 1987, and 1993; Barnard & Sato 1975) believed that Chinese metallurgy derived from the highly-developed indigenous ceramic industry. According to him, given such a technological condition, humans could react in the same way even in different times or places. Ancient metallurgy may not be necessarily invented once in the Near East; ancient Chinese artisans were certainly capable of creating their own specific metal production (Barnard 1983). He argued that copper and tin sources were accessible to Anyang founders within a 300 km radius. With such raw material, metal smelting was done in an advanced way to obtain pure copper and tin from the ores, and subsequently mixed to cast copper-tin alloys. The kiln used for pottery firing could attain the necessary temperature for bronze-casting. To him, although ancient Chinese metal bore certain foreign elements from the west, Chinese metalworkers merely copied the shapes or décor of exotic items and cast objects in intricate clay moulds rather than the heavy smithing work of the western tradition.

Metal working also independently emerged in Africa (Trigger 1969), southern America (Lechtman 1977; 1979) and northern America (Ehrhardt 2009). These examples suggest that the invention of early metal technology was not restricted to one place (western Asia).

1.5.3 Synthesis of diffusionist and autonomous assumptions

Debates which arise from these two competing perspectives lie in different methodologies employed to interpret archaeological data. Proponents of the diffusionist

theory adopt a top-down approach to explaining archaeological evidence on a macro scale. The ultimate goal is to understand an overall picture of the development of metal use and production over time and space. It becomes inevitable to selectively abandon those "outliers", which do not fit the general trend of metal distribution. On the other hand, those who advocate the independent origins of metallurgy prefer the bottom-up method to see things on a micro scale. Their priority is to first understand regional/cultural variations and only after intense archaeological research in various places can one connect individual developments of metal use and argue for the dynamics of metallurgical systems.

Neither diffusion nor local invention of metallurgy can satisfactorily interpret the spread of metal and its relationship to human societies. This happens for the reason that both models are not fully integrated to generate a more comprehensive understanding of ancient metallurgy. In order to synthesise both perspectives, Thornton & Roberts (2009) organised a session at the 73rd meeting of the Society for American Archaeology in which they invited papers from a number of archaeologists working on the use of early metal in their respective regions. One of the key topics at this meeting addressed the inception of early metallurgy and how well does the diffusionist or indigenous approach fit into individual case studies. The participants all rejected the simplistic culture-history perspectives and embraced subtler investigations on the nature of technological transfer, the adoption and adaption of new materials and techniques and the influence of other existing crafts in a specific socio-cultural context (Thornton & Roberts 2009: 182).

With an increasing volume of archaeometallurgical research worldwide, Benjamin W. Roberts and his co-workers have recently published an article to provide an up-to-date overview of spread of metallurgy in the Old World. While accepting that metallurgy was first invented in western Asia, they argue that the adoption of technology throughout the rest of Eurasia was conditioned by changing cultural norms and consumer demands (Roberts *et al.* 2009: 1019). According to their research, the *chaîne opératoire* of metallurgical practices are too complex to have been copied without face-to-face instructions from experienced metalworkers. As a result, the movement of skilful metal artisans is a necessity to successfully transfer metallurgical knowledge from one area to another (Ibid. 1018). Western Asia is most likely to be the source of ancient metallurgy since metalworkers in that region had been developing varied metal

technologies for millennia (Ibid. 1019). Nonetheless, the mechanism and speed of the adoption process are determined by socio-cultural desires rather than by functionality. This is the reason why regional innovations appeared sporadically outside the western Asian centre. Rather than passively receiving the new technology, people tended to transform it into a new form in the social acceptance.

Roberts' perception that the adoption of metallurgy is shaped by social and economic factors is reflected by a case study on the spread of steppe metal weapons in ancient China during the Shang-Zhou period (Rawson 2015). She suggests that steppe-related materials and technologies in central China cannot be explained as a pure adoption. While hand-to-hand steppe weapons were readily taken up by the central Chinese, they were adapted to the existing military practices in ancient China, which emphasised large infantry armies led by an elite leader. That is, the borrowed materials and technologies were transplanted to suit the existing political and social environments, which cannot be understood as a single developmental trajectory.

1.6 Chernykh's archaeometallurgical research on Eurasian metal

1.6.1 Chernykh's methodology in interpreting chemical data

Although many compositional studies of archaeological metal from the Steppe were undertaken in the first half of the 20th century, the majority were essentially characterisation studies, limited in both scale and scope (Melikov 1904; Chikashige 1920). However, from the 1960s onwards, this situation changed dramatically, as a number of large-scale analytical programmes were initiated within the Academy of Sciences of the former Soviet Union. Undoubtedly, the most significant of these was led by E. N. Chernykh and his research group at the Institute of Archaeology in Moscow (Chernykh 1966, 1970, 1976; Chernykh & Kuz'minykh 1989a). His team has generated tens of thousands of chemical analyses of metallic specimens using the optical emission spectroscopy (OES) housed at the Spectrographic Analysis Laboratory in the Russian Academy of Sciences. As the majority of data collected in this thesis come from his database, it is crucial to understand how Chernykh and his colleagues interpret those analytical data to construct the metallurgical framework of the Steppe (see Chapter 3, section 3.6 for the description of the analytical protocol).

As Chernykh's intention is to make sense of a large amount of chemical data, he has developed an approach to characterising the composition of copper and copper alloys

based on two concepts: the metallurgical group and chemical group (Chernykh 1970, Ch.2). The metallurgical group is referred to as copper objects with the addition of other alloying elements. This addition can be artificial in the case of tin-bronze which Chernykh sets up an arbitrary 1% cut-off to distinguish the tin-bronze from "clean" copper. There is still a naturally-occurring copper alloy, with combined arsenic and antimony over 1%. This alloy type is frequently found in the territory of Volga and Kama Rivers so that Chernykh denoted it as the VK (ВК) metal.

Chernykh proposed that chemical groups with distinct compositions can be linked to known ore sources. He selected a suite of elements (tin, lead, bismuth, silver, arsenic, antimony, iron, nickel and cobalt), and used them to draw frequency histograms and scatter plots and statistically defined the boundaries to differentiate between chemical groups (Figure 1.5). The symbol of each group represents particular known or plausible copper deposits exploited in antiquity as shown on the map (Figure 1.6). Among them, MP (МП), chemically originated from copper sandstones, is the most widespread metal category for the production of "clean copper" in the west of the Ural Mountains. It is seldom alloyed with tin and usually very low in other impurities except for silver. EU (ЕУ) group is another source of "clean" copper in the east of the Urals, related to the mining fields of Elenovka and Ush-Katta. This chemical group usually occurs in tin-bronze and has lower silver levels than MP group. In addition, TK (ТК) group is associated with arsenical copper produced from Tash-Kazgan deposit in the eastern slope of the Urals. According to Chernykh (1970), it accounts for the majority of arsenical copper objects in Abashevo and Sintashta cultures (Chernykh 1992: 202). Finally, both VK (ВК) and VU (ВУ) groups are characterised by high arsenic, antimony and nickel, but the latter often contains intermediate levels of these three impurities. As mentioned above, while VK objects chiefly concentrate on the river basins of the Volga and Kama, VU metal has a slightly eastern distribution between Volga and Ural interfluve.

Having identified different metallurgical and chemical groups, he puts a lot of effort on the classification of metal artefacts on the basis of typology (Chernykh 1970, Ch. 5). By relating artefact chemistry to typology, he attempted to match compositional variances with varied cultural groups in the Steppe and weave a narrative of the history of metallurgy. His construction of "Metallurgical Provinces" aims to investigate the changing production centres through the course of metallurgical development

(Chernykh 1992). A province is composed of several “metallurgical foci” (extractive metallurgy) and “metalworking foci” (manufacture).

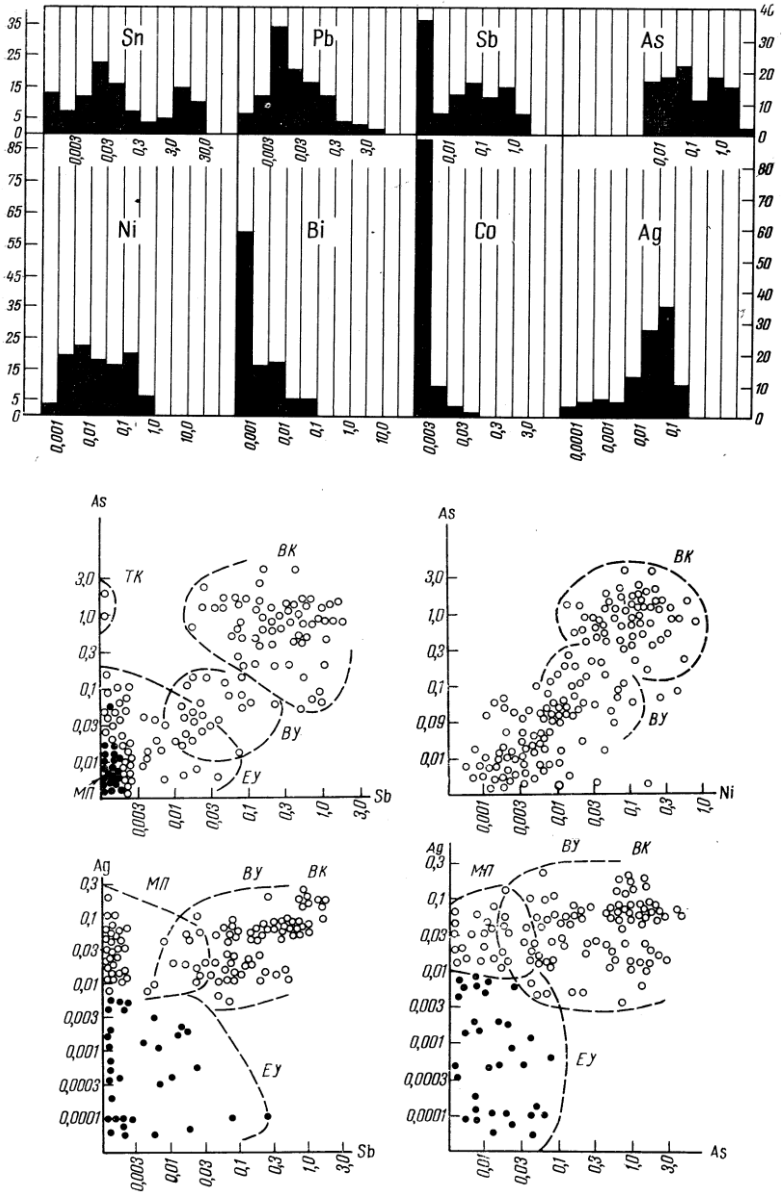


Figure 1.5 Grouping of object chemistry. From Chernykh (1970:16-17).

1.6.2 Metallurgical provinces in the Eurasian steppe

Using the methodology discussed above, Chernykh and his colleagues have published a series of papers and monographs on an enormous amount of ancient Eurasian copper and copper alloys over the last fifty years (Chernykh 1980, 1992). The overall outcomes have developed into a complex world-systems approach to the investigation of archaeological metalwork (tools, weapons, ornaments etc.). Over the last ten years, these data have been integrated with absolute chronology, using a system of bulk

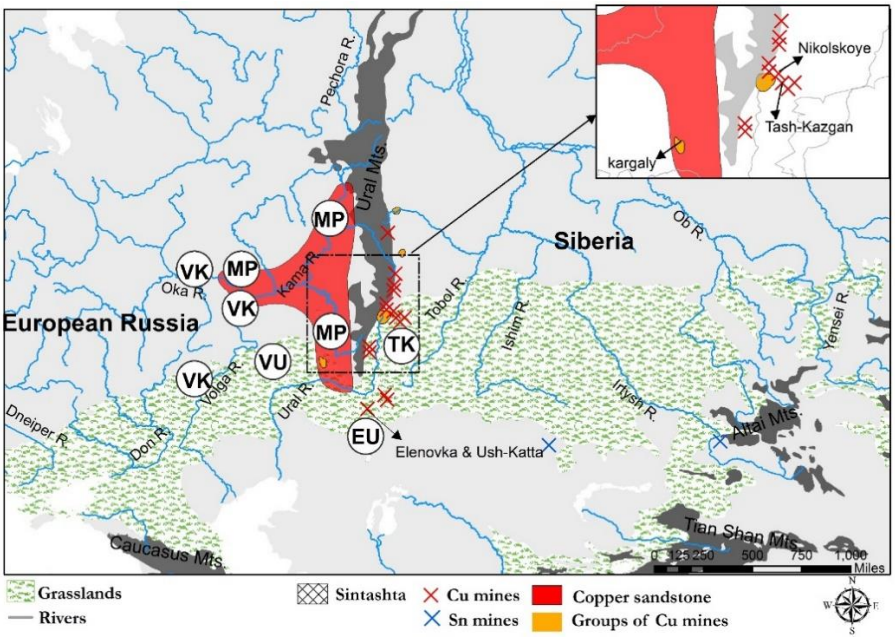


Figure 1.6 Spatial distribution of Chernykh's chemical groups. MP&EU: pure copper. TK: arsenic-rich copper. VK&VU: arsenic-antimony copper. Modified from Chernykh (1970:37, fig. 32)

processing to define the boundaries of cultural phases (Chernykh 2008, 2009a). The primary focus of this remarkable research has been the western steppe where a very comprehensive analysis of metal production and distribution has been carried out, covering the Chalcolithic Period to Late Bronze Age (Chernykh 1992; 2007; 2009b; 2013). On the basis of mine survey, artefact typology and metal chemistry, shifting core areas of production were identified and the more extensive, branched networks of cultural and material exchange, which formed around them, were gradually delimited. Together, these two elements (typology and chemistry) define the 'metallurgical province', the concept around which these grand-scale narratives of historical development for the Early Metal Age were structured, as three stages: (1) Carpatho-Balkan Metallurgical Province (CBMP, 5500 to 3000 BC); (2) Circumpontic Metallurgical Province (CMP, 4000 to 2200 BC); (3) Eurasian Metallurgical Province (EAMP, 2200 to 1000 BC) and Steppe East Asian Metallurgical Province (SEAMP, 3000 BC to 1000 BC).

(1) Carpatho-Balkan Metallurgical Province (Chernykh 1992: 35-53, 2008: 38-41)

While the metal technology of the CBMP may have had the possibility of influence from Anatolia, metallurgy there had developed on its own terms. It is reflected by the formation of three cultural groups in the CBMP (Figure 1.7). The first group, situated in the north Balkans and the Carpathian Basin, acts as the most essential mining and metal production centre in the CBMP. It includes the well-known Varna necropolis and the Ai Bunar copper mines (Todorova 1999). This region not only produced numerous copper tools, weapons, and ornaments, but exported the copper to other less ore-rich

regions (Chernykh 2008: 39). The second group refers to the Cucuteni-Tripolye culture, a farming society in the northwest Black Sea, in modern day Moldavia and western Ukraine (Ellis 1984). Over 500 copper artefacts, mainly ornaments and tools, have been found in Tripolye settlements or hoards. They were made from native copper by cold-worked or hot-forged techniques (Chernykh 1992: 40-41). The third group are the steppe stockbreeders inhabiting in the southern half of eastern Europe, known as the Dnepr-Donetsk, Sredni Stog, and Khvalynsk cultures (Rassamakin 2004). Metallurgy in this area still remained rather primitive with only a few small ornaments and tools being excavated.

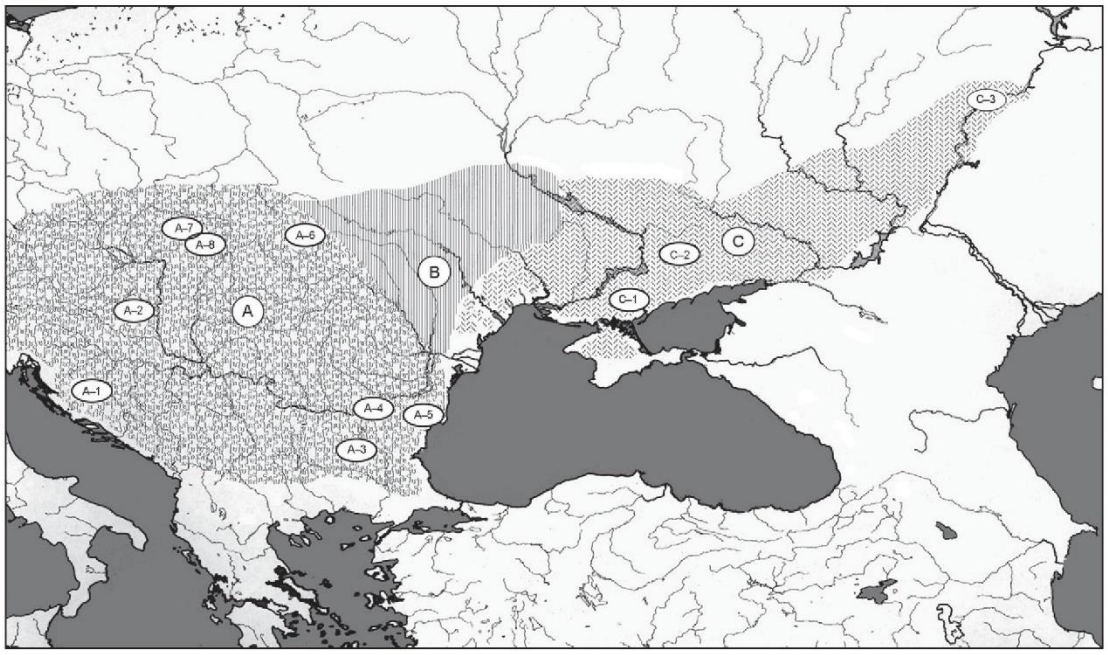


Figure 1.7 Carpatho-Balkan Metallurgical Province (CBMP). A: central block of sedentary cultures. B: Cucuteni-Tripolye block. C: block of stockbreeding cultures, including Dniper-Donets/Mariupol (C1); Sredni-Stog (C2); Khvalynsk (C3). From Chernykh (2008: 39, fig. 2).

(2) Circumpontic Metallurgical Province (Chernykh 1992: 54-96, 2008: 41-46)

The second metallurgical province in Chernykh's model is called the Circumpontic Metallurgical Province (CMP). The CMP covered the regions from the west to east (the Adriatic Sea to southern Urals), as well as the south to north (Levant, Mesopotamian and forest zones of Upper Volga). The first phase of the CMP was represented by the prestigious Maikop phenomenon, chronologically parallel to the Uruk culture in Mesopotamia (Figure 1.8). The Maikop culture, located in the northern Caucasus, was recognised by its large kurgan burials which yielded abundant bronze artefacts (arsenical copper), silver and gold (Chernykh 1992, fig. 24-26). Turquoise and

carnelian beads also appeared in the Maikop kurgans (see Kohl 2007 for a comprehensive study of the Maikop culture).

The second phase of the CMP embraces the coming of the steppe kurgan cultures, namely the Yamnaya (Pit Grave, acquiring its name from digging a burial pit beneath the earth mound) and the Catacomb communities. These two cultures, coexisting for a

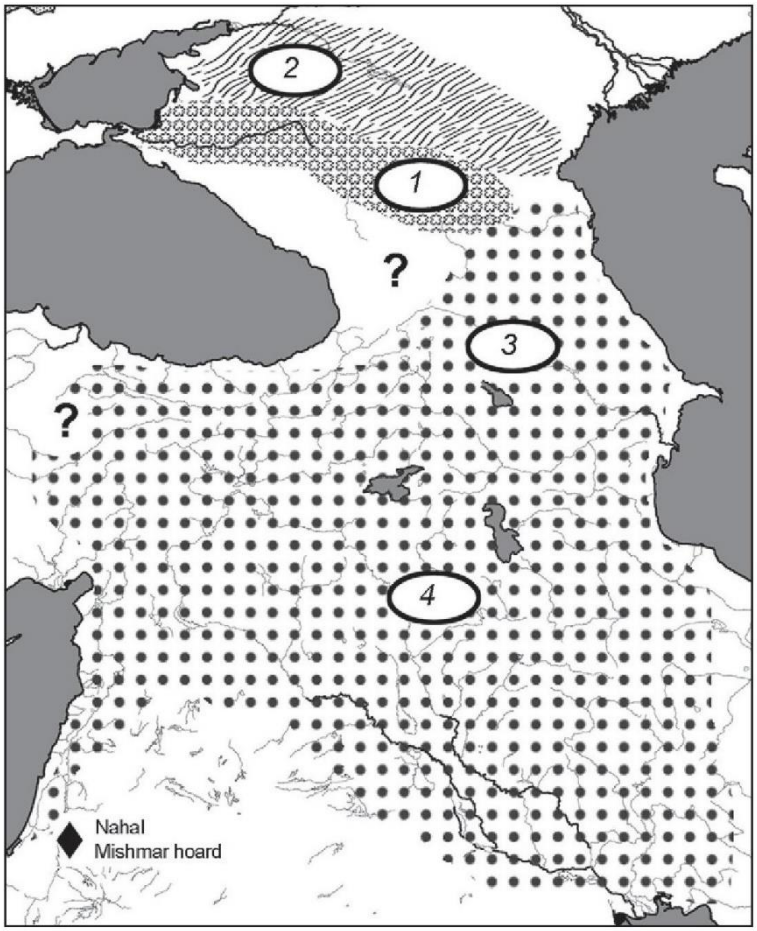


Figure 1.8 The early phase of Circumpontic Metallurgical Province (CMP). 1: Maykop culture proper. 2: sites of the Steppe Maykop. 3. Kura-Araks culture. 4: Late sites of the Uruk community. From Chernykh (2008: 42, fig. 4).

long time from approximately 2700 to 2100 BC, occupied slightly different territories (Figure 1.9). The Yamnaya culture was distributed over the steppe region from Pannonia to the southern Transurals. The practice of the pastoralist lifestyle was confirmed by numerous kurgan burials and few settlements (Shishlina 2001). The Yamnaya metal assemblage consisted of copper or arsenical copper tools and ornaments, such as shaft-hole axes, tanged double-bladed knives, flat adzes, awls, rings, and punched appliques (Chernykh 1992, fig. 28 & 29). The Catacomb culture occupied

a relatively restricted block, stretching from the Lower Volga to Trans-Dnieper regions, bordering the northern Caucasus (Chernykh 2008, 45). The Catacomb peoples possessed more advanced metallurgical techniques than their Yamnaya neighbours in terms of their diverse metal assemblage. They included northern Caucasian style arsenic-copper products (e.g. tanged knives with broad leaf-like blades, awls with bevelled shaft, flat and socketed adzes, and Y-shaped forks) as well as bronze shaft-hole axes with the elongated body in the Dnieper-Don region (Chernykh 1992, fig. 44 & 45).

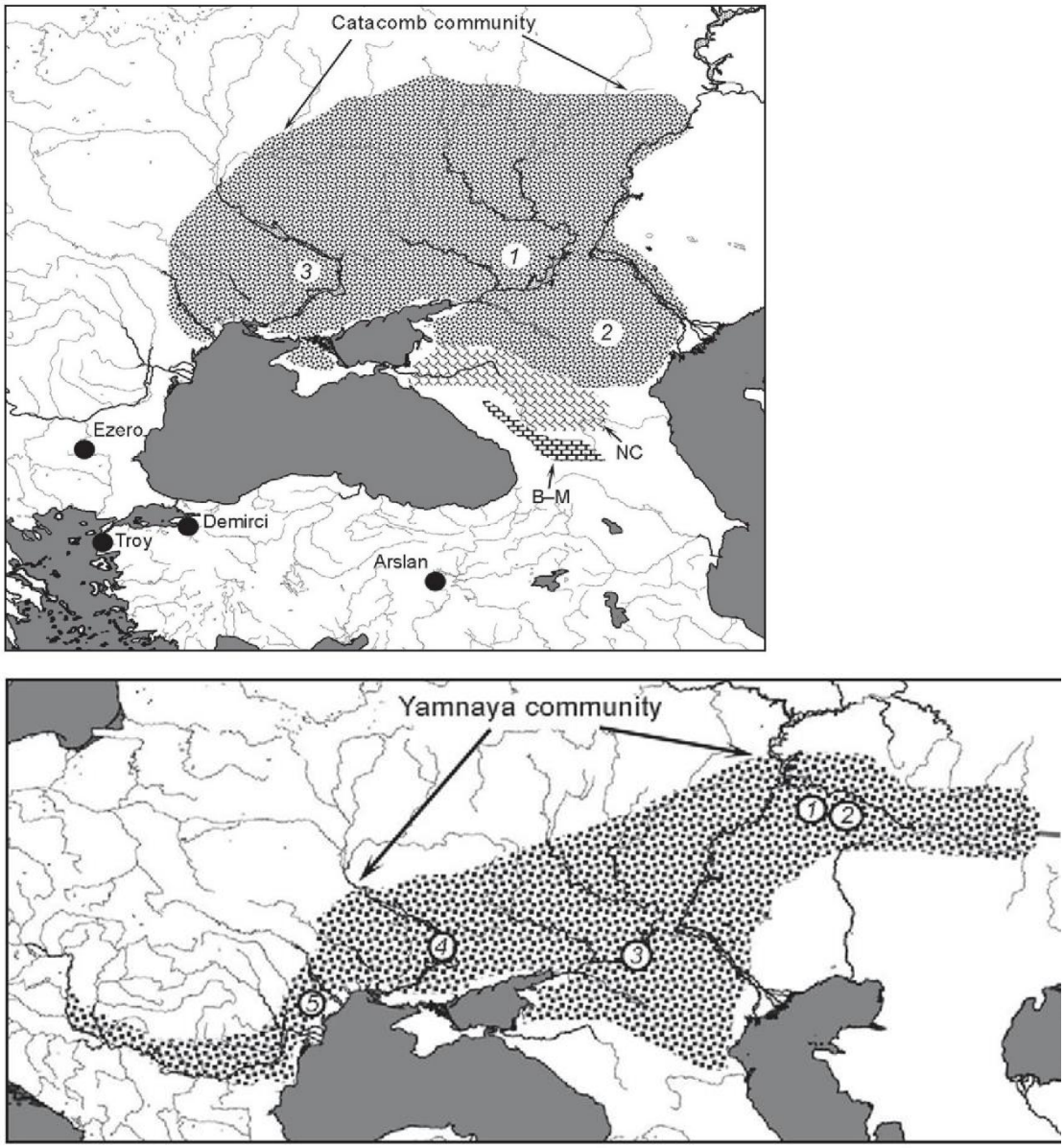


Figure 1.9 The later phase of Circumpontic Metallurgical Province (CMP). Catacomb and Yamnaya communities showing overlapping territory. From Chernykh (2008, fig. 7 & 8).

(3) Eurasian Metallurgical Province and Steppe East Asian Metallurgical Province (Chernykh 1992: 172-215, 2008: 45-50)

The final metallurgical province signifies the complete formation of the steppe belt culture across Eurasia, a structure of full stockbreeding society remaining unchanged until the pre-modern date (Chernykh 2008: 45). Following the disintegration of the CMP, metallurgy at this time travelled across the boundary of the Ural Mountains, extending as far as the East Asian region. There were two metallurgical focuses forming the interweaving metal network, namely Eurasian Metallurgical Province (EAMP) and Steppe East Asian Metallurgical Province (SEAMP).

The EAMP was built upon the preceding CMP traditions but expanded its influence over the forest zones of Northwest Asia, the central Asian desert zone, western Siberian steppe, the middle Yenisei, the foothills of the Altai and as far east as Xinjiang in West China. The EAMP metallurgists acquired the copper ores from various sources, including the eastern Urals, Kazakh, and the Altai region. The supplies of tin chiefly came from the Kalba and Narym ranges of the western Rundy Altai as well as the desert zone in the southern central Asia. Tin-bronzes were regularly made on the eastern side of the Ural Mountains as opposed to the arsenic-copper tradition in the Pontic-Caspian steppe (Chernykh 2008: 46).

The first phase of the EAMP revealed two opposite ways of migration in the Eurasian steppe and forest zones (Figure 1.10). The eastward movement was marked by the dissemination of three cultures dated roughly around 2200 to 1700 BC: Abashevo (eastern European steppe), Sintashta (southern Urals), and Petrovka (northern Kazakhstan) communities (Koriakova & Epimakhov 2007: 57-96). Most of the Abashevo metal artefacts were found in the settlements, some from burials or hoards. Metalworking remains from the settlements, such as crucibles, slags and casting waste, confirmed the existence of specialised metallurgists on sites. Metal objects, mostly made of arsenic-copper alloy, included shaft-hole axes, forged spearheads, both single and double edged knives, rosette appliques for the headdress or clothing (Chernykh 1992, fig. 68). The Sintashta culture was characterised by its larger fortified settlements and burials interred with two spoke-wheeled chariots drawn by horses. The artefacts contained arsenic-copper objects (knives, forged spearheads, and shaft-hole axes with a protruding butt) as well as bone cheek-pieces (Chernykh 1992, fig. 78).

The westward movement was referred to as the Seima-Turbino phenomenon (2200 to 1700 BC) in the forest and forest-steppe regions throughout Eurasia, spanned from the Sayano-Altai area to Moldova and Finland (Chernykh & Kuz'minich 1989a). Chernykh maintained that the Seima-Turbino peoples were skilful metallurgists capable of casting socketed celts, socketed spearheads, and single-bladed curved knives with zoomorphic pommels. He believed that the Seima-Turbino metal artefacts, stemming from the Altai region, greatly contributed to the developments of eastern Asian metallurgy (Chernykh 2008: 50-51). Several parallels of Seima-Turbino metal artefacts have been found in northwestern and central China (Fitzgerald-Huber 1995; Mei 2003).

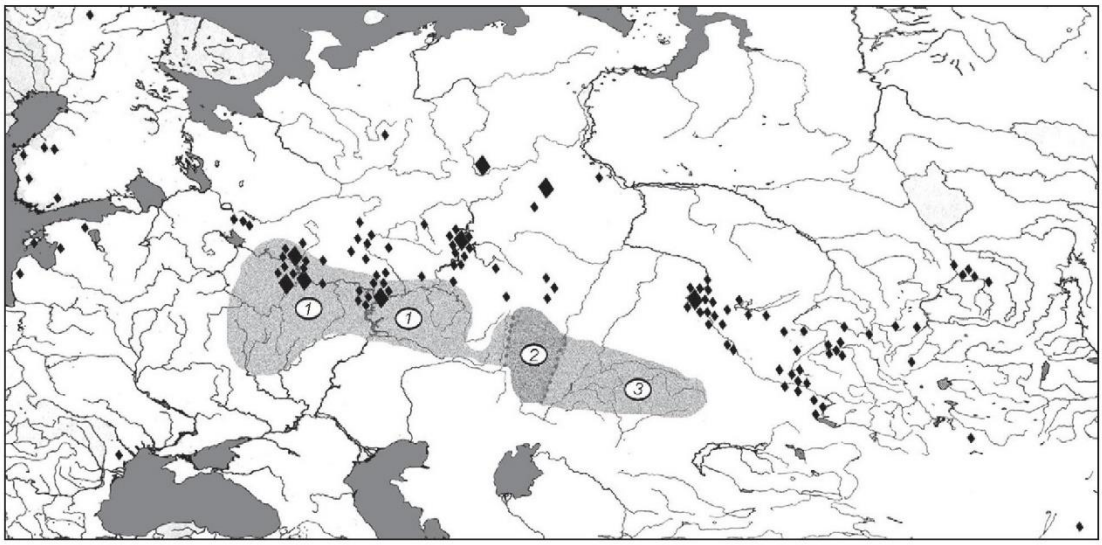


Figure 1.10 The early phase of Eurasian Metallurgical Province (EAMP). 1: Abashevo. 2: Sintashta. 3: Petrovka. Black markers: Seima-Turbino finds. From Chernykh (2008: 47, fig. 9).

The second phase of the EAMP (the first half of 2nd millennium BC) displayed an even more homogeneous cultural continuity across the steppe belt (Figure 1.11, also see Chernykh 2008: 48) In the western of the Ural Mountains, the Srubnaya (Timber Grave) communities constructed wooden chambers inside the burial pit covered with logs or beams. Their metal artefacts comprised shaft-hole axes, forged and cast socketed spearheads, hook-tanged sickles, double-edged daggers, and clay moulds for axes and sickles (Chernykh 1992, fig. 69). In the eastern side of the Urals, the Andronovo cultural horizon dominated the territory from Transurals to the Minusinsk basin as well as parts of Xinjiang. This culture is notable for geometric-patterned ceramics and tin-bronze products (Kuz'mina 2007, fig. 12 & 13; Chernykh 1992, fig. 71)

(4) Steppe Eastern Asian Metallurgical Province

The Steppe East Asian Metallurgical Province (3000 BC to 1000 BC), more or less contemporary with the EAMP, is a less-studied metallurgical region without well-defined boundaries and archaeological cultures. Its core area included the Altai-Sayan Mountains and its peripheries, possibly extending into steppe zones of Mongolia and northern China. The early phase of the SEAMP (3000 to 1700 BC) marked the

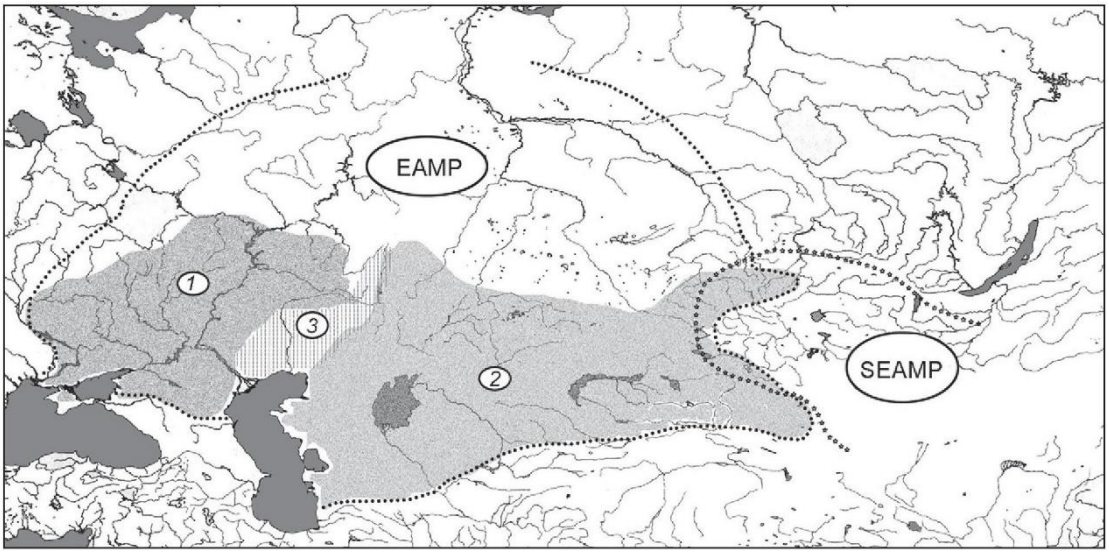


Figure 1.11 The later phase of Eurasian Metallurgical Province (EAMP). 1: Srubnaya 2: Andronovo. 3: Mixed zone. From Chernykh (2008: 49, fig. 11).

manufacture of unalloyed copper artefacts. The Afanasevo culture (c.2800- 2400 BC) in the Minusinsk Basin and around the Altai Mountains yielded ceramic pots with round or pointed bottoms resembling the Yamnaya pottery, and a stray find of a copper shaft-hole axe is also associated with the Yamnaya metalwork (Chernykh 1992: 182-183). After the Afanasevo culture, the Okunevo communities appeared in the basin (c. 2200-1900 BC), with notable animal-style art on bones or rock engravings (Chernykh 1992: 183). The Okunevo culture is also renowned for its tin-bronze production, the cast spearhead, and bone-handled bronze knives and awls (Chernykh 1992, fig. 65). The bone-handled metal objects demonstrate the connection with the Seima-Turbino and other eastern Eurasian communities. The later phase of the SEAMP (c.1400 to 1000 BC) is referred to as the Karasuk culture. Chernykh (2008:50) argues that there is a clear connection between Seima-Turbino and Karasuk types of metalwork; however, he finds it difficult to explain the gap of several hundred years between these two

cultures (Karasuk culture is dated to between 1400 and 900 cal. BC, see Svyatko *et al.* 2009).

In interpreting the formation of the SEAMP, Chernykh gave most credit to the Seima-Turbino metalwork as similar types of bronze artefacts were dispersed over the territory of the SEAMP, including the Minusinsk Basin, the Hexi Corridor and even central China during the late-Shang period (Chernykh 1992: 215-234; Chernykh and Kuz'minich 1989a).

1.7 Hypotheses of change and interaction in the prehistoric Eurasian steppe

Chernykh's painstaking work clearly demonstrates shifting metalworking histories that are interregional or cross-cultural in character. Precisely because of this unique trait, the Eurasian steppe has become a popular research area for the debate and theorising on change among mobile communities and on their interaction with sedentary societies, such as ancient Mesopotamia, Iran and China. While I cannot offer an all-embracing methodological overview of how change and interaction in the Steppe came about, I feel obliged to pinpoint some key publications that provoke meaningful theoretical discussions in recent decades.

1.7.1 The world-systems perspective on the Trans-Eurasian exchange

The world-systems theory stems from Immanuel Wallerstein's book "The Modern World-System" in which he discusses how capitalist economy shaped modern Europe and its exploitation of colonies from the 16th century AD onwards (Wallerstein 1989). He thinks that a world-system is "a social system, one that has boundaries, structures, member groups, rules of legitimation, and coherence", and it is defined by "the fact that its self-containment as an economic material entity based on extensive division of labour and that it contains within it a multiplicity of cultures." Wallerstein's model (1993) is economic, which he called "world-economies" to differentiate from "world-empires" in the preceding imperial era. He also brings out core/periphery relation as active agents in a world-system. A core area contains states with superior political, military and technological advantages, while a periphery is considered as pre-states or incipient states, which possess valuable raw materials exploited by core states.

Although Wallerstein's world-system or world-economy approach is a method to conceptualise the political and economic structures of the modern time, archaeologists

have modified his theory to interpret long-term cycles of socioeconomic expansion and contraction in ancient world.

Andrew Sherratt (1993, 1995) employed the world-systems theory to interpret cultural transformation in European prehistory. Traditionally, scholars had attributed social change in prehistoric Europe to two competing perspectives: one evolutionary or autonomist, and the other diffusionist or interventionist (Sherratt 1993: 1). The former standpoint stresses the changes resulting from ecological factors, population growth, agricultural advances, or the indigenous development of technologies. The latter highlights foreign influences that involve trade and exchange of commodity or the dissemination of ideologies. Nonetheless, Sherratt takes a new approach to explaining how prehistoric societies were transformed, in what he calls the "interactionist approach" (Sherratt, 1995: 10). He defines the nature of the core-periphery correlation, as well as the introduction of the "margin." To him, the core refers to the "large masses of urban consumers and manufacturing centres" and the periphery to the "surrounding penumbra of politically and economically less-developed societies, typically chiefdoms or secondary states in which the structural transformation occurs as a result of regular exchanges of material products with privileged consumers elsewhere" (Sherratt 1993: 4-5). Additionally, the margin would apply to the areas which receive indirect contacts and influence from urban trading networks. The exchange routes for specific goods or ideas might travel between the core and marginal regions over a great distance without creating apparent inter-dependent relationship (Sherratt 1993: 6). The determination of the core-periphery-margin relation heavily relies on the position of regions in response to local ecological settings and natural resources (Sherratt 1993: 3) That is, the geographical location of a cultural entity would determine what role a society plays within the core-periphery-margin system.

Sherratt's observation regarding European cultural developments emphasises three major points: (1) processes of contagious spread; (2) movement of objects or non-material culture; (3) the consumer-oriented exchange network. The first aspect attempts to demonstrate that transitions between different cultural contexts resulted from waves of new technologies or ideas circulating among societies. The second angle stresses that it was the trading/exchange activity rather than subsistent or demographic variables that determines the social change. As a result, accessible transportation was crucial to facilitate the movement of goods or technologies that altered the structures of ancient

communities. The ultimate perspective focuses on the consumer's rather than producer's views as deciding which products or technologies will prevail and which will not. The tastes of consumers will project social meanings on both luxuries and bulk goods by which new modes of consumption behaviour will drive trading activities.

Sherratt also attempts to illuminate the interconnections between prehistoric Eurasian societies, notably the prehistory of Chinese relations to the West (Sherratt 2006, 2011). He argues that the Trans-Eurasian exchanges had been already underway through crop exchange long before the second millennium BC. The cereal cultivation reflects upon two cultural entities, which are wheat/barely in western Eurasia (the Near East and Europe) and rice/millet in eastern Eurasia (eastern Asia and southeastern Asia). The communication between these two distinct crop systems initiated in India subcontinent where wheat/barely was cultivated in the northwest and rice in the northeast during the 3rd millennium BC (the remains of wheat were also found in the Gansu province, northwest China by the second millennium BC, see Liu *et al.* 2014).

The usage of precious stones in prehistoric Eurasia highlights another cultural difference between the East and the West. Jade in China and lapis lazuli in Mesopotamia represent prestigious as well as ritual emblems among their communities. Both of them sprang from the upthrust of the Himalayas, separated by 900 km by the Pamir. According to Sherratt (2006), the movement of jade, as the eastern segment of the later Silk Road, began from the renowned Hetian jade in Xinjiang, along the Gansu corridor down to the heartland of the central Yellow River plain. In western Eurasia, the exploitation of lapis lazuli during the fourth millennium foresaw the western section of the Silk Road between Bactria and Mesopotamia. Lazurites were transported from their source in the Chagai Hills and Badakhstan, cross the Iranian Plateau, and arrived at the Mesopotamian alluvial plain.

Apart from the spread of crops and precious stones, Sherratt (2006) also highlights the connection of metallurgy across Eurasia. In western Eurasia, metalworkers had developed the multi-metallic and sheet-metal working traditions. Metallurgy began much earlier than the East, with the use of copper in the seventh millennium BC, gold in the fifth, and silver in the fourth. Instead, eastern Asian metalwork featured heavy bronzework achieved by casting skills. Metalworkers came to learn the hollow-casting techniques from Siberian peoples and applied them to the manufacture of highly-

intricate ritual vessels in association with indigenous Chinese pottery industry and wood and stone carving (known as the piece-mould casting). Due to the high demand for ritual bronze vessels, ancient Chinese eagerly expanded their exchange networks to obtain necessary raw materials (copper, tin, or lead ores).

These two distinct metal traditions, one from western Eurasia and the other from eastern Eurasia, met in the steppe zone, where the conjunction of sheet-metal (e.g. forging socketed spearheads from Arkaim and Sintashta sites) and hollow-casting techniques (e.g. Seima-Turbino socketed weaponry) took place. The Steppe became an important intermediary to the movement of ideas and metal technologies between the Near East and ancient China.

1.7.2 Interconnections of the Eurasian prehistory

Kohl (2008) asserts that prehistoric Eurasian societies do not exist in isolation but are shaped by interlocking, web-like connections which he terms "social fields". This concept is initially derived from Alexander Lesser who thinks that "social relations within the field are patterned, not unstructured, adventitious, or incidental. . . the field concept rather than the concept of society as an isolated or closed system reflects socio-historical processes more accurately – that human contact and patterned interpersonal relation are not restricted to social interaction within a singled localize social aggregate, but are a universal constant of social life" (Lesser 1985:94-94). Kohl (2008: 503) urges archaeologists to focus on finding regularities or patterns of cultural evolution within macro-historical processes in order to narrate interconnections of human history. To him, the material nature of archaeological evidence makes it appropriate to reconstruct prehistoric mode of production, technologies, environments and to some extent, subsistence strategies (Ibid. 500). He gives two examples regarding the diffusion of technologies in the Steppe: wheeled vehicles and similarity of metal weapons and tools. The extensive use of wheeled wagons is documented in the burials of the Kuban plain of the northwestern Caucasus and the neighbouring Pontic-Caspian steppe region in the late fourth and early third millennium BC (Kohl 2007: 196-199). By the mid-third millennium BC, oxen-driven wagons made their appearance in kurgans of southern Caucasus and penetrated into the royal tombs in southern Mesopotamia. The similar practice is also identified in the burial context of Gonur-depe in southern Turkmenistan, where Bactrian camels may possibly have been utilised with wheeled transportation. In

the following second millennium BC, the innovation of horse-driven chariot in the central Eurasian steppe spread rapidly into the settled communities in the ancient Near East and the metropolitan China. The distribution of similar metal inventory across the Steppe provides another example of interrelated technology shared by steppe inhabitants. This strand of long-distance contact is well articulated by Chernykh's metallurgical provinces (as discussed in Section 1.6).

Kohl (2008: 496) admits that while it is not so difficult to describe the general trajectories of historical development across different societies of the Bronze Age Eurasia, the assessment of the significance of these interconnections is much harder to be achieved given the relatively little settlement data associated with steppe people. He considers that the classification of the world-system approach is oftentimes misleading as Bronze Age Eurasia cannot be subdivided into cores, peripheries and semi-peripheries (Ibid. 497). One of the key features in ancient innovations lies in "transferable technologies", which cannot be monopolised but freely dispersed from one place to another through the exchange of commodities and ideas (Kohl 1987:16-17). As a result, diffusion takes place along multiple pathways, demonstrating an "overlapping and interconnected shared social fields" (Kohl 2008: 503).

1.7.3 Change of pastoralist economies in the Eurasian steppe

The development of pastoralism has long been preoccupied by the linear diffusion and migration models (Gimbutas 1965; Koryakova and Epimakhov 2007; Shnirel'man 1992). This methdology emphasises a single origin for specialised herding strategies derived from agricultural societies living in the northern shores of the Black Sea in the end of the fifth millennium BC. Along with population migration in response to environmental change and demographic pressure, this mode of economic life spread into to the western Eurasian steppe throughout the fourth and third millennia BC, and finally took up the rest of steppe regions by the mid-second millennium BC (Kuz'mina 2008).

Such grand narratives of Eurasian prehistory have recently been systematically challenged by Michael D. Frachetti, who proposes that, rather than seeing the Steppe as a unified cultural unit, the formation of mobile pastoralists is actually shaped by distinct local trajectories in different parts of the Eurasian steppe (Frachetti 2012). Drawing from evidence of faunal remains, he argues three specific herding subsistence

patterns in the late fourth and third millennia BC: the cattle-focused Pontic-Caspian steppes, horse-focused Kazakh steppes, and sheep-focused Altai-Tianshan steppes. These specialised economies motivated a political organisation different from the conventional hierarchies of statehood or the confederacy of chiefdoms. Instead, he presents a new paradigm called "non-uniform institutional complexity" to explain the relationship between steppe groups with different pastoralist lifestyles and their extensive networks of interaction.

According to Frachetti (2012: 5), institutions are defined as "the organizational and ideological norms that sharp practical interactions of agents and communities." These may include burial rituals or other political and social structures, such as kinship, bureaucracy, and trading networks, to set the "rules of engagement" between interactive bodies. The term "non-uniformity" refers to a situation wherein some institutions are widely shared by different steppe communities through inter-regional or long-distance contacts, while others remain restricted and specific to local development. For instance, horse sacrifices and domesticated grain offerings in mortuary context are present across a variety of pastoral groups by the mid-second millennium BC (Outram *et al.* 2011), yet their political and economic organisations remain locally defined. The specific/local institutions can be transformed into general/universal ones if they align with one another at a given time between different communities. The spread of metallurgy and wheeled chariot technology are good examples of such transformation. They used to be locally adapted innovations in the western Eurasian steppe (metallurgy) and the southern Urals (chariot), yet became widely accepted as the symbols of power across Eurasia by the late second millennium BC (Frachetti 2012:18). This change in institutional geography was due to the re-shaping of "the contours of social participation" by different societies (Ibid. 19).

1.7.4 Change of political organisations in the Mongolian steppe

The formation of the first steppe empire (known as Xiongnu) in Inner Asia by the late first millennium BC has proven the capability for mobile nomads to develop a state-like organization. However, scholars differ in the opinion of what the driving force is for this dramatic transformation. Conventional text-based models emphasise the unstable herding economy in the pastoral communities that accumulation of surplus is unattainable (Kürsat-Ahler 1996, Khazanov 2001, 2004, 2009). Raiding and exchange

initiated by nomadic groups are needed to obtain sedentary products from the agricultural civilisations. This dependent relation provides an opportunity for the emergence of elite class and statehood in nomadic groups. Therefore, increasing warfare and trade between Inner Asian nomads and settled Chinese states facilitated the rise of the Xiongnu Empire (Barfield 2011; Di Cosmo 1994).

Contrary to such dependency hypothesis, Honeychurch (2015) argues for the entanglement of political alliances and negotiations that transform local nomadic politics into a larger sphere of interaction. Pastoral nomadism is not merely a substance strategy involving herding animals and periodic movement. Rather, it is a social process that embraces the flexibility of diets, mobility, technology, habitation patterns, landscape arrangements, rituals, and belief (Ibid. 57). He proposed the term "spatial politics" to explain the state formation of the Xiongnu based on mobility. Mobility creates a political venue in which different nomadic groups negotiate their mutual relationships. Archaeological evidence from central Mongolia shows that during the fourth/third century BC local communities adopted shared material, technology, rituals and symbols including the introduction of iron, the first appearance of cultivated grain, the application of animal-style art, and the possession of exotic goods. Since there is no clear evidence for population migration or replacement in this area, nor can we observe dramatic social changes driven by increasing conflict or violence in mortuary evidence, the transformations of material culture in central Mongolia were more likely choices made by local factions to maintain the legitimacy of their leadership (Honeychurch 2015: 240, 245). Therefore, the Xiongnu statehood, based on mobility and regional interactions, is extremely strategic, opportunistic and flexible in the framework of the decentralised and horizontal integration. This specific character of nomadic states cannot be derived from sedentary states featuring centralised, bureaucratic and hierarchal settings (Honeychurch 2015: 67).

1.7.5 Change of ideology in northern frontiers of ancient China

Present-day northern borders of China, known as the "Northern Zone" is an area crucial to our understanding of interactions between pastoral, semi-sedentary and sedentary communities (Watson 1971). Drawing on archaeological records in the late second and early first millennia BCE (such as ceramic types, metal assemblage, settlement patterns, and burial practices), Shelach (2009) devises a novel theoretical approach to uncovering

the mechanisms behind the cultural changes in this region. He argues that during the transition to the first millennium BCE, aspects of everyday life (ceramics) and economic strategies (mixing herding and agriculture) changed less than ritual and ideological representations. The latter displays new elements of material culture marked by the burials constructed in stone and accompanied by steppe-style metal weapons and ornaments with distinct zoomorphic motifs, especially in the eastern part of the Northern Zone (Shelach 2009:73). He thinks that these changes reflect outside influences but he does not dwelt on tracing origins of these external drivers. Rather, he pays much attention to the process by which these new materials come to be the part of the Northern Zone communities through long-distance contacts. First of all, he concludes two ways of communication: a movement of people (through migration) and a movement of artefacts (through trade) (Shelach 2009: 117). The continuity of pottery and stone artefacts does not support the hypothesis of an extensive population replacement in the Northern Zone by the end of the second millennium BC. Although trade could be the alternative reason to induce changes, intensive exchange took place mainly within the societies of the Northern Zone and with their southern agricultural neighbours in the Central Plains of China in terms of imported Chinese ritual vessels and cowrie shells in mortuary assemblage (Ibid. 127-128). On the contrary, we have little evidence to suggest actual material exchange between the Northern Zone and the Eurasian steppe, yet steppe-style artefacts are ubiquitous throughout different ranks of graves. In fact, Shelach points out metal objects from the Northern Zone demonstrate clearly regional variations of production, which are not the result of direct transmission of the steppe objects (Ibid. 139). Therefore, he considers another mechanism – the creation of identity – to suggest why similarity of bronze inventory emerged suddenly in the Northern Zone with typical steppe tradition in character.

A person's identity is 'his or her psychologically salient individuality, the way he or she feels different from or similar to other people' (Luhrmann 2001:7154). Shelach (2009: 111) argues that the Northern Zone communities during the first millennium BCE underwent a significant change in ideological expressions of burial furnishing – from ceramic vessels to bronze weapons and ornaments. In the second millennium BCE, the Northern Zone people used pottery as a symbol to connect individual families or households within the small group; yet by the first millennium BCE personal metal items became specifically for the purpose of "showing" interaction with people outside

the local society and even some from remote communities in the Eurasian steppe (Ibid. 112). Interestingly, this shared behaviour appears among both commoners' and elite burials, suggesting this steppe fashion is an egalitarian manifestation rather than a prestigious one. According to Shelach (2009: 145), this new construction of identity in the Northern Zone was probably motivated by increasing pressure from the southern Chinese states in the Central Plains. This forced the northerners to adopt a non-Chinese symbolic system in order to maintain their local identity. Another external source of symbols, namely the societies of the Eurasian steppe, was borrowed to fulfil this need.

Given such wide range of theoretical frameworks to explain change and interaction between prehistoric societies, it seems to me that no single approach is universally applicable to each archaeological observation in the Eurasian steppe. The authors may derive different conclusions and perspectives from their respective research areas or themes. Nonetheless, they have one thing in common – moving away from simple question of ultimate origins to a more sophisticated and meaningful question of processes of technological or social transformations. Inspired by this new mindset, this thesis will mainly focus on how chemical variations in ancient metal reflect the ways ancient communities interacted with one another. Rather than adopting any theory to provide definite interpretations of metallurgical change in the Steppe, this study attempts to present new information that can be of value for further holistic research combining other strands of archaeological evidence.

1.8 Outline of chapters to come

This thesis focuses primarily on the circulation of copper and copper alloys in the Eurasian steppe, from the end of the third towards the end of the first millennia BC. Unlike existing provenance approaches, I attribute change in artefact chemistry to human decisions on re-making of metal objects according to different backgrounds of socio-political conditions, natural environments, and ways of organising. These are conceptualised in a series of metal recycling, mixing, alloying and direct exchange. This new perspective on analysing metal production in the Eurasian steppe is fundamentally different from Chernykh's methodology which regards metal composition as a fixed and static attribute chiefly related to ore sources and overlooks the dynamic human interactions with metal and metal artefacts. To demonstrate how human engagements shape the life histories of metal objects, Chapter 2 introduces a

new integrated methodology to identify the flows of metal based on thermodynamic modelling, experimental results and archaeological reasoning (Bray & Pollard 2012). I will first review past scholarly studies on metal provenance and propose potential drawbacks of this approach. The behaviour of each element in a copper-alloy system is explained based on thermodynamic estimation and experimental data. This knowledge leads to the development of the main approach used by this thesis to characterise the copper-based objects by trace element composition, to re-define the concept of copper alloys, and to re-orient lead isotope data toward the aspect of metal mixing. Many case studies (e.g. Bronze Age Iran, China, Britain and Italy) have taken advantage of this new methodology to provide fresh interpretations for ancient metal production, circulation, and recycling.

Chapter 3 presents the geographical and chronological framework for the assembled bronze data. A general overview of archaeological cultures and their material remains is discussed. I also examine the latest mining and smelting evidence in the Steppe, which provides the information of initial composition of copper being produced from ores. In the end, as chemical data is compiled from different published sources with varied analytical methods, I evaluate the data quality based on results from previous inter-laboratory comparisons between different techniques and suggest some precautions needed to use the legacy data.

Chapter 4 to 7 situate the proposed methodology in the investigation of the metal flows in the Steppe during 2000 to 300 BC. I first focus on the rise of the Seima-Turbino tin-bronze metallurgy in the eastern Eurasian steppe and how this new alloying technology becomes prevalent in western Eurasia (Chapter 4). This phenomenon is followed by the expansion of tin-bronze technology within the extent of the Andronovo cultural horizon (Chapter 5). After the Andronovo metalwork, many regional metallurgical centres come into existence in Kazakhstan, Minusinsk Basin, Mongolia, Baikal and Northern Zone of China. The circulation of metal becomes much more diverse compared with previous eras (Chapter 6). The last case study highlights the increasing mobility of horse-riding communities during the Early Iron Age and their network of metal exchange within the steppe zone and its long-distance connections with southern settled societies. (Chapter 7).

The final chapter addresses the broader archaeological implications for the observed chemical pattern of Eurasian metallurgy from the previous chapters. I will pinpoint different trajectories of metal movement over time and space through constant recycling, mixing, alloying or direct exchange. In addition, I also explore two important alloying practices performed by the prehistoric steppe societies: arsenical copper/bronze and tin-bronze. The genesis, manufacture and distribution of these two alloying traditions are examined in comparison with Middle Eastern and European datasets. In the end, I propose some current challenges and future trajectories for the Eurasian metallurgy on the basis of proper use of "legacy" data, refined artefact chronology, further thermodynamic calculations and experiments, and better collaboration between different disciplines of archaeometallurgy.

2. Methodology

2.1 Overview of archaeometallurgical research

2.1.1 Studies on metal composition

As this thesis deals with a large amount of compositional data, it is critical to evaluate the works done by past scholars who have interpreted the pattern of artefact chemistry in many different ways. The chemical study of ancient metal has been undertaken since the 1790s (Caley 1951, 1967; Pollard 2013). The initial intention was to know what these objects were made from, and to suggest a chronological sequence of metal use from native copper to copper-arsenic, to tin-bronze, leaded tin bronze and ultimately to brass. Even though this proposition had been gradually abandoned after the introduction of absolute dating methods, the concept of "technological progress" is still implicitly rooted in the study of archaeometallurgy.

Another important aspect of early chemical research on metal is marked by the provenance approach to tracing metal artefacts back to their geological sources (Göbel 1842; Damour 1865). The advent of new analytical techniques after the 1930s allowed archaeological scientists to generate a large body of reliable chemical analyses in a short time. This major breakthrough contributed a series of analytical projects on the provenance determination of prehistoric European metal (Preuschen & Pittioni 1937; Otto & Witter 1952; Coghlan & Cook 1953; Junghans *et al.* 1960, 1968, 1974). The *Studien zu den Anfängen der Metallurgie* (SAM) program, led by Siegfried Junghans and Edward Sangmeister in Stuttgart, was amongst the best known research teams to establish a chemical system for trace element data. It pioneered several important achievements in the ancient metal study: (1) the construction of over 20,000 chemical analyses of European copper-based objects from the Chalcolithic period to Bronze Age; (2) the selection of As, Sb, Ag, Ni, and Bi as classifying elements; (3) division of analyses into 29 metal groups based on the statistical method (seeking for the normal distribution with small standard deviation); (4) the attempt to connect metal groups with cultural, chronological, and geographical backgrounds. For instance, the SAM project is able to identify Group A as the Singen metals from southwestern Germany, with a particular range of trace elements (Bi< 0.082%, Sb>0.40%, Ag>0.25% and Ni>0.50%).

In addition to the Stuttgart team, many researchers had developed their own way to interpret chemical datasets. Waterbolk and Butler (1965) proposed another classification criterion, alongside the graphical presentation, to demonstrate variations of metal chemistry. Instead of dividing objects by the absolute cut-off values, as the SAM project did, Waterbolk and Butler set up numerical intervals to group objects. (Figure 2.1). Each data point is then plotted on the histogram charts by percentage of the assemblage to reveal the general distribution of a particular metal type (Figure 2.2). Boomert (1975), on the other hand, combined both Hodson's cluster analysis (1969) and Waterbolk & Butler's logarithmic scale (1965) to re-evaluate 163 analyses from the Early Bronze Age cemetery in Gemeinlebarn, the Lower Austria. These two methods are in agreement with each other and both demonstrate unique trace element patterns between varied cultural/regional metal productions.

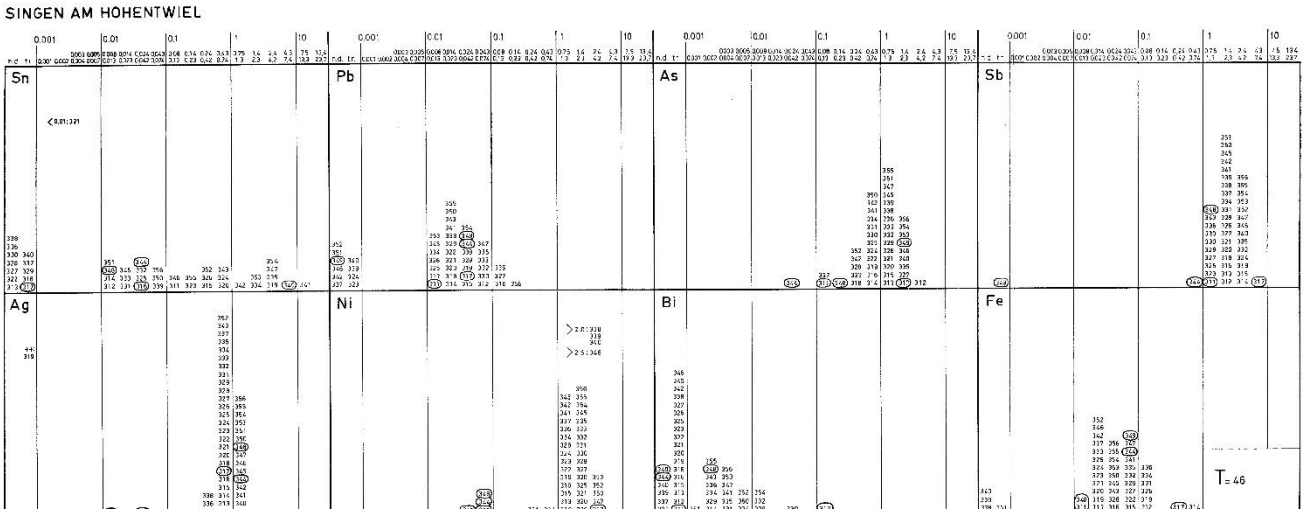


Figure 2.1 Singen metals from S. W. Germany. Each number represents one data entry, which is classified by intervals of 0.001, 0.01, 0.1, 1, and 10 % for each element. From Waterbolk & Butler (1965, Table 2).

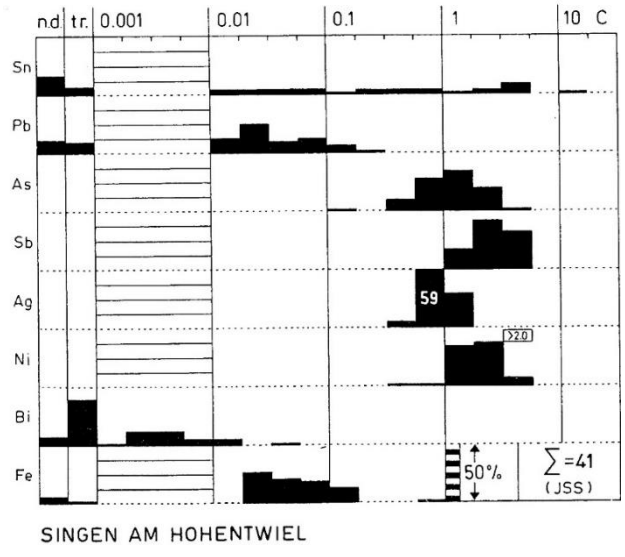


Figure 2.2 Histogram of Singen metals from S. W. Germany by percentage of total analysed assemblage. From Waterbolk & Bulter (1965, graph 8).

Liversage & Liversage (1989) also adopted Waterbolk & Bulter's graphical method to re-examine 616 SAM analyses of Danish copper-alloy objects. They first compiled each analysis into the logarithmic diagram (similar to Figure 2.1) and then plotted each entry on a scatter chart to determine the limits of values for the grouping of objects (Figure 2.3). The results indicate that Danish bronzes are a mixture of copper with different combinations of impurities, including indigenous arsenical copper (with As between 0.1 and 2%), As-Sb-Ni copper, the Singen metals from central Europe (high As, Sb, Ag, and Ni), As-Ni copper from Dutch Bell Beaker culture, and Ösenring metals from the Alps (As, Sb, Ag, and low Ni). Most importantly, they noticed that high-tin Danish bronzes tend to have lower impurities than their contemporary central European bronzes. The authors suspect that the re-melting of tin-bronze in Denmark might have led to the oxidisation of other trace elements within copper. Nonetheless, their approach to defining metal groups has two defects. Firstly, determining the limits of values via the scatter diagram is arbitrary. Secondly, some analyses outside the defined ranges of metal groups are regarded as deviants and left unexplained. Actually, these analyses may enclose important messages for the questions of metal usage.

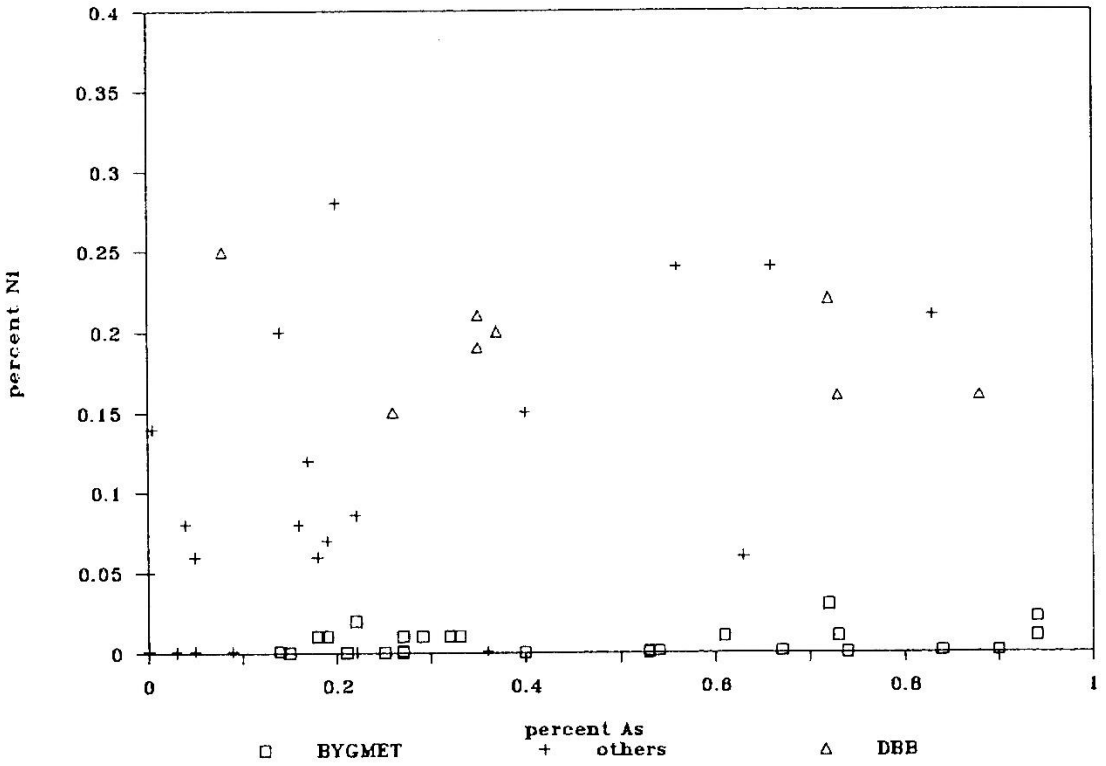


Figure 2.3 Scatter chart of Danish flat axes with As< 1% and Ni< 0.4%. Each legend represents a particular type of axes from a cluster with similar As/Ni concentrations. From Liversage & Liversage (1989: 59, graph 6).

Later on Liversage (1994) investigated the Early Bronze Age copper-alloy artefacts from the Carpathian Basin. Detailed radiocarbon dates in this region allow him to observe the usages of metal groups chronologically, which gives a good example for the study of metallurgical structures in prehistoric societies. He generated abundant histogram diagrams to demonstrate how the distribution of particular elements can give us some hidden information. For instance, the tin content in early Carpathian copper-based objects shows a bimodal pattern with one peak at around 10% and the other at trace level, which means that no mixture of tin occurred in the initial use of tin-bronzes (Figure 2.4). Tin was a rather sparse metal, and therefore, the addition of tin was restricted to the full bronze objects and other metal objects were left unalloyed.

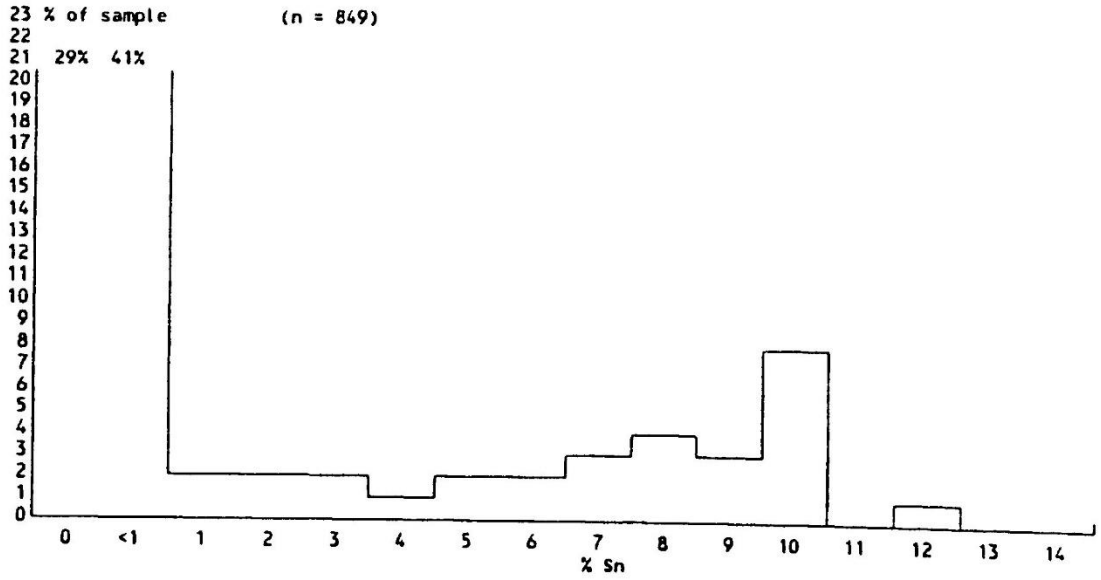


Figure 2.4 Histogram of tin concentration on Carpathian bronzes during the Early Bronze Age. From Liversage (1994: 75, fig. 1)

2.1.2 Metal provenance through isotopic analysis

One of the most serious drawbacks in the early metallurgical studies lies in the uncertainty to relate trace element data to ore chemistry. Pyrometallurgical processes (e.g., smelting, refining, casting and annealing) to transform ores into metal artefacts could potentially alter the original chemical signatures of raw material, making the metal provenance extremely difficult or even invalid (see Section 2.2). This challenge is potentially circumvented by the application of lead isotopy to copper and copper alloys (Gale & Stos-Gale 1982; Branigan 1982; Pernicka *et al.* 1984). This is not the place to explain the principles of lead isotopy as it has been done elsewhere (Pollard and Heron 2008, Ch. 8). The advantage of using lead isotopes over trace elements for

metal provenance is that lead isotopic composition would remain constant (or the change is smaller than the measurement errors) even after anthropological processing of metals or metal artefacts (Gale & Stos-Gale 2000). With this major breakthrough, many archaeometallurgists have turned to collecting and generating isotopic data of ore deposits and metal artefacts to draw a linear relationship between raw material and finished products (Gale and Stos-Gale 1992; Hauptmann *et al.* 1992; Yener *et al.* 1991; Pernicka *et al.* 1993). Provenance determination through isotope analysis has become one of the most dominant disciplines of archaeological science.

However, one critical problem of lead isotope analysis is marked by the overlapping of isotopic signatures of ore deposits (there are other limitations, see Section 2.1.3). In geology, lead isotopy is used to determine the geological age for the orebody. Ore deposits formed practically at the same time in the same manner and in the same host rock would tend to have quite similar isotopic composition on formation. In order to safely attribute metal artefacts to a particular ore source, one should expect that source to have a unique lead isotope composition. However, it is not always the case. For instance, isotopic ratios of copper ores and slags around the regions of Southwest Asia demonstrate a considerable degree of overlap, making it impossible to securely assign the provenance of a Mesopotamian metal object to a specific ore field (Pernicka 2014, also see Figure 2.5).

To overcome this potential overlapping issue, Pernicka *et al.* (1997) proposed to combine both trace element concentrations and lead isotope values to differentiate one source from another. They classify copper objects from prehistoric Bulgaria into nine chemical clusters by trace elements and eleven grouplets by isotope ratios, which are used to match with known local copper ore deposits (Figure 2.6). Although two ancient copper mines for producing Bulgarian copper contain partly overlapping isotopic compositions, trace element pattern is able to tell them apart (Figure 2.7). Srinivasan (1999) also applied this synthetic method to the examination of Indian metal coins. Even though this practice seems to circumvent the overlapping problem, there are still many limitations, either geological or man-made factors, which make the successful metal provenance an exception rather than a rule.

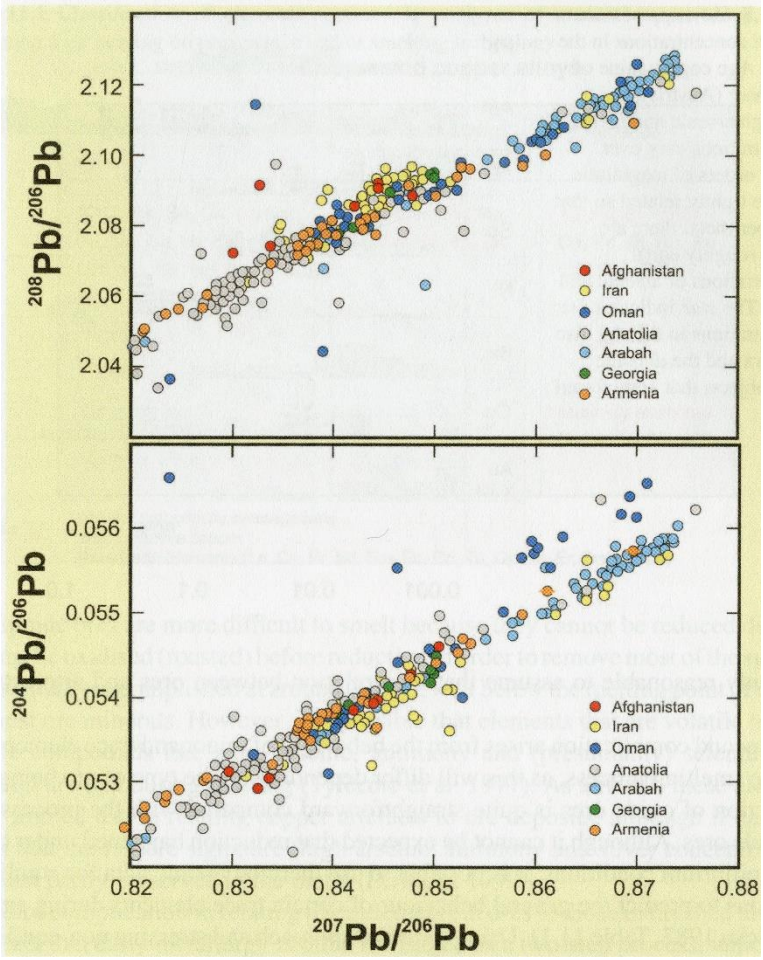


Figure 2.5 Distribution of lead isotope values in copper ores, slag and native copper from the Near East. This diagram shows a serious overlap between different source regions. From Pernicka (2014:250, fig. 11.4).

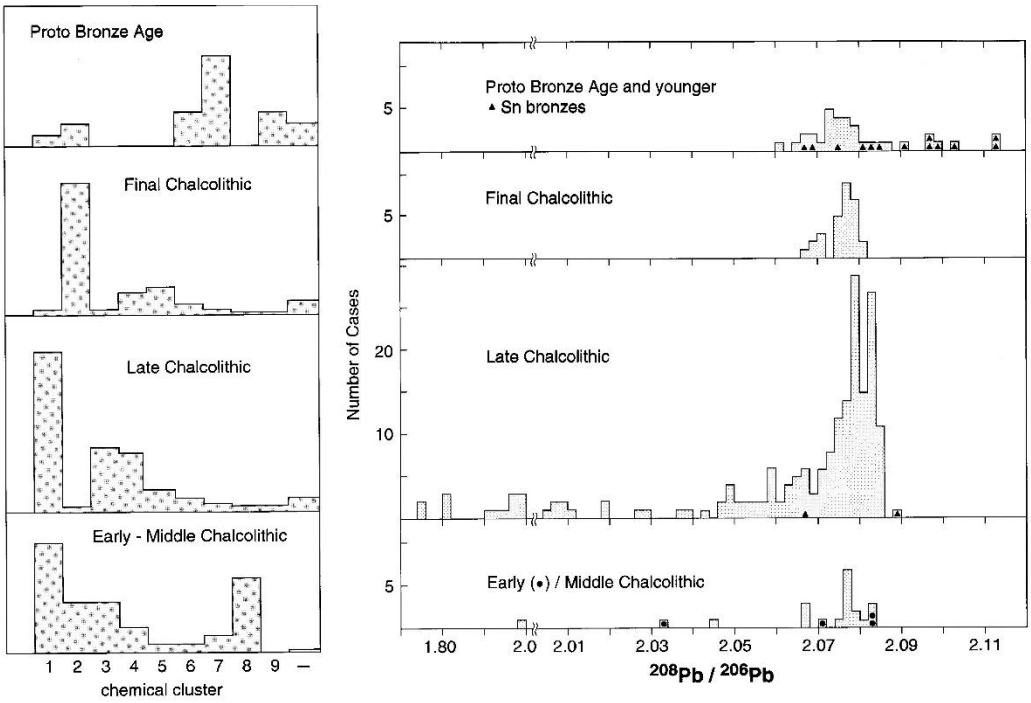


Figure 2.6 Chemical groups (left) and isotopic groups (right) of prehistoric Bulgarian copper-based objects. From Pernicka (1997, fig. 24 & 25).

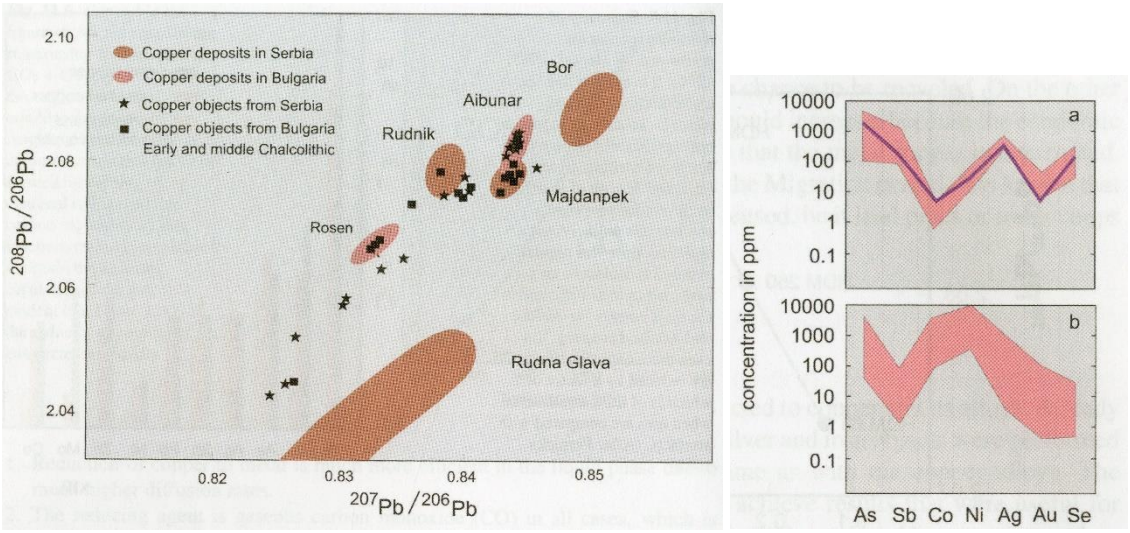


Figure 2.7 Lead isotope ratios showing an overlap between Ai Bunar and Majdanpek mines (left), but trace element patterns of copper objects assigned to these two mines are different (right). The solid line represents the trace element pattern of Ai Bunar mine which fits nicely with artefact chemistry. From Pernicka (2014: 256-57, fig. 11.8 & 11.9).

2.1.3 Potential problems of the provenance approach: geology, thermodynamics and human engagement

Metal provenance, no matter what chemical "fingerprints" are used (trace elements, lead isotopy or both), appears quite problematic if we take both ore geochemistry and human engagement with metals into account. Firstly, the nature of ore formation makes the provenance quest unpredictable. Ixer (1999) argues that the majority of ore deposits vary in chemistry and mineralogy due to uneven spatial and temporal distributions. An orebody usually comprises different zones, which yield ores with distinctive chemical signatures even if these ores spring from the same source. Moreover, mineralisation of ore deposits have generally undergone multiple geological events taking place at different times. There may be some cases where one metal mineralisation of an earlier age is superimposed upon another metal mineralisation of a younger age. In such a case, one orebody can contain at least two sets of ore with different composition. In order to succeed in provenance research, one requires as many ore samples as possible to understand the biography of ore deposits. Then, one can define ore fields as references to compare with isotopic ratios of metal objects. Unfortunately, such data is always insufficient in archaeological-related mines.

Ixer also points out that modern human mining activities can potentially exacerbate the hope for the provenance as ancient working events may dramatically alter the original signals of ores. Some mining constructions such as drives, shafts, and stopes provide passages for the flow of groundwater. When groundwater contacts with pyrite or other

iron sulphides, it becomes acid and can change the composition of mineral by either removing metals from minerals or reprecipitating metals from minerals to produce a new mineralisation with different composition. Therefore, the ore samples we select today are not the same as the ores used by ancient miners as a consequence of these hydrological processes.

Furthermore, previous data interpretations assume the normality of lead isotope ratios, and therefore the values that did not conform to expected ranges were dismissed as outliers (Pollard and Heron 2008, Ch.8). However, it is now generally accepted that lead isotopic values of ore samples are not normally distributed (Baxter and Gale 1998; Scaife *et al.* 1999). Some anomalies that were previously regarded as measurement errors may be a genuine reflection of chemical variations in individual ore deposits.

In addition to uncertainty derived from inhomogeneity of ore deposits, Budd *et al.* (1996) assert that chemical composition of metal objects does not remain constant throughout the usage of their lifetime. Given that metallic ores are generally unevenly distributed and some types of ore deposits (e.g. tin and gold) are limited to certain geographical locations, one would expect that ancient metalworkers may recycle or mix metals from different geological sources. These human engagements with metals and metal artefacts could potentially eliminate the original chemical signatures of ore sources, making metal provenance unattainable. Though the provenance approach is potentially valid in certain circumstances, the idea that this is the only, or even the dominant relationship, risks completely overwriting the complexity of prehistoric relationships with metals, leading to potential misinterpretations of the data. The investigations of varied chemical compositions, altered by the refining, casting, alloying, recycling and mixing, have only received limited attention by the greater archaeological community.

This oversight of potential chemical change in metal recycling and mixing is probably due to unfamiliarity with thermodynamic behaviours of elements in copper-alloy systems (Sabatini 2016). Even though archaeometallurgists are aware of the works undertaken by experimental archaeologists and modern foundries (Mckerrell & Tylecote 1972; Beeley 2001, also see Section 2.2), it is difficult to address the issues of re-using metals by the traditional method. As a result, those who advocate metal provenance tend to assume that there was no metal recycling or that recycling only

played an insignificant role in antiquity. Before going further to explore whether recycling occurred in prehistoric societies, it is essential to know how elements behave in the copper melt.

2.2 Behaviours of elements observed by experimental archaeology

Ancient pyrometallurgy generally involves two major activities that bring forth chemical alteration through high-temperature thermodynamic reactions. One is copper smelting, a procedure to remove impurities from copper ores in order to convert copper with oxidation states +1 or +2 into its pure state in a reducing reaction. The other is elemental changes resulting from subsequent metal casting and working practices. Since this thesis focuses on recycling and metal flow, chemical changes that are the result of primary copper smelting will not be discussed (see Friedman *et al.* 1966; Lorenzen 1966; Tylecote 1977 *et al.*; Craddock & Meeks 1987; Hauptmann *et al.* 1992 for the detail). Instead, I will highlight chemical changes that occur in copper-melting experiments and their underlying thermodynamic reasoning.

Metal losses are achieved by volatilisation and oxidation. Metallic elements can be removed as pure substances, volatile oxides or non-volatile oxides as dross. A useful tool to determine the ease of reduction of metal oxides and sulphides is based on the calculated Gibbs free energy of formation (y-axis) in given temperature (x-axis) at equilibrium (Figure 2.8). The more negative the free energy is, the stronger the affinity between the metal and oxide (or sulphide). According to this diagram, we are able to predict a sequence of oxidative loss by element. For example, with the presence of oxygen in a copper-tin alloy melt, one would expect the tendency for the formation of SnO_2 before the oxidation of copper due to higher negative Gibbs free energy.

Experimental archaeometallurgy has improved our understanding of the behaviours of elements during copper melting and casting. One of the most influential projects was carried out by Mckerrel and Tylecote (1972) who investigated losses of arsenic and antimony in copper alloys through re-melting and hot-working. Their experiments clearly demonstrated appreciable losses of arsenic and antimony under oxidising working conditions (Figure 2.9). In particular, they also show that arsenic is not lost under non-oxidising conditions but is readily lost in the presence of oxygen (Figure 2.10). They concluded that the depletion of arsenic is due to the formation of arsenic trioxide rather than the volatilisation of elemental arsenic.

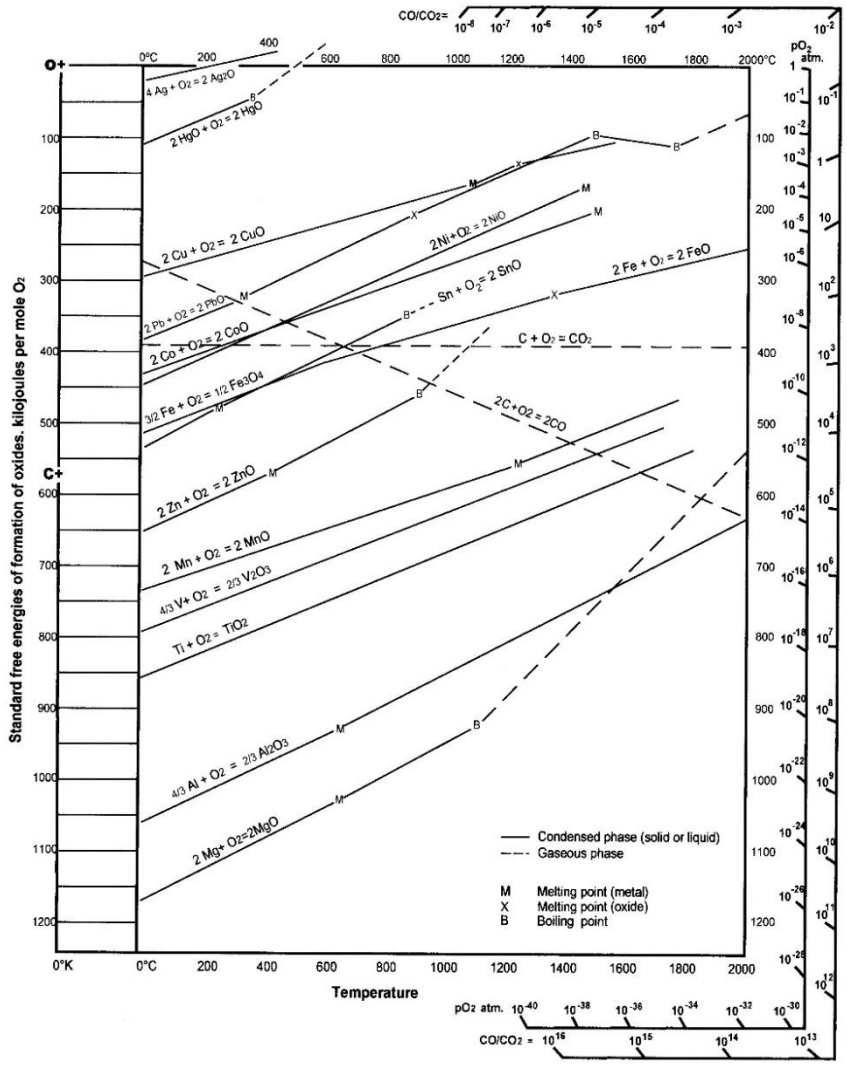
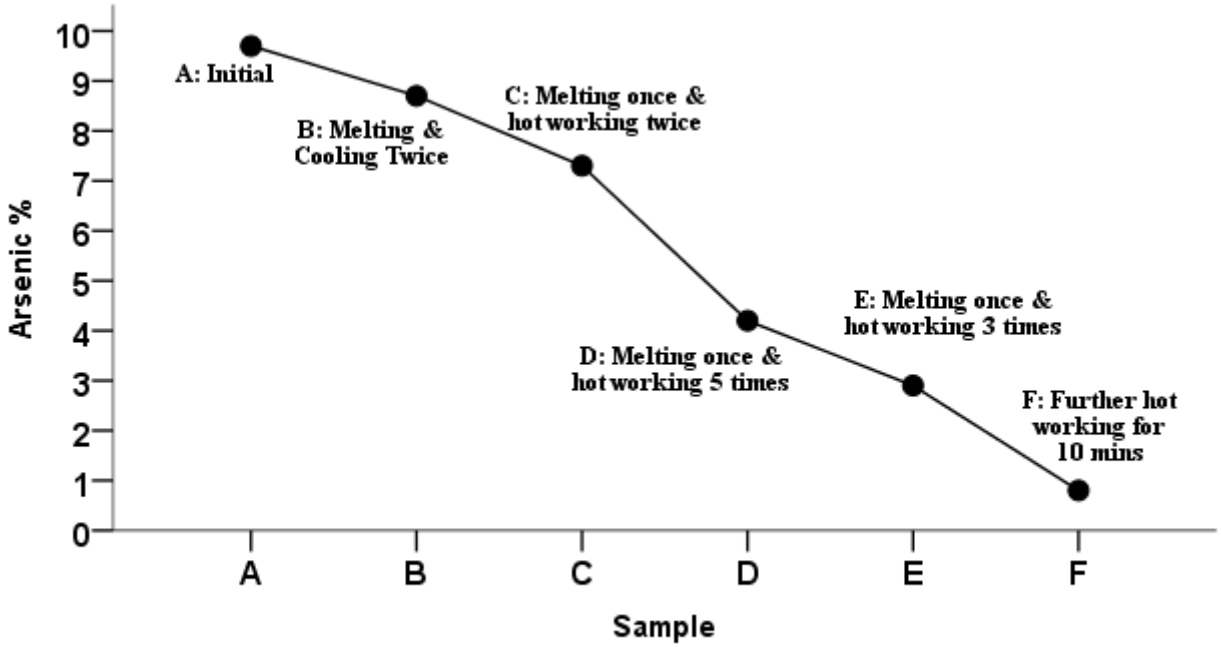


Figure 2.8 The Ellingham diagram of selected metals and oxides. From Killick (2014, p. 30, fig. 2.3).



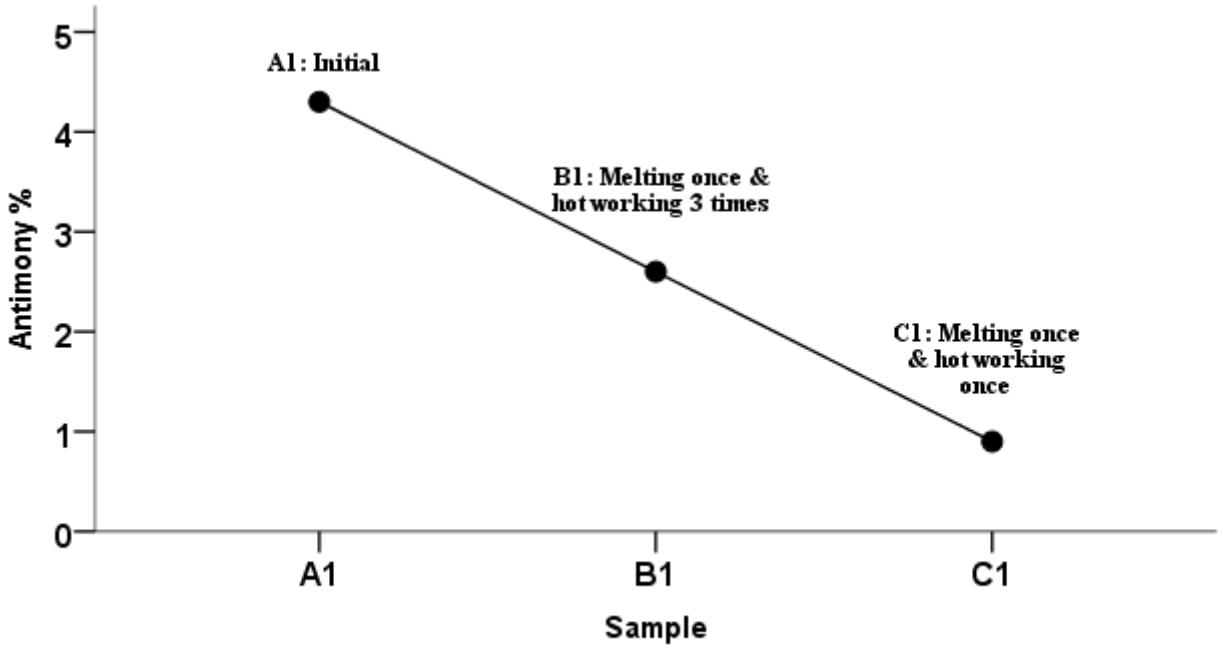


Figure 2.9 Loss of arsenic and antimony under the oxidising working conditions. Data from McKerrell & Tylecote (1972).

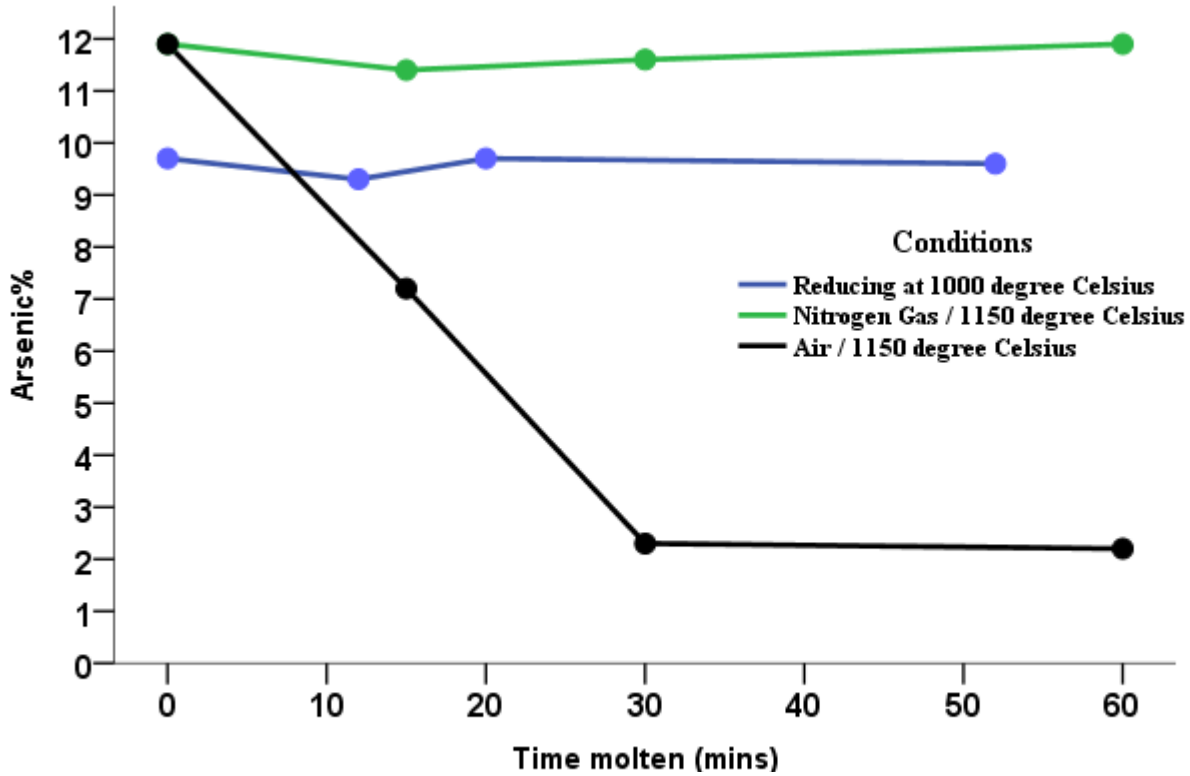


Figure 2.10 Changes in arsenic content under different conditions. There is practically no change for the reducing atmosphere and the presence of nitrogen gas. Losses occur in the presence of oxygen. Data from McKerrell & Tylecote (1972).

Their findings are in agreement with the calculated activity of copper-arsenic alloy systems developed by Sabatini (2016), despite their incorrect attribution of losses to

arsenic trioxide (see Section 2.3). Similar outcomes of arsenic losses are documented in Tylecote *et al.* (1977) and Park & Gelegdorj (2015).

Equally important experimental work was performed by John Merkel (Merkel 1983; 1990), and summarized by Pernicka (1999; 2004) to reconstruct and simulate ancient copper smelting and refining technologies of furnaces excavated at Timna, southern Israel. Merkel conducted a series of melting experiments on smelted copper (Figure 2.11), and his results demonstrated that simple fire-refining can lead to great losses of iron and sulphur under reducing condition (use of charcoal as fuel). The loss of iron during copper refining is also noted by a recent experiment (Park & Gelegdorj 2015). Other elements (e.g. arsenic, silver, antimony, nickel, and lead) start to be lost when air blasts are intentionally blown over molten copper. However, the losses are insignificant due to low concentrations of impurities at the initial charges. It is better to begin with high concentrations (ideally several percent) in order to observe more apparent changes.

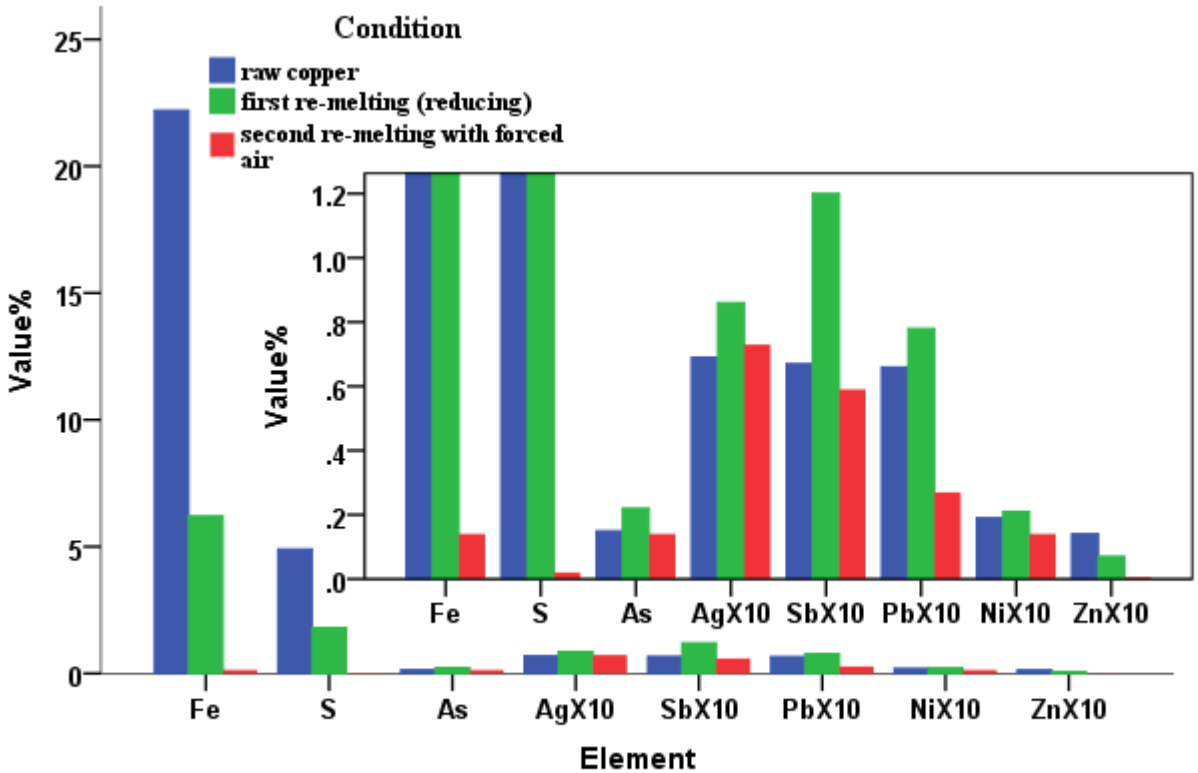


Figure 2.11 Results of re-melting experiments undertaken by Merkel (1983). They demonstrate that Fe and S drop dramatically after the first melt under a reducing condition.

Tin could be potentially lost during the recycling of tin-bronze under an oxidising atmosphere. Godfrey (1996) undertook melting experiments of three copper-tin alloys all starting with around 10% tin. Each specimen was placed in an uncovered clay-

graphite crucible in an electric muffle furnace, running at three different temperatures at 1100°C, 1200°C and 1300°C. This procedure was repeated eight times every 15 minutes. The results are shown in Figure 2.12.

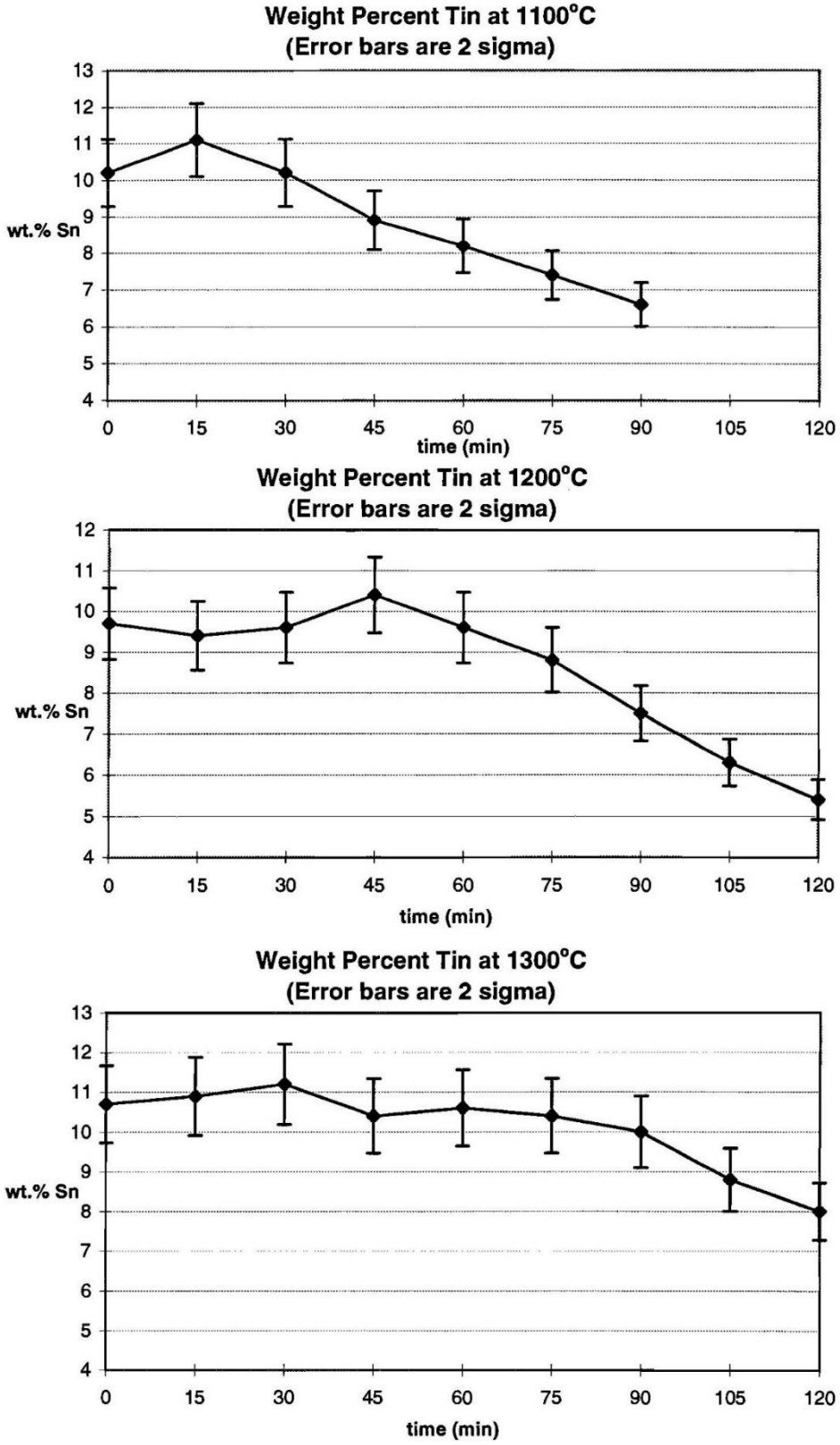


Figure 2.12 Tin losses under different melting temperatures over time. From Godfrey (1996:48 fig. 3.5).

Samples at 1100°C show a steady loss of tin throughout the whole operation, followed by the loss of tin at 1200°C after 60 mins, and a considerable delay of tin loss in the samples melted at 1300°C. Godfrey (1996: 49) argues that the efficiency of the release of carbon from the crucible increases as temperature goes up. Therefore, at 1100°C, it is inefficient to produce CO_2 to react with carbon to generate carbon monoxide. The system is oxidising and evaporation of tin is greater than copper. At 1200°C, the crucible burns off and releases carbon to create reducing conditions, followed by oxidation after 60 mins. At 1300°C, the reducing atmosphere lasts even longer and oxidation does not take place until 90 mins.

Godfrey's findings suggest that tin will not be lost by any significant amount under the reducing condition, but it is readily lost under the oxidation. This outcome can be further confirmed by Ottaway & Wang (2005) who utilise the charcoal as fuel sources to maintain tin concentrations in the re-melting of the copper alloys.

The rapid loss of zinc as either pure species or oxides due to its high vapour pressure is also recognised in both archaeological literature and melting experiments (Pollard and Heron 2008, Ch.6). The decrease in zinc concentrations in metal artefacts during recycling is unavoidable unless the calamine process is employed.

Despite the usefulness of archaeometallurgical experiments, most of them do not articulate why and how elements behave. This oversight is probably due to the unfamiliarity in archaeology with the thermodynamic principles that govern the elemental changes. This results in the misuse of certain thermodynamic tools and ideas to predict the chemical results of ancient metallurgical practices. For example, as Sabatini (2016: 31) points out, the Ellingham diagram is calculated solely based on the oxidation of pure metals with oxygen, and it may not adequately account for the majority of ancient copper-alloy objects that contain more than one additional element/component. Thus, it is necessary to recalculate the Gibbs free energy of formation based on the measure of activity of all present solutes in order to obtain a realistic order of oxidation and likelihood of element loss. This work has been recently introduced to archaeometallugy by Sabatini who estimates thermodynamic behaviours of metallic elements in various copper-alloy systems.

2.3 Thermodynamic modelling of the recycling of ancient metal

2.3.1 Background

Sabatini (2016: 10) notes that the study of the thermodynamic properties of copper-based alloys has been commonly undertaken in modern metal industry to produce well-controlled compositions and the refining of scrap metal. In contrast, such research has been overlooked by the archaeological community, which has led to the misinterpretation of chemical data on ancient copper alloys. Despite the applications of thermodynamics to the production of ancient high-zinc brass (e.g. Caley 1964; Dungworth 1995; Bougarit & Bauchau 2010), the chemical behaviours of many archaeological metals with varied amounts of different elements remain unclear to those who wish to make sense of their chemical composition. To fill this significant knowledge gap between thermodynamic theory and real-world archaeological observations, he built predictive models for the likelihood of metal losses over the course of ancient pyrometallurgical recycling through the oxidation and volatilisation of each element. This method is grounded in established thermodynamic theories and methods, and supported by empirical data from modern refining and experimental techniques under controlled parameters. He uses the concept of the activity, the activity coefficient, and vapour pressure to predict the probability of metal losses from copper-alloy mixtures (see Sabatini 2016 for more details).

2.3.2 Thermodynamic behaviours of the copper binary system

A concrete example of thermodynamics applied to ancient metal composition is the binary Cu-As system. Under approximately 11% arsenic, the likelihood of arsenic losses as a pure element is low because there is a very strong bond between copper and arsenic in the melt, especially under reducing conditions and in the closed crucible (Sabatini 2016: 73). Beyond this critical point in composition, arsenic will tend to show significant losses. Furthermore, the loss of arsenic can also result from the evaporation of volatile oxides. As has already been discussed, Mckerrel and Tylecote (1972) documented the decrease in arsenic from Cu-As alloy, provided with a constant air flow of oxygen when melted. Sabatini (2016) gives a more sophisticated explanation on why it occurs. At above 700°C, arsenic will sublime to form the dimer (As_2). According to the Gibbs free energy of formation, arsenic will be preferentially oxidised compared with copper. Arsenic oxide (AsO) has far greater vapour pressure than as its pure state. The evaporation of arsenic oxide accounts for the diminishing arsenic in the

observations, and not arsenic trioxide as has been commonly suggested. Similar to arsenic, antimony in the Cu-Sb binary system demonstrate the similar behaviour of metal losses due to the formation of volatile oxides in at least partially oxidizing conditions (Sabatini 2016:93).

Nickel, on the other hand, has relatively low vapour pressure compared to arsenic and antimony, and thus the loss of nickel through volatilization is very unlikely (Sabatini 2016:95). Under an oxidising atmosphere, nickel can form oxides as NiO and to be removed as the dross. However, the presence of arsenic or antimony would readily reduce nickel oxide, due to a relatively positive Gibbs free energy of nickel.

Silver, as one of the noble elements, forms unstable oxides at copper melting temperatures according to the Ellingham Diagram. Therefore, it is easily reduced to pure metal at high temperatures and is not lost as an oxide. The vapour pressure of silver is relatively low, which further prohibits the possible loss in ancient copper recycling and re-melting (Sabatini 2016: 97).

Zinc has by far the highest vapour pressure compared with other commonly seen elements in archaeological copper-based alloys. It is also readily oxidised as ZnO with a vapour pressure roughly ten times of the pure metal (Sabatini 2016:94). Therefore, the loss of zinc is inevitable in an open system, which has been demonstrated by various experiments (Merkel 1983; Pernicka 2004).

The removal of lead in the copper-lead alloy is expected due to the repulsive forces between lead and copper ions. Furthermore, lead has a greater vapour pressure and more negative Gibbs free energy than copper, it will be readily lost as the pure gas monomer or partially as lead monoxide (Sabatini 2016:95).

Tin in low concentrations is unlikely to be lost in the copper melt under reducing conditions. However, it is readily removed in an oxidizing atmosphere in two ways: One is the formation of SnO_2, which might be trapped into the slags; and the other is by the oxidative evaporation of SnO that is reduced by carbon from SnO_2 (Sabatini 2016: 95).

In sum, Sabatini's research provides thermodynamic explanations of why and how elemental changes occur in the above experiments. Most importantly, he concludes elements that are useful to interpret ancient metal recycling and mixing. Arsenic,

antimony, tin, and lead would potentially be lost during pyrometallurgical processes, while nickel and silver are likely to be retained. Experimental results, combined with Sabatini's thermodynamic interpretations, establish the framework to model the changing chemistry of copper-based artefacts due to re-melting/recycling.

2.4 A new interpretive approach to trace the metal flow

2.4.1 Theoretical background

As noted above, the changing nature of chemical composition in the copper alloy can potentially undermine the premises of the conventional provenance approach. This causes a problem to justify the unambiguous use of trace elements and lead isotopy for sourcing given that metal recycling and mixing are expected in the extensive trading network across the Bronze Age of Eurasia. However, if we shift our focus from the simple provenance question (such as *from which ore deposit does this metal object originate*?) to a more sophisticated one asking how ancient people actually used metal, these potential metal losses during the recycling can provide us a new way to investigate ancient metallurgy. Accordingly, Bray and Pollard (2012) propose an alternative paradigm focusing on the life history of the metal from which the objects are made. This is the key to understand how ancient societies engaged in metal production and circulation. Bray, Pollard and their colleagues at the University of Oxford have published a series of papers to contextualise this new idea in conjunction with new analytical tools to explain the potential change in artefact chemistry (Pollard *et al.* 2014; Pollard & Bray 2014; Bray *et al.* 2015; Pollard *et al.* 2015; Perucchetti *et al.* 2015; Cuéond *et al.* 2015; Hsu *et al.* 2016). First of all, these authors compare the flow of metal through human communities to that of a river fed by its tributaries (Bray *et al.* 2015:203). The exploitation of metallic ores is analogous to the origin of water. When objects made from those ores travel through different societies, their chemical signatures may be altered by re-casting, re-working, re-alloying with other inflows of metal from different sources, similar to the tributary streams of a river that would be changed by chemical properties of different water sources. As distances from individual objects' "birthplaces" increase, their composition would bear the characteristics of metal from different origins, which allows us to identify the circulation of metal artefacts as a proxy for both technological and social contexts (traded, looted, exchanged, gifted, etc.). They note that the flow of copper objects could be potentially made up of all accessible copper (either from ores or scrap metals) at a

particular time and place. The consumers are generally unaware of the origins of the metal; they mainly participate in metal trade in a local or long-distance contact. This is why metal provenance has little archaeological meaning, but the flow of metal directly reflects the actual human participation in metal exchange.

Bray *et al.* (2015: 203) also emphasise three intrinsic "attributes" of metal artefacts that can facilitate us to disentangle the dynamics of ancient metallurgy: trace element or isotopic composition, alloy composition, and form. The first two parameters can objectively reflect the metallurgical choices made by ancient metalworkers, and the final factor is determined by object typology shaped by social/cultural preferences.

These three attributes together can explain the two major modes of metal flow (Bray *et al.* 2015:204). One is the linear relationship between a particular artefact being made from a specific metal source. The typology of the object is fixed to serve certain ritual or social purposes. Some prestigious items might have been treated in this way. Their peculiarity ensures that they were not re-cast or recycled. Thus, their trace elements or lead isotopic ratios are comparable to those of the original smelted copper. In such a linear scenario, the conventional provenance study could nicely connect object chemistry with ore chemistry.

The other form of metal flow takes a long, complex, and branching trajectory (Bray 2009; Bray & Pollard 2012; Bray *et al.* 2015:204). It is likely to have been the more common process of the metal circulation in ancient times, since exploitable metallic resources (especially for tin) were spatially uneven distributed. Objects, made from a unit of copper, can be transferred to a new metal-producing community in the form of ingots or scrap metal. In the new hands, they are re-cast, re-worked, or re-alloyed into fresh items, with different forms or shapes, according to personal or social tastes. This sequence might repeat itself for years or centuries, until the objects were buried and re-discovered by archaeologists. This dynamic flow of metal suggests that it is better to understand the life histories of objects rather than to search for potential ore sources, which is somewhat unrelated to the human society as the whole (Bray *et al.* 2015: 205).

2.4.2 Analytical tools

To put these ideas into action, a series of interpretive tools has been developed to better discern the pattern of chemical changes in copper-alloy artefacts (Bray 2009, Bray & Pollard 2012, Bray *et al.* 2015). Drawing from experimental outcomes and

thermodynamic modelling, they recognise that some relatively vulnerable trace elements in copper-alloy artefacts (e.g. zinc [Zn], arsenic [As], antimony [Sb], and iron [Fe]) at high temperatures are more preferentially 'lost' through oxidation and volatilization by comparison with other elements (e.g. gold, silver, and nickel). Although these relative changes in chemical composition over the lifetime of a unit of copper have often been presented as a challenge to provenance studies, Bray *et al.* (2015) turn this completely around by using these shifts as invaluable signs of the different aspects of objects' life – casting, re-melting, mixing, and curation. The final composition of ancient copper-based artefacts is a palimpsest of factors, including of course the initial ore structure but also including aspects of past people's technological choices.

(1) Trace elements and copper groups

In practice, a small group of four trace elements (As, Sb, Ag, and Ni) is selected as key indicators that can be used to assign analysed objects to different copper groups. These four elements are commonly reported in archaeological literature and they also show recognisable traits under high-temperature melting (As and Sb decrease; Ag and Ni are relatively stable). The next step is to estimate the concentration in elements that are present in the copper before it is deliberately alloyed with tin, lead, or zinc. It is achieved by using the following formula:

$$\%\ \text{of element estimated} = 100 \times \frac{\%\ \text{of element}_{\text{measured}}}{\text{analytical total} - \%\ \text{of alloying elements}_{(Sn+Pb+Zn)}}$$

Within this mathematical calculation lies the assumption that these trace elements come from the copper itself rather than the alloying components (principally tin, lead and zinc). Nevertheless, this assumption is not always true, especially when the deliberate addition of lead may result in elevated silver content in objects. One should be particularly cautious about dealing with highly leaded artefacts.

The modified data is then classified into sixteen copper groups based on presence/absence (Y/N) of trace elements (Table 2.1). The cut-off value for presence or absence is a pragmatic balance of factors, including the limit of detection (LoD) of the analytical instruments (for detailed comparison of LoD, see Pollard *et al.* 2007: 61,

Fig. 3.4). In this study, I deliberately adopt the threshold of 0.1 wt% because the chemical data is analysed by a variety of analytical methods.

Table 2.1 Copper groups defined by the presence or absence of arsenic, antimony, silver and nickel.

16 copper groups based on the presence/absence of element							
CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8
pure	As	As/Sb	Ag	Ni	As/Sb	Sb/Ag	Ag/Ni
NNNN	YNNN	NYNN	NNYN	NNNY	YYNN	NYYN	NNYY
CG9	CG10	CG11	CG12	CG13	CG14	CG15	CG16
As/Ag	Sb/Ni	As/Ni	As/Sb/Ag	Sb/Ag/Ni	As/Sb/Ni	As/Ag/Ni	As/Sb/Ag/Ni
YNYN	NYNY	YNNY	YYYN	NYYY	YYNY	YNYY	YYYY
Sequence: As Sb Ag Ni N when element ≤ 0.1%; Y when element >0.1%							

These 16 copper categories, derived from presence or absence of key elements, are simply an organising step that allows us to see the combination of elements present in the metal objects. The precise level of the diagnostic elements will be altered by three processes: oxidative loss and volatilisation; mixing of copper from different sources, and deliberate alloying. Therefore, each copper group is not seen as relating to one source, and over the course of "lifetime", a unit of metal may pass between different groups. The stepwise process of assigning a broad universal group, then examining the distribution and average level of key elements allows us to untangle the life-histories of objects. Bray *et al.* (2015) argue that a one-stage clustering statistical approach, which is admittedly current standard practice, is wholly inappropriate for disentangling the range of factors that create the final composition. Chemical composition is not a static concept, and it may be altered by oxidative loss, a consequence of casting, alloying, refining, and recycling.

This trace-element grouping developed by Bray *et al.* (2015) is particularly effective to identify possible movement of copper-based metals in a well-studied archaeological context with good object typology and chronology. Compositional data can be examined through the ubiquity distribution (percentage of the assemblage composed of that particular copper group) to characterise the copper/bronze production within or between regions/cultures. In general, the further away from the source of particular copper group the objects are, the more likely they are produced from recycling or

mixing of other metal stocks. If the ubiquity of copper group 2 (arsenic-only) among the metal assemblage from the region A is 90%, it is probably close to the source of this specific metal production. Another region B, having only 50% of CG2 among its metal assemblage, may receive metals from the region A if A and B are culturally or geographically related. As a result, the ubiquity percentage indicates the directional flow of metal from A to B.

This hypothetical scenario can be seen in the metal trade during the Early Bronze Age of European and Western Asia (Figure 2.13). By using ubiquity analysis, Bray *et al.* (2015: 206) note that the metal marked by CG2 travelled from the Iberia to France and Britain along the Atlantic coast, and meanwhile, another possible source coming from Anatolia to the Balkans.

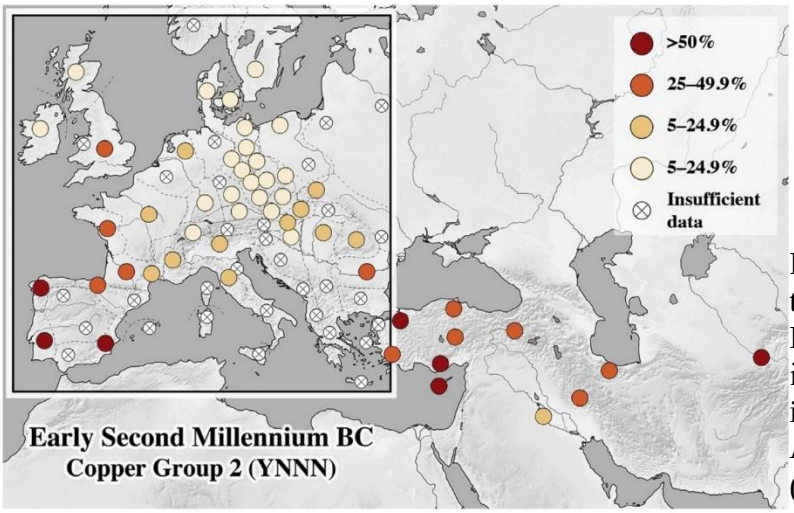


Figure 2.13 Map showing the distribution of CG2 in Europe and the Near East. It is marked by the "hotspots" in Iberian Peninsula and Anatolia. From Bray *et al.* (2015: 206, fig. 2).

(2) Alloying compositions

Another new tool is devised to redefine the concept of the copper alloy. Traditionally, alloying elements (Sn, Pb, Zn, and in some cases As and Sb) are considered as the deliberated additions in copper when the resulting compositions benefit the physical properties of copper alloys. However, Pollard *et al.* (2015) contend that it is inappropriate to impose the assumption that all ancient metalworkers acknowledged the mechanical effects brought by alloying, and subsequently copper alloys in antiquity were all intentionally designed. Instead, it is better to impartially evaluate composition of copper alloys by admitting the possible practices of recycling and mixing. Bray *et al.* (2015) propose the use of presence/absence of alloying elements to demonstrate the mixing nature of the copper-alloy assemblage. By setting the threshold of presence at 1% (for Sn, Pb, and Zn), we can derive an eight-fold classification for copper-alloy

systems: copper, leaded copper, bronze, leaded bronze, brass, leaded brass, gunmetal, and leaded gunmetal (Table 2.2). Although this cut-off value is much lower than the definition of the modern standard of copper alloys, the new classification method has the advantage of identifying the simultaneous presence of several alloying components at low levels (Pollard *et al.* 2015: 699).

Table 2.2 Alloy groups defined by the presence or absence of tin, lead and zinc.

Alloy groups based on the presence/absence of Sn, Pb and Zn			
Cu	Cu+Sn	Cu+Sn+Pb	Cu+Pb
Pure	Tin-bronze	Leaded tin-bronze	Leaded copper
	Sn>1%	Sn>1%; Pb>1%	Pb>1%
Cu+Zn	Cu+Sn+Zn	Cu+Pb+Zn	Cu+Sn+Pb+Zn
Brass	Gunmetal	Leaded brass	Leaded gunmetal
Zn>1%	Sn>1%; Zn>1%	Pb>1%; Zn>1%	Sn>1%; Pb>1%; Zn>1%

Using these new alloying categories, the recycling and mixing of ancient copper alloys can be visualised through both ubiquity analysis and the pattern of alloying element distribution. The ubiquity analysis of the copper alloy is similar to that of copper groups by trace elements. If a high proportion of the metal assemblage contain multiple alloying elements, it may suggest that this alloy type is the result of mixing from more than one copper alloy (Bray *et al.* 2015: 206). Pollard *et al.* (2015) apply this new alloying concept to characterising copper-alloy artefacts in Britain in the first millennium AD. By plotting the ubiquity of the alloy types against the chronologies (Figure 2.14), one may observe that in Britain a new injection of brass (Cu-Zn) was brought by the Romans by the first century AD (as suggested by Caley 1964) and this metal stock was mixed with tin-bronze (Cu-Sn) to become the gunmetal (Cu-Sn-Zn) in the second century AD. During the Anglo-Saxon period, there was a further mixing and recycling of bronze and leaded bronze to create the leaded gunmetal. This conclusion can be attested by the decreasing zinc levels over different alloy types due to the recycling and mixing (Figure 2.15).

In addition to the ubiquity of alloy types, it is also useful to investigate the distribution pattern of alloying element concentrations among the metal assemblage. In theory, a stock of primary or designed copper alloys tend to demonstrate an approximately normal distribution of an alloying element (Bray *et al.* 2015: 207). In a graphic

representation, we may identify a diagnostic peak centred on a range of high concentrations (Figure 2.16, left). On the contrary, a metal stock made from recycling/mixing copper alloys is more likely to concentrate at the low levels of alloying composition, leading to a decreasing line with a tail towards higher values (Figure 2.16, right). This primary and recycling trajectories of ancient copper alloys are well attested by a case study on the bronze metalwork in the Near East (Cuénod *et al.* 2015). A primary tin signal is clearly shown by the Luristan bronzes focusing on around 10% tin, while metal artefacts from ancient Mesopotamia present the declining pattern of tin level probably due to recycling and mixing (Figure 2.17).

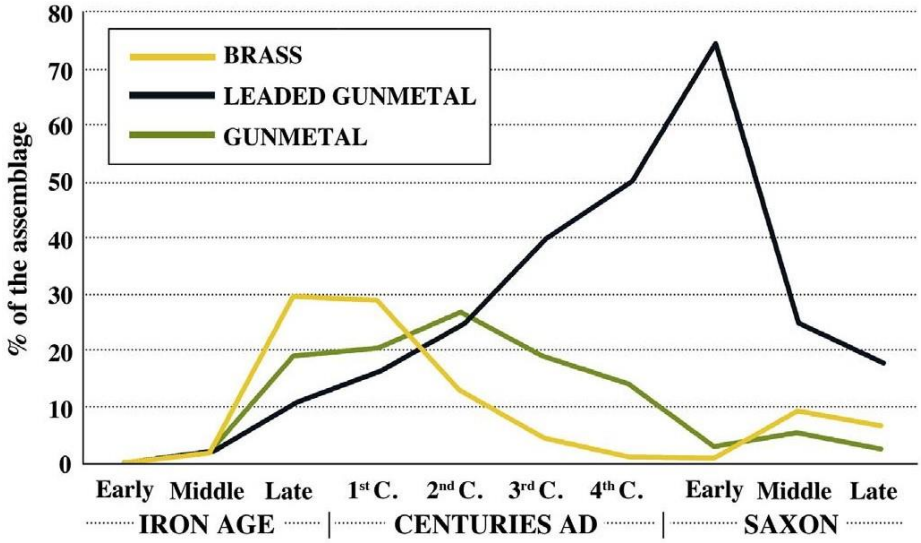


Figure 2.14 Distribution of alloy types in Britain over time. From Bray *et al.* (2015: 206, fig. 3).

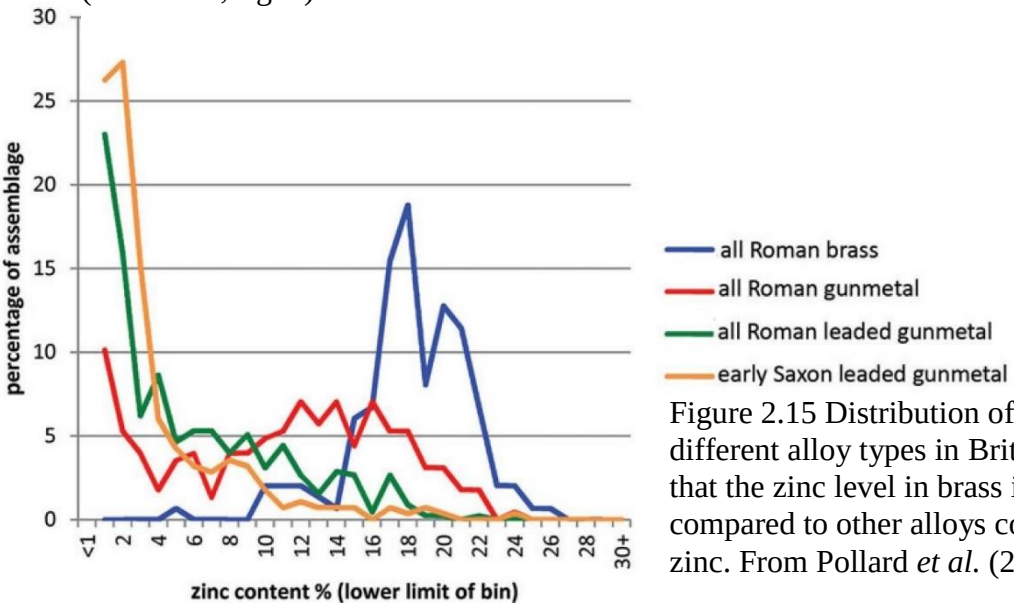


Figure 2.15 Distribution of zinc content over different alloy types in Britain. It demonstrates that the zinc level in brass is the highest compared to other alloys containing diluted zinc. From Pollard *et al.* (2015: 705, fig. 4).

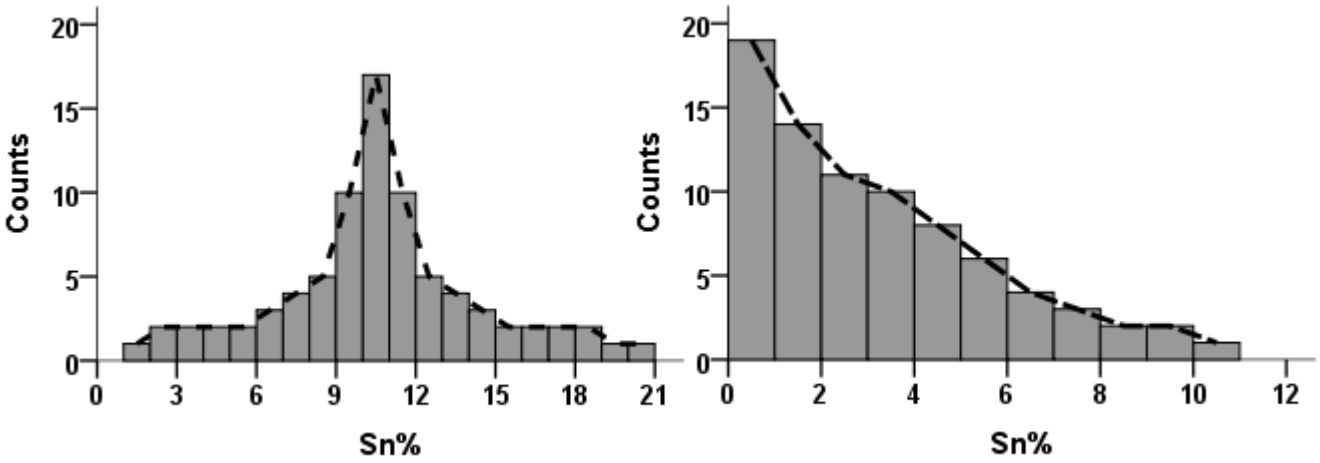


Figure 2.16 Graphic representations showing a primary tin-bronze production (left) and production based on recycled tin-bronze (right).

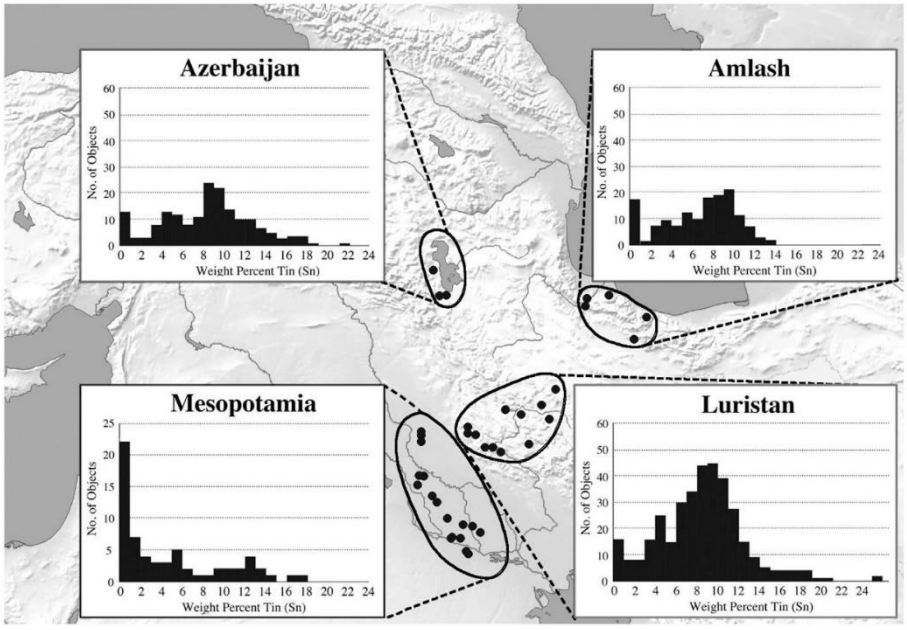


Figure 2.17 Diagram showing tin distribution across the Near Eastern copper-based objects in the late second to mid-first BC. From Cuénod *et al.* (2015).

(3) Lead Isotopic Compositions

If we accept that mixing or recycling of ancient metals can be manifested by recognisable patterns of both trace and alloying elements, then lead isotope data, as part of the chemistry of the copper alloy, should also reflect the changing nature of metal in circulation. Conventional lead isotopic studies in archaeology aim to link lead isotope ratios to specific ore sources from which the objects are made by plotting a pair of bivariate scatter charts. However, this graphic representation does not directly explain the mixing practices of copper from different sources. Borrowed from the idea of strontium isotope mixing model (e.g. Faure 1986), Pollard and Bray (2015) propose another way to present data by plotting the lead concentration against each lead isotopic ratio. This new approach has the advantage of showing the mixing line of copper-alloy

objects from isotopically different sources. They use the chemical data from the copper oxhide ingots found in Sardinia to illustrate how the new presentation can really be useful for the understanding of mixture

Figure 2.18 illustrates the relationship between 1/Pb (ppm^{-1}) and measured isotopic data in ingots and artefacts found in Sardinia. The spike with the 208Pb/206Pb value ≈ 2.075 represents the copper sources from Cyprus (Stos-Gale *et al.* 1997, Gale 1999, Stos-Gale 2000, Gale 2001), while the isotopic ratio ≈ 2.115 corresponds to the Sardinian sources. They argue that there are two scenarios in which Sardinian artefacts were mixed. The line A represents the mixture of Sardinian objects and Cyprian ingots, and the line B suggests some mixing between Cyprian ingots and another unknown sources with a much lower isotopic value. This new way of plotting isotopic data can reveal more information regarding the circulation of ancient metals than the conventional bi-plots.

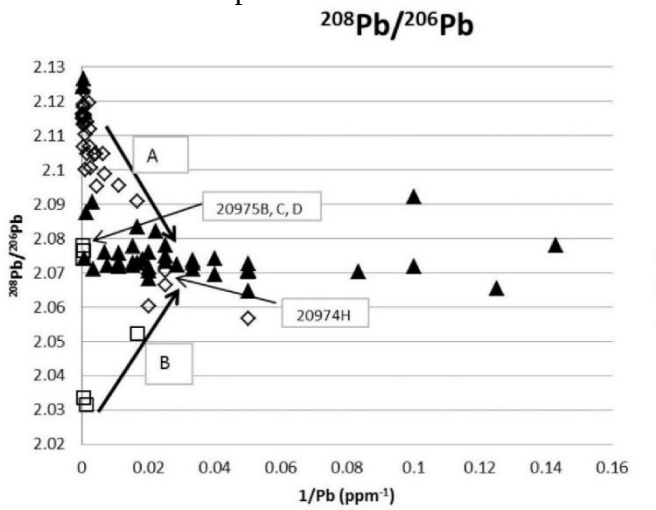


Figure 2.18 A bi-plot showing the mixing lead isotope ratios between Sardinian objects and Cyprian ingots found in Sardinia. From Pollard & Bray (2015: 1006, fig. 7)

(4) Geographical Information Systems and Metallurgy

Topographical and ecological factors play an important role in determining the movement of trade goods and people in antiquity. However, such essential information is rarely considered in the study of archaeometallurgy. The current geographical divisions of chemical data often comply with modern administrative boundaries, which may not reflect past circulation of metals in a realistic landscape such as mountain terraces, watersheds, and catchment zones. Therefore, Perucchetti *et al.* (2015) devise an analytical tool to utilise the Geographical Information Systems (GIS) to explore the movement of metals in terms of landscape features. Combined with this GIS tool, copper groups, alloy types and isotopic composition of a particular metal assemblage

can be used to illuminate possible routes of metal flow based on natural environments. For instance, in the study of the Chalcolithic and Early Bronze Age metalwork in northern Italy, Perucchetti *et al.* (2015) argue the Alpine range did not serve as a physical barrier between the north-south transportation of metal because copper objects with similar trace element patterns are found on both sides of the Alps. Instead, the circulation of metal mainly focussed on an east – west axis following watersheds and river systems, particularly tin-bronze (Figure 2.19).

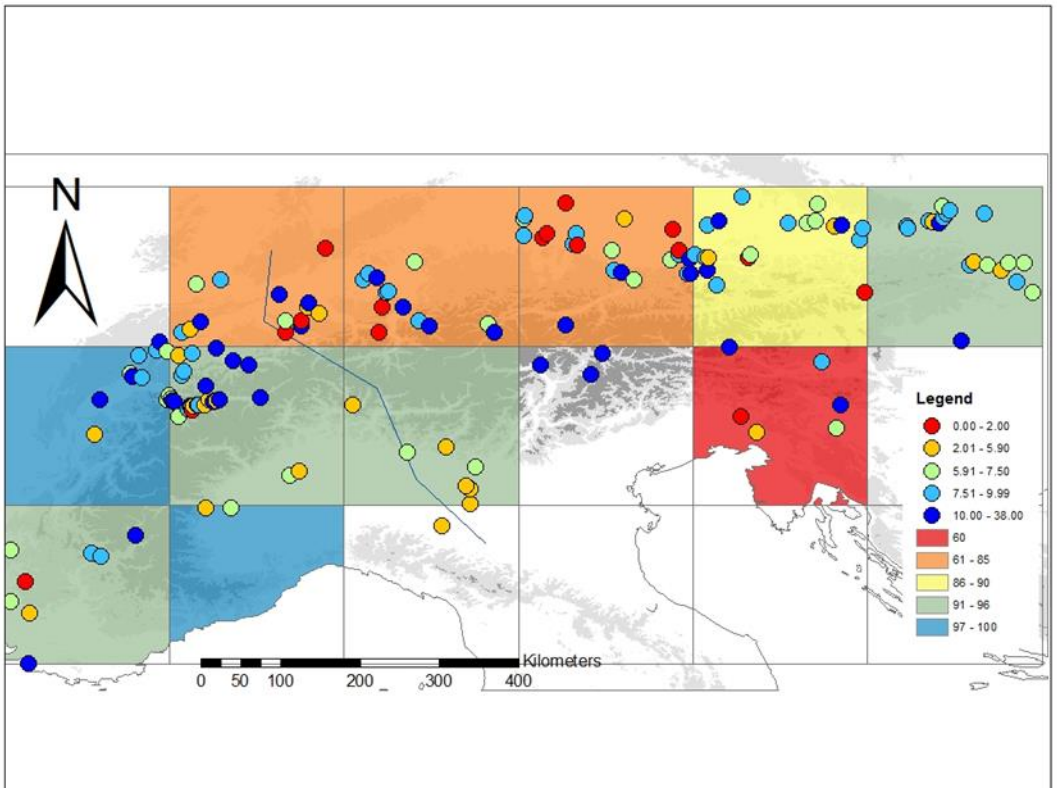


Figure 2.19 Map showing the ubiquity of tin-bronze (tin>1%) across the metal assemblage in the second phase of the Early Bronze Age (A2a). It is marked by the South-West focus of tin. From Perucchetti *et al.* (2015, fig. 13).

2.4.3 Applications to the Eurasian steppe

Presented above serve as the core methodological framework in the whole thesis to process chemical datasets of metal artefacts from the Eurasian Steppe. For the classification of copper groups, I also apply 0.1% as the threshold to the Eurasian copper-based metals for the sake of consistency over a wealth of chemical data. One reason to select this figure is due to the fact that a great proportion of data is analysed by the Arc Optical Emission Spectroscopy (Arc-OES) with its detection limit around 0.1% for arsenic, and even lower limits for antimony, silver and nickel (see Chapter 3

for details). It is justified that a metal object with arsenic lower than 0.1% represents the absence of arsenic. Of course, 0.1% may be arbitrarily divided the same metal stock into two separate groups, and thus I will acknowledge this potential issue over the course of discussions.

Past studies have shown that major alloying elements used in the Eurasian Steppe are tin and arsenic (Chernykh 1992). The question of deliberate arsenical bronze is still a matter of much debate, which I will investigate in greater detail in Chapter 3 and 8. Hence, for the alloy composition, besides the typical pure copper, tin-bronze and leaded tin-bronze, in some datasets I will treat arsenical copper as another alloy type to demonstrate the possible arsenic-alloying tradition in the Steppe and its mixing nature with tin-bronze.

Unfortunately, there are currently very few lead isotope analyses of the Eurasian artefacts (e.g. Kapitonov *et al.* 2007; Gorelik *et al.* 2013). In this thesis, I mainly use isotopic data to explore the exchange of metal supplies between northern China and the Central Plains of China in the late second millennium BC (see Chapter 6).

Finally, as the Steppe is an open landscape with multiple influences from all directions. It becomes very obvious that material culture of archaeological communities is intermixed and it is sometimes difficult to impartially differentiate one metal artefact type from the other. This indicates that assigning metal analyses to a particular cultural group may be somewhat subjective. Therefore, the application of GIS become very important to identify the movement of metal artefacts between different landscapes. In this thesis, most divisions of chemical data follow either river systems or isolated mountain valleys (basins), reflecting potential migrations of prehistoric mobile pastoralists.

3. The Bronze Database

This chapter is composed of three sections. The first part attempts to outline geographical and chronological frameworks for analytical data of Eurasian copper and copper alloys. This facilitates us to assign analysed objects to associated regions, dates and archaeological cultures for a comparative study. The second part mainly explores the mining and smelting evidence from the Eurasian steppe, showing the diversity of metal technologies over time and space. The final portion evaluates the quality of chemical data, pinpoints difficulties in using a large and fragmented database, and proposes some precautions to interpret such a varied dataset.

3.1 Geographical and chronological framework

To determine geographical boundaries and chronologies of prehistoric cultures in the Eurasian steppe has been proven extremely intricate. This complexity rests on the intense interactions between different steppe communities that often contribute many sites with mixed material evidence (Koryakova & Epimakhov 2007:12). Even though many recent radiocarbon dating projects have enriched our understanding of individual cultures or sites (e.g. Hanks *et al.* 2007 and Molodin 2012 *et al.*), many regions in the Steppe, such as western Siberia, Kazakhstan, and Xinjiang, still lack reliable absolute dates, making it difficult to construct a unified chronological system under the area of study. This situation is even getting worse as quite a lot of metal artefacts are claimed to be chance finds or museum collections without detailed archaeological context. Therefore, in deciding both geographical and chronological frameworks of analysed objects, I tend to adopt the information given by the original publications, which are mostly based on metal artefact typology, cross-cultural/regional analogies and stratigraphic positions in the case of well-excavated sites. Regions for which chemical data is collected are illustrated in Figure 3.1. The groupings mainly follow the boundaries of natural environments (e.g., river systems, mountain valleys/basins and alluvial plains), but do not necessarily reconcile with cultural entities. Whenever a culture distributes across an enormous territory (e.g., Seima-Turbino sites), the data will be separated into several areas to examine the regional variations within a single archaeological horizon. In addition, analysed objects from the regions of Mongolia and Xinjiang are highly scattered, so when dealing with their compositional data, I tend to refer to the present-day administrative boundaries.

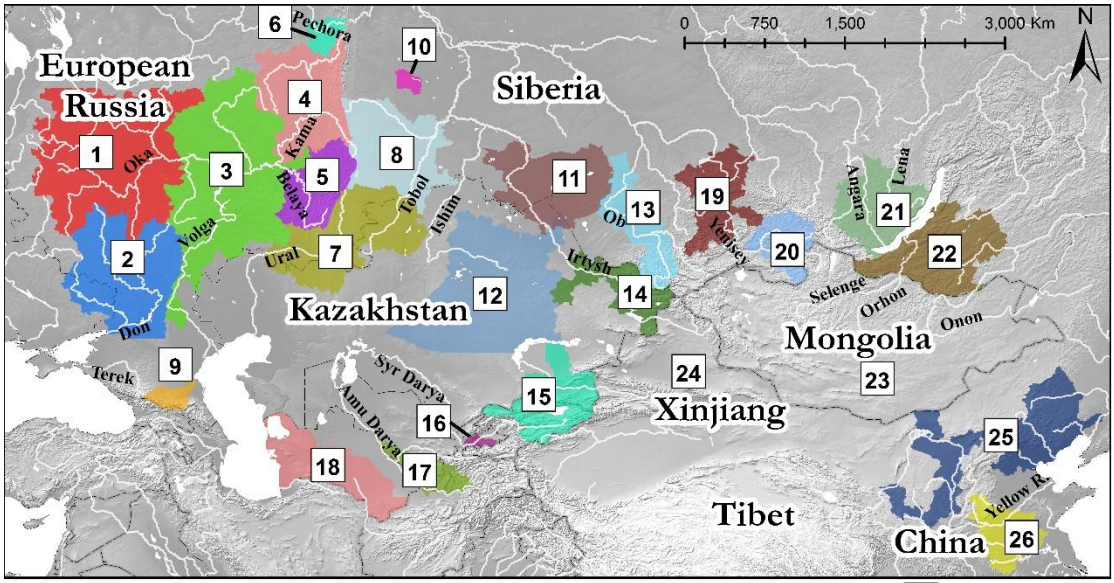


Figure 3.1 Map showing geographical regions in which compositional data come from.

Raw analytical data collected for this thesis is compiled in the supplementary material (excel files). Table 3.1 provides a summary list of the references, numbers of analyses, and corresponding regions. According to Chernykh's and other scholars' chronological research, the Bronze and Early Iron Ages of the Eurasian steppe feature several phases of development (Table 3.2). The Middle Bronze Age (c. 2200-1800/1700), corresponding to the first phase of the Eurasian Metallurgical Province (EAMP), was represented by the spread of the Seima-Turbino phenomenon across Eurasia and Abashevo-Sintashta-Petrovka communities in the western and central Eurasian steppes. The next stage of development is referred to as the second phase of EAMP, namely the rise of Srubnaya and Andronovo cultures during the Late Bronze Age (c. 1700-1500/1400 BC). The subsequent phase marked a shift of metallurgy towards the eastern part of the Eurasian steppe in the Final Bronze Age (c. 1400-900 BC), composed of metal production within the EAMP and Steppe East Asian Metallurgical Province. Eventually, the Early Iron Age (c. 900-300 BC), despite the emergence of iron technology, was characterised by the intense application of animal motifs to copper-based artefacts among the mobile pastoralists in eastern Europe, Kazakhstan and Siberia.

Table 3.1 List of chemical entries collected in this thesis based on geographical areas. MBA: Middle Bronze Age (c. 2200-1800/1700 BC); LBA: Late Bronze Age (c.1700-1500/1400 BC); FBA: Final Bronze Age (c. 1400-1000/900 BC); EIA1: Early Iron Age Phase 1 (c. 900-650 BC); EIA2: Early Iron Age Phase 2 (c. 650-300 BC).

Period	Region	N. of Analyses	Source
MBA	Cisbaikal	40	Goryunova & Pavlova 2008; Sergeyeva1981; Grishin 1971; Tishkin 2010
	Minusinsk	113	Khavrin 1997; Khavrin 2006; Sergeyeva1981; Chernykh & Kuz'minykh 1989a
	Volga	159	Chernykh 1970; Chernykh & Kuz'minykh 1989a; Peterson et al. 2015
	Oka	109	Chernykh & Kuz'minykh 1989a; Baderb 1970
	Kama	128	Chernykh & Kuz'minykh 1989a; Baderb 1970
	Altai	46	Degtyareva et. al 2010; Kiriushin & Tishkin 2003; Chernykh & Kuz'minykh 1989a
	W. Siberia	51	Chernykh & Kuz'minykh 1989a
	Forest Zone	37	Trufanov 2011
	Don	14	Chernykh & Kuz'minykh 1989a; Chernykh 1970
	Transurals	392	Degtyareva et. al 2001; Degtyareva 2009; Chernykh & Kuz'minykh 1989a; Vinogradov et al. 2013; Grigor'yev 2013; Chernykh 1970
	Cisurals	61	Grigor'yev 2013; Chernykh 1970
	N. Caucasus	36	Motzenbäcker 1996
	Pechora	24	Chernykh & Kuz'minykh 1989a
Subtotal		1210	
LBA	Minusinsk	22	Lun'kov et al. 2009,2011,2013
	Volga	209	Chernykh 1970; Peterson et al. 2015; Lun'kov et al. 2009,2011,2013
	Don	100	Chernykh 1970; Chernykh & Kuz'minykh 1989b; Lun'kov et al. 2009,2011,2013
	Oka	24	Chernykh 1970; Lun'kov et al. 2009,2011,2013
	Kama	12	Chernykh 1970
	Cisurals	106	Chernykh 1970; Kuz'minykh 1983; Lun'kov et al. 2009,2011,2013
	Transuals	165	Chernykh 1970; Tigeyeva 2013; Flek 2008, 2010; Degtyareva & Kostomarova 2011; Tigeyeva 2011; Kostomarova & Flek 2008; Potemkina 1985; Lun'kov et al. 2009,2011,2013
	Middle Urals	509	Chernykh 1970; Tigeyeva 2013; Flek 2008, 2010; Degtyareva & Kostomarova 2011; Tigeyeva 2011; Kostomarova & Flek 2008; Potemkina 1985
	W. Siberia	1	Grishin 1971
	N. Caucasus	25	Motzenbäcker 1996
Subtotal		1173	

Period	Region	N. of Analyses	Source
FBA	Minusinsk	1128	Khavrin 2001; Sergeyeva 1981; Chlenova 1972; Chlenova 1968; Khavrin 2001; Khavrin 2010; Chase & Douglas 1997; Zyablin 1977; Bobrov et. al 1997; Bogdanova-Berezovskaya 1963; Grishin 1971
	Tuva	5	Sunchugashev 1969
	Lake Baikal	70	Sergeyeva 1981; Sergeyeva & Khamzina 1975; Grishin 1971
	Altai (Upper Ob)	18	Pyatkin 1978; Grishin 1971
	Altai (Irtysh)	32	Chernikov 1951
	W. Siberia	58	Molodin et al. 2003; Molodin et al. 2009
	Fergana	176	Bogdanova-Berezovskaya 1962; Kuz'mina 1966
	S. Turkmenistan	689	Kuz'mina 1966; Galibin 1983; Ruzanov 2013
	Bactria	356	Sarianidi et al. 1977; Ruzanov 2013
	Semirech'e	80	Chernikov 1951; Vinogradov & Zharnikova 1983; Kuz'mina 1966; Ryndina et al. 1980
	N. & C. Kazakhstan	234	Chernikov 1951; Alekseyev & Kuznetsova 1983; Kuznetsova &Teplovodskaya 1994
	Central China	696	Hubei 2001; Bagley (ed.) 1987; Gettens 1969; Yoshiyuki & Junko 2014; Institute of Archaeology 1980; Li et al. 1984; Mao 1993; Institute of Archaeology 2005; He & Ou 1994; Ji 1997; Zhao 2004; Liu et al. 2005; Song & Nan 2012; Feng 1982; Liang 1950
	Northern Zone	268	Chase & Douglas 1997; Youshimitsu 2001; Li et al. 1984; Mei & Chen 2006; Jia 2011; Cao 2014; Liu 2015
	Mongolia	30	Chase & Douglas 1997; Korenevskij 1982
	Xinjiang	27	Li & Lu 2008; Qian 2006;
Subtotal		3867	
EIAI	Transbaikal	173	Sergeeva 1981
	Cisbaikal	85	Sergeeva 1981
	Minusinsk	760	Sergeeva 1981; Bogdanov-Berezovaya 1963; Bobrov 1976; Khavrin 2007a; Khavrin 2001; Martynov & Bogdanov-Berezovaya 1966; Grishin 1971; Sunchugashev 1975; Tikhonov & Grishin 1960; Chase & Douglas 1997
	Tuva	155	Pyatkin 1983
	Altai	139	Khavrin 2008
	N. Zone of China	56	Chase & Douglas 1997; Youshimitsu 2001; Hsu 2014; Northover unpublished;
	C. China	923	Gettens 1969; Bal et al. 2006; Zhang et al. 1999; Lu & Hu 1988; 曾侯乙墓; Zhang et al. 1999; Mao et al. 2002; Holemes et al. 1995; Shaanxi 2006; Gansu 2009; Zhou et al. 2009; Hua & Li 1982; Li & Han 1999; Luyang 2002; Tian 1981; Jia 2011; Wei 2007; Jia et al. 2012; Liang 1950
	Hexi	14	Zhongguo 2006; Qian 2006
	Xinjiang	62	Qian 2006
Subtotal		2367	

Period	Region	N. of Analyses	Source
EIAII	Transbaikal	174	Sergeeva 1981
	Cisbaikal	85	Sergeeva 1981
	Minusinsk	655	Khavrin 2007a; Martynov & Bogdanov-Berezovaya 1966; Chase & Douglas 1997; Hsu 2014;
	Tuva	42	Devlet 2007; Grishin 1971; Sunchugashev 1969; Devlet 1975
	W. Mongolia	179	Sergeeva 1981; Korenevskij 1982
	C. & E. Monoglia	39	Park et al. 2011; Korenevskij 1982
	Altai (Upper Ob)	109	Troitskaya & Galibin 1983
	Altai (Irtysh)	48	Khavrin 2007b
	C. Kazakhstan	195	Bartseva 1987; Kuznetsova &Teplovodskaya 1994
	Transurals	68	Bartseva 1987
	N. Zone of China	651	Chase & Douglas 1997; Zhang & Zhi 1982; Beijing 2009; Inner Mongolia 2010; Youshimitsu 2001; Li et al. 1984; Wei 2007; Li 2010; He & Yang 2009; Liu 2015; Northover unpublished; Hsu 2014
	C. China	702	Hubei 2001; Gettens 1969; Huang et al. 2008; He 1998; Mao 2002; Jenny 1995; Barnard & Sato 1975; Shaanxi 2006; Hunan 2011; Suizhou 2008; Shandong 2007; Shanxi 2009; Li et al. 1984; Chen et al. 2009; Institute of Archaeology 2003; Shanxi 1996; Institute of Archaeology 1994; Tian 1981; Song & Nan 2012; Jia 2011; Meng et al. 2009; Hubei 1991; Luo 2008; Liang 1950
	Xinjiang	60	Mei 2012; Ling et al. 2012; Mei et al. 2002; Qian 2006
Subtotal		3007	

Note: EIA2 data from the Transbaikal, the Cisbaikal, and partly from the Minusinsk is reused due to the wide chronological ranges given by the original publications.

Table 3.2 Chronological framework in this thesis. Dates from Kohl & Trifonov (2015); Kohl (2007); Chernykh (2008); Koryakova & Epimakhov (2007); Moskova & Rybakov (1992); Wu (2008); David-Kimball *et al.* (1995); Zaitseva *et al.* (2004, 2007); Alekseev *et al.* (2001); Sememtsov *et al.* (1998); Svyatko *et al.* (2009); Tsybiktarov (1998); Novgorodova (1989); Kovalev & Erdenebaatar (2009); Kuz'mina (2007, 2008); Molodin *et al.* (2012); Molodin & Durakov (2013); Molodin (2014).

<table>
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<tr><td>2000</td></tr>
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<tr><td>2100</td></tr>
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<tr><td>700</td></tr>
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<tr><td rowspan="3">Early Iron Age II</td><td>500</td><td rowspan="5">Ulamgom Pazyryk</td></tr>
<tr><td>400</td></tr>
<tr><td>300</td></tr>
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<tr><td>2100</td><td rowspan="5">Sapalli</td></tr>
<tr><td>2000</td></tr>
<tr><td>1900</td></tr>
<tr><td>1800</td></tr>
<tr><td rowspan="3">Late Bronze Age</td><td>1700</td><td rowspan="9">Namazga VI</td></tr>
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</table>

3.2 Metal-using cultures in the Eurasian steppe and beyond

Since this thesis primarily concentrate on the aspect of metal flow across the Eurasian steppe, it is beyond the scope to describe material culture of related archaeological communities in a great detail. Therefore, the following overview simply highlights important characterisitics of associated bronze-producing societies in a chronological order.

3.2.1 The Middle Bronze Age (2200-1800/1700 BC)

(1) Abashevo culture (Chernykh 1992: 200-203; Koryakova & Epimakhov 2007:57-65)

The Abashevo culture (c. 2200-1700 BC) primarily occupies the forest-steppe zone of eastern Europe, with a few sites extending into the steppe zone of the Middle Volga (Pryakhin 1976:164-166). In the western part Abashevo sites are represented by settlements in the Don River basin. The centre part in the middle Volga is mostly kurgan burials. The eastern part of the Abashevo communities, known also as the Balanbash in the Cisurals and Transurals, features a number of metalworking settlements that play an important role of metal production in the central Eurasian steppe (Koryakova & Epimakhov 2007:33).

More than two hundred Abashevo settlements have been documented. They are generally situated on high promontories overlooking waterways, with a short period of occupation. Settlements are usually unfortified and most houses inside settlements are built as above ground wooden constructions with slight underground depressions. Dwellings with different sizes and interior designs probably suggest different functions of usages. Along the Belaya River, settlements such as Balanbash yielded crucibles, slag, casting remains and copper artefacts, indicating a domestic primary metal production.

Abashevo kurgan cemeteries consist of burial pits under kurgans. Most mounds do not exceed 0.5 m in height and in some cases they are surrounded by a circular ditch or stone and wooden fence. The body is usually in supine position with legs bent, a tradition inherited from the preceding Yamnaya culture in the Volga. Some burials belong to bronze smiths who are buried with two-part moulds for shaft-hole axes, crucibles, and metalworking tools.

The most abundant collection of the Abashevo culture is pottery and animal bones. Abashevo ceramics are influenced by the Catacomb culture in both decoration

(horizontal line-and-dot, horizontal fluting) and technology (shell tempering). The basic types of pottery are jugs, bowls, cans and miniature vessels. Animal sacrifices are insignificant in the burial context: mostly cow and sheep bones. However, animal bones recovered from settlements allow us to confirm a livestock-breeding economy. Cattle are most numerous (68-78%), then followed by sheep and pigs. Unlike other archaeological cultures during the Middle and Late Bronze Ages, Abashevo only yields very limited horse bones.

Abashevo metal artefacts are found in settlements, burials and hoards, but are more common in settlements. The set of categories includes shaft-hole axes with elliptical in cross section, knives with a waisted tang, spearheads forged from a single sheet of copper, single-edged knives, and socketed chisels and gouges (Figure 3.2). The most diagnostic Abashevo metalwork is the production of rosette applique used for ornaments and clothing headdresses. Small rings, pendants, bracelets, and large torques are also very typical of Abashevo metal assemblage.

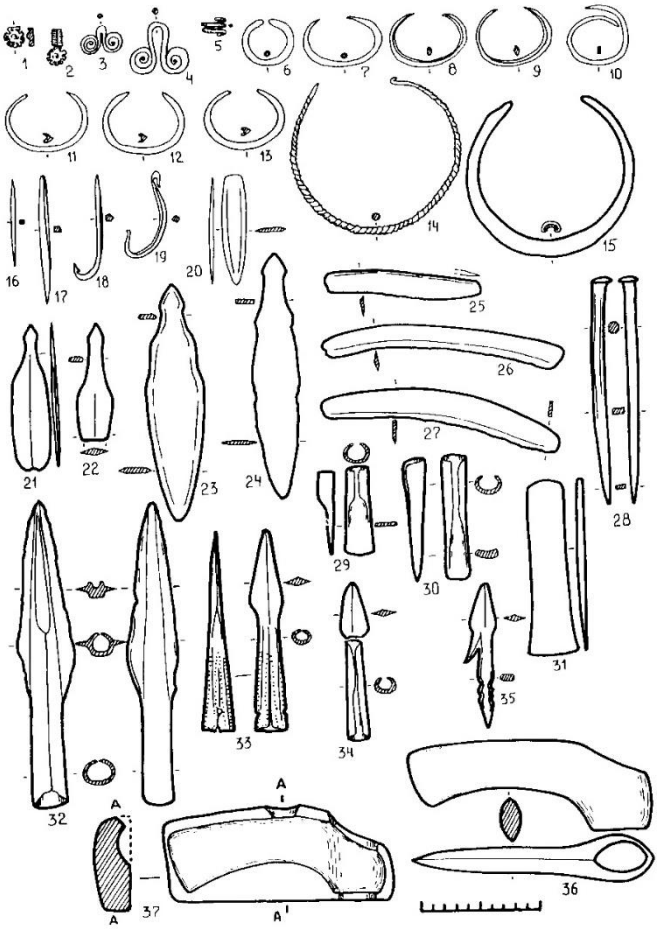


Figure 3.2 Metal artefacts from the Abashevo culture. From Chernykh (1992:196, fig. 68).

(2) Sintashta Culture (Koryakova & Epimakhov 2007: 66-80; Anthony 2007: 371-411)

The Sintashta culture (c. 2200-1900 BC) within the central Eurasian steppe has been recognised as one of the most important archaeological complexes in Eurasian prehistory (Boyle *et al.* 2002; Jones-Bley & Zdanovich 2002; Gening *et al.* 1992; Lamberg-Karlovsky 2002; Levine *et al.* 2003; Mallory 1989). Sintashta sites (both settlements and burials) are concentrated in the steppe region of the southern Transurals, along the tributaries of the Tobol and Ural rivers. Sporadic graves were found in wider areas in Cisurals, Kazakhstan and the Volga. Although the Sintashta culture occupies rather smaller territory than the Abashevo communities, many distinct features of social, economic, and political organisations and metal technologies have greatly drawn scholars' attention to explore the nature of inter-regional and intra-regional exchange.

The most representative Sintastha archaeological remains are the fortified settlements situated in the centre of large river valleys, on spacious, flat, dry ground. They are closed strongholds constructed with ramparts and ditches, encircled by a fence or wall. A well-studied fortress is the Arkaim settlement. Its outer wall has four entrances guarded by counterforces, towers, and other constructions. The internal structure of Arkaim is organised into sectional blocks in which several frame-pillar dwellings were built. Every house has one or several wells adjacent to the remains of a furnace probably associated with metallurgical activities. Sintashta settlements usually yield a great number of objects related to metal production such as pestles, abrasives, nozzles, slags and metal drops. However, very few finished metal objects have been recovered from settlements.

Sintashta burials are highly associated with fortified sites, following the model "one settlement – one cemetery." Cemeteries are mostly visible kurgan complexes, with single burial pits in varied sizes. The layout of the burial ground is arranged by the biggest central graves surrounded by several satellite graves in the outer space. One of the most astonishing features of the Sintastha funeral practices is the rich animal sacrifices. The deceased are mainly interred with domestic herds such as horses, cattle, sheep and dogs. The whole horse skeletons with traces of two-wheel chariots and cheek pieces confirm the usage of the horse-drawn chariots. Anthony (2007) considers that the Sintashta chariots, along with accompanying weapons, were the first horse-driven vehicles for the military purpose. This technology was later introduced to the Near East

through central Asia (Anthony 2007:403). Besides the chariot technology, the Sintashta culture is also marked by metal artefacts mostly from the burial ground, including spearheads, arrowheads, knives with a waisted tang, shaft-hole axes, flat axes and small implements (Figure 3.3).

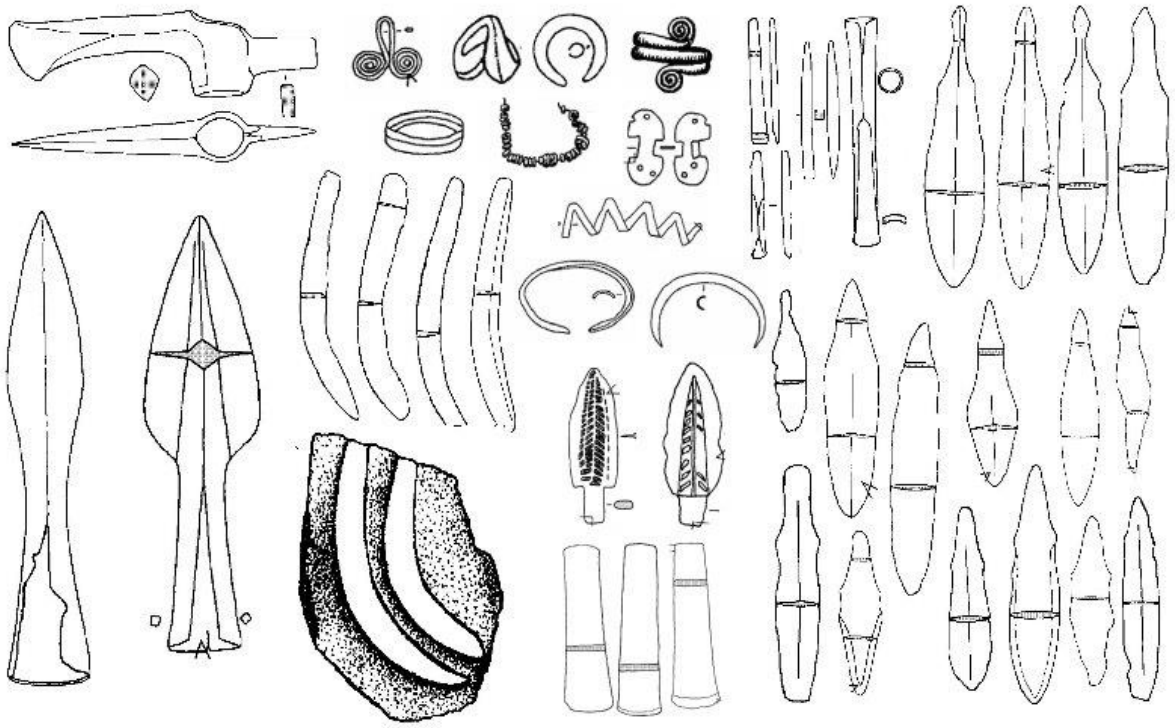


Figure 3.3 Metal artefacts from the Sintashta culture. From Degtyareva (2007).

(3) Petrovka Culture (Koryakova & Epimakhov 2007: 81-85; Anthony 2007:441-442)

According to stratigraphic position and radiocarbon dates, the Petrovka sites (c.1900-1700 BC) are considered as the transitional culture between the earlier Sintashta and later Andronovo (Alakul) cultures. The presence of Petrovka settlements and cemeteries was first identified in northern Kazakhstan, and subsequent research has confirmed its geographic extent into the Transurals, Middle Tobol and central Kazakhstan.

Around a dozen settlements have been well studied and their general structures are very similar to Sintashta settlements. Petrovka fortified settlements also occupy the flat river valley for the access to water resources. The construction of fortifications was still in use but it declined in sophistication compared with the Sintashta type. At the site of Kulevchy, the outer defensive wall becomes rather symbolic as a simple enclosure. Furthermore, unlike Sintashta sites having well-organised sectional blocks, Petrovka

settlements have a linear street layout. The above-ground dwellings at the Petrovka settlements are similar to the Sintashta sites with a frame-pillar construction. Each house is furnished with a well and a furnace related to metallurgical processes. Like the Sintashta culture, many Petrovka settlements show the traces of metalworking activities.

Petrovka cemeteries are represented by small kurgans: 0.5-0.7 m in height and 20-25 m in diameter. They are marked by wooden or earthen constructions, but very often burials are hardly recognised on the surface. The centre of a kurgan contains a larger tomb accompanyed by several satellite burials, a typical Sintashta funeral layout. Many Petrovka kurgans are multilayer containing earlier Sintashta burials. The bodies are usually placed in a contracted position on the left side with their heads toward either the west or the east. The richer tombs are constructed with wooden material, including roofing, frames and wall covering fastened by vertical pillars. The practice of animal sacrifices is also prevalent in the mortuary ritual. Men were buried with horses and chariots and children with sheep. Grave goods also present different arrangements in terms of gender (Figure 3.4). Spearheads, shaft-hole axes and arrowheads were dedicated to male graves while female tombs were usually accompanied by decorative items: bracelets, pendants, rings and beads.

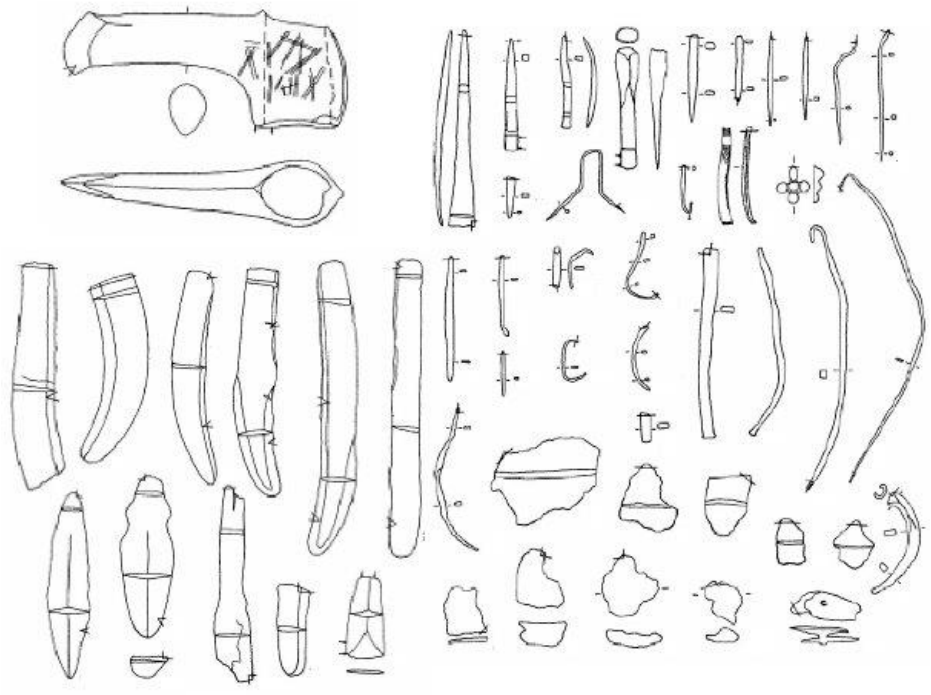


Figure 3.4 Metal artefacts from the Petrovka culture. From Degtyareva *et al.* (2001).

(4) Seima-Turbino Phenomenon (Koryakova & Epimakhov 2007: 106-110; Chernykh & Kuz'minykh 1989a)

The Seima-Turbino (hereafter ST) trans-cultural phenomenon (c 2200-1800/1700 BC) is referred to as a widespread archaeological horizon across the steppe and forest-steppe zone of Eurasia. It is well-represented by five major cemeteries: Seima, Turbino, Reshone, Rostovka and Satyga, with other small scattered burials and hoards. The general contour of the burial practices remains unclear due to being looted or unfavourable soil conditions for the preservation of human skeletons. Accordingly, most of what we know about the ST material culture comes from their artefacts, especially from various bronze weapons and implements. Their stylish bronzes contain spearheads with furcate midrib, socketed axes with geometric motifs, single-bladed knives with zoomorphic pommel, metal-blade with bone handle, as well as fragments of stone or clay mounds (Figure 3.5). Although the core area of the ST sites is concentrated on the Altai Mountains to the East and the Upper Volga to the West, Seima-Turbino-like objects have been discovered as far as the Central Plains of China (Lin 2015).

There are several unique characteristics of the ST phenomenon (Anthony 2007:443-447) Firstly, ST sites do not have common ceramic types and funeral practices. In the east, the Rostovka cemetery in the Tomsk region yields nineteen hundred sherds of Krotovo pottery, and Satyga burials contain pottery fragments closed to those from forest zone of western Siberia. Ceramics from Seima and Turbino graves in eastern Europe are similar to Abashevo type. The varied ceramic types suggest the ST phenomenon was formed by multiple cultural groups. Secondly, unlike the Abashevo-Sintashta metalwork which mainly produced hammered or flat metal artefacts, the ST people had probably developed sophisticated lost-wax methods for the three-dimensional animal figurine on the pommel of the dagger (Chernykh & Kuz'minykh 1989a). ST metalworkers were capable of casting thin-walled spearheads and socketed axes with a suspended core in mould. Lastly, artefacts from ST sites demonstrate incredibly long-distance connections with other faraway cultures. The Rostovka cemetery contained nephrite rings possibly from Lake Baikal regions, a lapis lazuli bead from Afghanistan, and stemmed flint projectile points similar to those from Sintashta cemeteries.

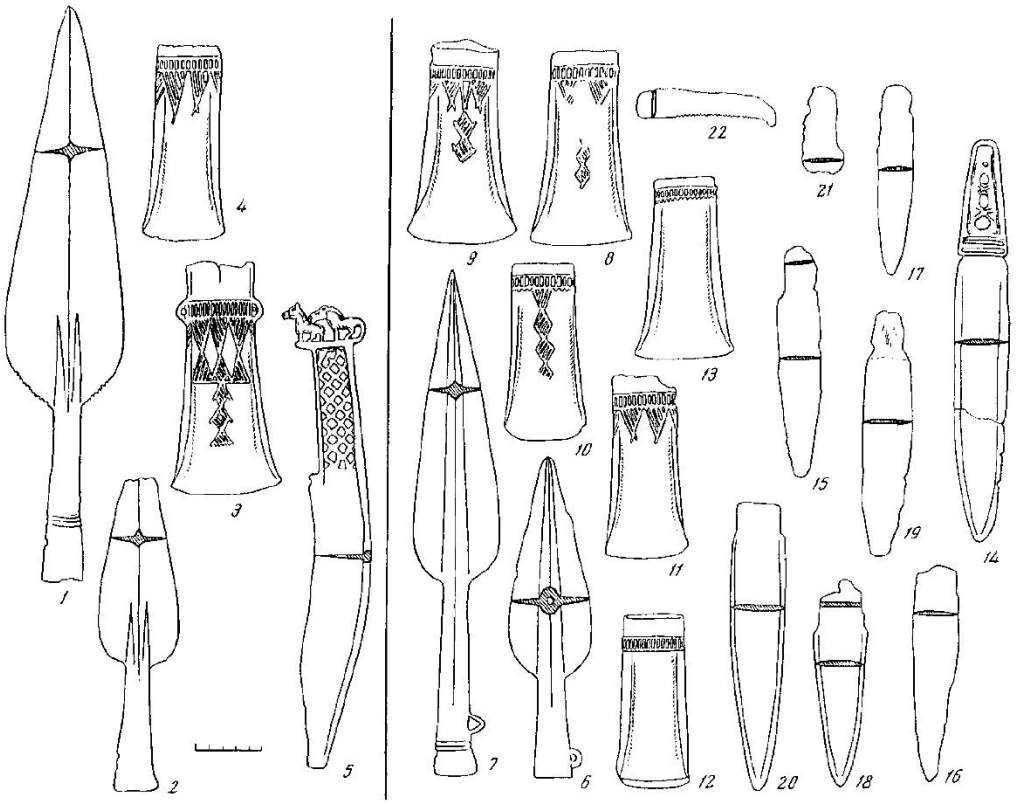


Figure 3.5 Metal artefacts from the Seima cemetery. From Baderb (1970:158, fig. 3).

3.2.2 The Late Bronze Age (c. 1700-1400 BC)

(1) Andronovo Culture (Cherynkh 1992: 210-214; Kuzmina 2007; Koryakova & Epimakhov 2007: 123-137; Anthony 2007: 448-451)

Russian archaeologists have recognised two major LBA cultural formations across the steppe and forest steppe areas of Eurasia, namely Andronovo in the east and Srubnaya in the west. The Urals serves as the contact zone where two cultures are highly mixed together. Ceramic typology is the most diagnostic trait to identify individual archaeological communities. The Andronovo culture, in particular, contains several sub-groups in terms of variations of pottery types, decorations and forms. The most prevalent ones are Alakul and Fedorovo types, although some other regional groups are known, such as Soliletsk, Kozhumberdy, Atasu, Amangeldy, Tautary and Semireche (Kuzmina 2007: 17-29). As the majority of the bronze data during this period come from the Alakul-type sites, I will be focussing on this branch of the Andronovo culture.

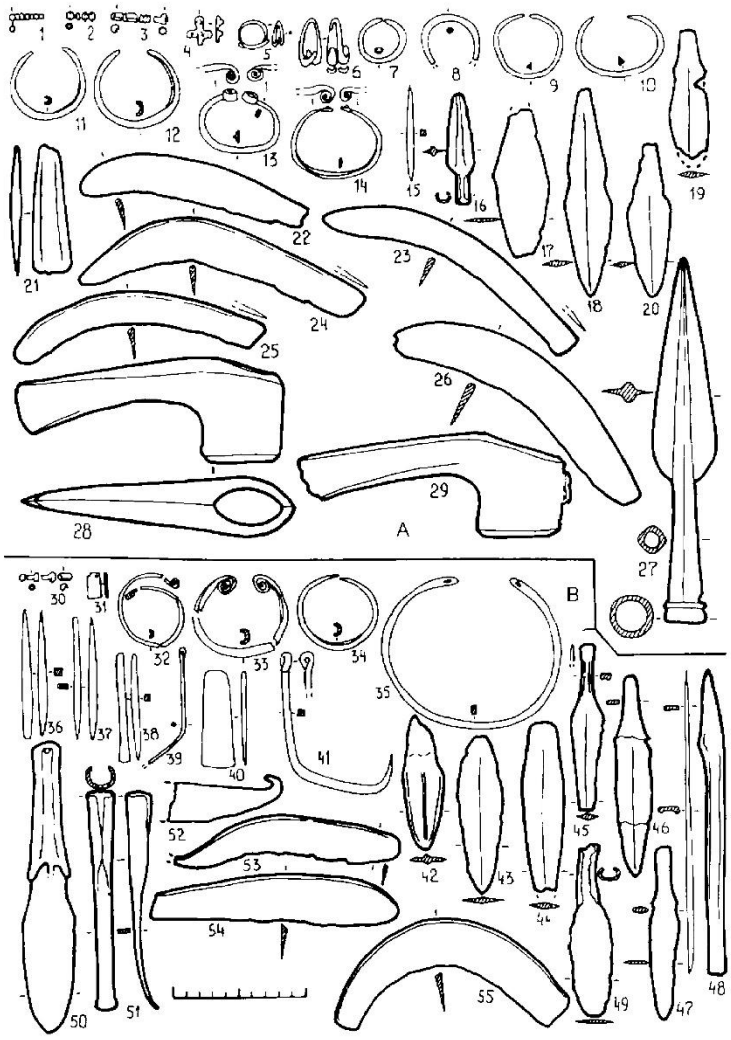


Figure 3.6 Metal artefacts from the Alakul culture. From Chernykh (1992:199, fig. 71).

Stratigraphically speaking, the cultural layer of Alakul sites superimposes the preceding Petrovka culture. Thus, it is commonly accepted that the Alakul culture evolved from the Petrovka. The Alakul sites mainly concentrate on the steppe and forest-steppe zones of the Transurals and Ishim River, with local variants in western and central Kazakhstan. Locations of Alakul settlements are usually connected with river valleys. Some sites contain traces of wooden fences, implying the construction of partially- enclosed settlements. Houses are subterranean wooden constructions of rectangular shape. Many postholes are found to divide a house into different partitions: wells, storage pits, fireplaces, and many other rooms for different purposes. Traces of metallurgical activities are discovered near fireplaces built with stone and baked bricks. The presence of large ash pits is characteristic to the Alakul settlements.

The Alakul burials feature child graves within settlements and kurgan cemeteries. Grave goods in child tombs are very poor, which only contain pottery. Kurgan burials were built in similar locations as the settlements. There are two main constructions of

kurgans. In the forest-steppe zone, the interior design of graves are made from wooden structures. In contrast, tombs surrounded by a stone ring with stone roofing are dominant in the treeless environment.

The mortuary practices are represented by inhumation, with the deceased flexed on the left side and heads oriented towards the west. Animal sacrifices are prevalent and the selected animals are similar to the previous Petrovka culture. Cattle are most numerous followed by sheep and horses. The only difference from the preceding era is that the sacrifice of whole animal skeletons was replaced by their heads and extremities in the Alakul burials. Men are often buried with weaponry (knives, spearheads, arrowheads, axes and maces) in contrast to exquisite ornaments (bracelets, rings, beads shells and earrings) found in female graves (Figure 3.6).

(2) Srubnaya Culture (Chernykh 1992: 204-210; Anthony 2007: 435-440)

The Srubnaya culture is a Late Bronze Age metal-producing community in eastern Europe. It mainly occupies the territory of the Pontic-Caspian Steppe and extends into forest-steppe zones of the Middle Volga. The name "Srubnaya" is derived from the kurgan burials containing wooden-framed chambers (Srub in Russian means "timber framework"). The ordinary Srubnaya kurgan features an earthen mound, with the dead covered by logs or beams. The body was placed in a contracted position with the head towards the north. Grave goods usually contain one or two clay vessels and occasionally copper or bronze spearheads, adzes, knife-daggers, beads, awls and suspensions (Figure 3.7). The practice of burial rites is in the form of the skull and forelegs of domesticated animals. Cattle and pigs predominate in the forest-steppe regions, while sheep and goats are more common in the steppes. Horses are raised in both ecological settings.

Thousands of Srubnaya settlements have been uncovered. They consist of a rectangular outline with either semi-subterranean or surface houses built inside. Some sites yield numerous debris of casting moulds and bronze-casting workshops. The Gorny settlement nearby the Kargaly mine in southern Urals, shows a unique craft specialisation in copper extraction (Kohl 2007:171-175). Miners lived in the year-round dwellings and engaged in primary extraction of copper ores. More than 3000 metal objects, 178 fragments of casting moulds and over 20kg of slags are discovered in this site.

Further in the southern Urals and western Kazakhstan, the Srubnaya community came into contact with the Andronovo culture in the eastern Eurasian steppe. The material culture in these regions is quite often intermixed with one another and it is nearly impossible to delineate either pure Srubnaya or Andronovo sites. As a result, some scholars prefer to treat the Late Bronze Age steppe culture as a single Srubnaya-Andronovo cultural entity (Chernykh 2008:49).

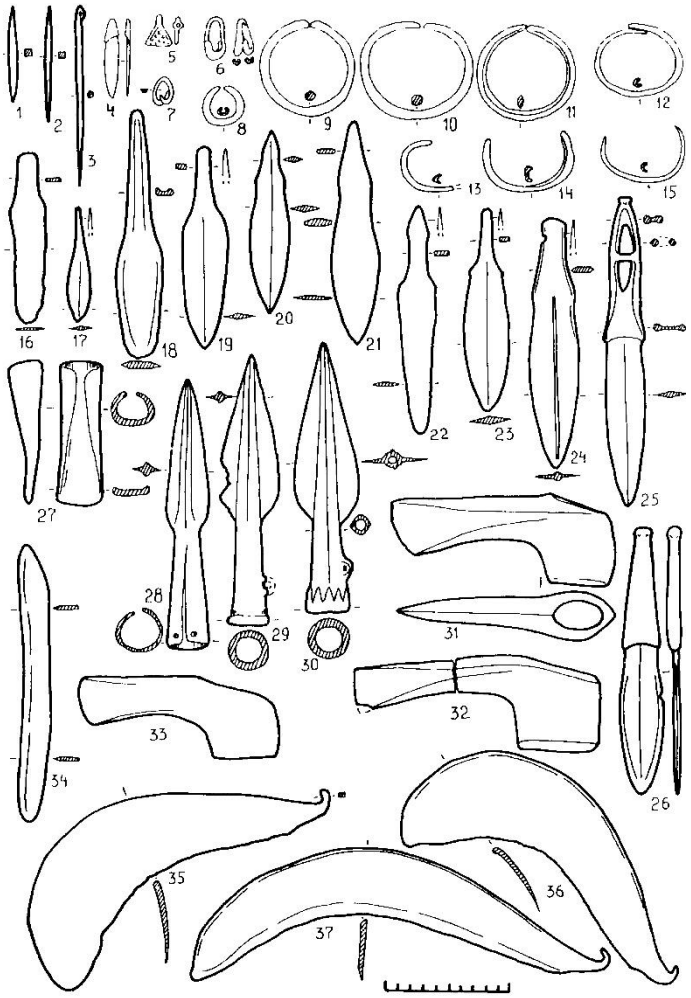


Figure 3.7 Metal artefacts from the Srubnaya culture. From Chernykh (1992, p. 197, fig. 69).

3.2.3 The Final Bronze Age

This period is marked by the increasing metal production in the eastern part of Eurasia. The bronze data is mainly collected from the Andronovo culture in Kazakhstan and Kirgizstan, the Karasuk culture in the Minusinsk Basin, the Irmen culture in western Siberia and the Upper Ob, Batrican and Namazga VI cultures in southern central Asia, and other FBA cultures in the Altai (eastern Kazakhstan), the Baikal region and Mongolia.

(1) Atasu and Dandybai-Sargary Cultures in Kazakhstan (Varfolomeyev 2003; Kuzmina 2007; Koryakova & Epimakhov 2007: 161-169)

In central Kazakhstan, the Andronovo culture showed a mixture between Alakul and Fedorovo pottery, and was known under the name of Atasu. This variant is dated to around the 15th to 13th centuries and associated sites include Atasu, Ayshrak, Ak-Mustafa, Koyshoku, Bylkyldak, Shet, Murza-Shoku, El'shibek, Aksu-Ayuly, Zhilandy, Zhaman-Uzen II, Lisakovskiy, Bes-Oba, Altyn-Tyube, Nurken, and Balakty (Kuzmina 2007: 27). Cemeteries are usually large burial complexes containing up to several dozen constructions. Graves are surrounded by round, oval and rectangular fences with two or more stone coffins in the centre. The arrangement of the body is similar to the Alakul culture, dominated by inhumation with head to west or south-west.

The most striking feature of the Atasu culture is the intense metalworking remains in the settlements. At the site of Atasu, archaeologists have found three sophisticated key-shaped smelting furnaces and numerous remains of copper ores, slag and finished products (Figure 3.8). Furthermore, the discovery of metal paw-shaped pendants and ornaments of round plates indicates a long-distance contact with the Minusinsk Basin to the north and Bactria to the south (Kuzmina 2007:28).

After the Atasu phase, another archaeological community arose, known as Dandybai-Sargary culture (Varfolomeyev 2003). It is roughly dated to the 13th to 10th centuries BC and occupies a large territory of the forest-steppe between Tobol and Irtysh, northern and central Kazakhstan.

The material is mainly recovered from settlements, cemeteries and chance finds. Settlements are of two types: (1) a large habitation area with semi-subterranean dwellings and (2) smaller seasonal settlements. Inside the settlement, houses are built from the frame-pillar construction and arranged along the river bank in one row. Settlements mainly yield animal bones and flat-bottomed pottery. Around 40% of ceramics are without decoration, and the remaining are decorated with patterns of incised, zigzag, rhombic, notches and horizontal herringbone around the neck and shoulder of pots.

Burial grounds in northern and central Kazakhstan feature stone cists with individual inhumations. There are a variety of arrangements for the dead: in a flexed position on the right or left sides, on the back and even in a seating position. Certain burials are

more enormously and elegantly made, possibly dedicated for the elite class. In central Kazakhstan, massive mausoleums were constructed. One burial ground (Begazy) measured 9.6m by 9.6m in dimension, and was enclosed by fences made of granite slabs of 2.3 m in height. The outer wall is covered with vertical plates, reaching a height of 3.5 m. There are many exotic goods related to the Karasuk culture in the Minusinsk Basin, including ceramic dishes, bronze singled-bladed knives and a knife-sickle.

According to animal bones from residential and funeral contexts, the economy of Dandybai-Sargary culture is mainly based on livestock herding. The most abundant domesticated animals are cattle, followed by horses and sheep. There is a tendency of increasing horse populations, suggesting an increasing mobility.

Overall, traces of metal production are visible in the FBA settlements of central Kazakhstan. The discovery of furnaces, casting moulds, and numerous metal artefacts (such as knives, sickles, flat axes, socketed gouges, socketed arrowheads and leaf-shaped knives) suggests the flourishing metalworking among the Dandybai-Sargary communities (Figure 3.9).

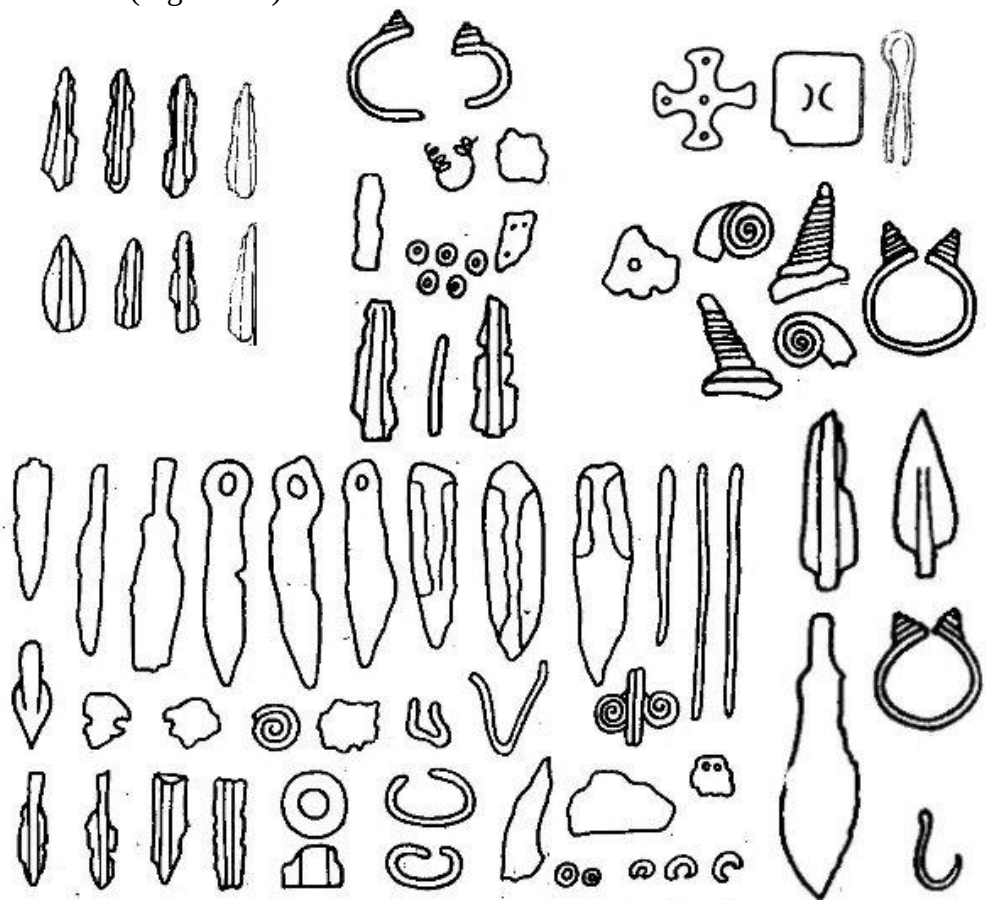


Figure 3.8 Metal artefacts from the Atasu culture. From Kuznetsova & Teplovodskaya (1994).

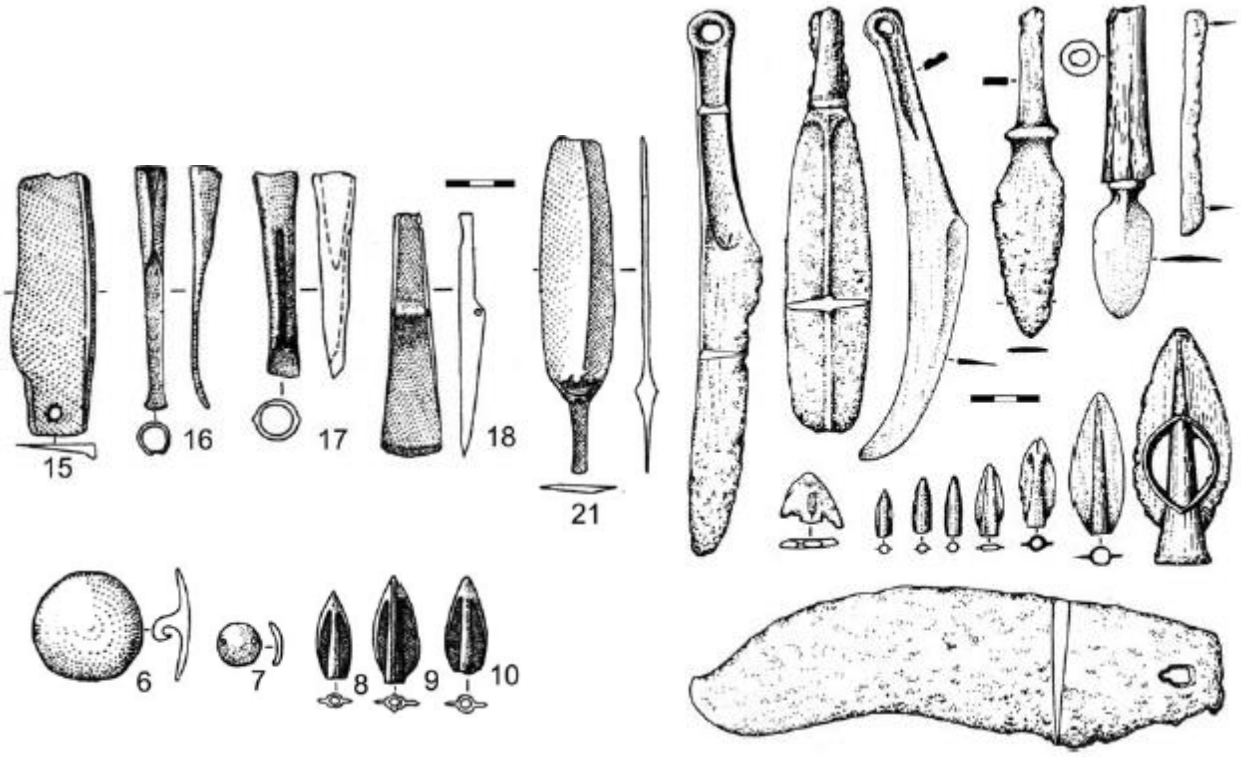


Figure 3.9 Metal artefacts from the Dandybai-Sargary culture.
From Koryakova & Epimakhov (2007: 44, fig. 1.9 & 165, fig. 4.3).

(2) Karasuk Culture in the Minusinsk Basin (Chlenova 1972; Legrand 2004 & 2006; Chernykh 1992, ch.9; Wu 1986; Shao 2007)

The Karasuk culture is an archaeological culture that thrived in southern and eastern Siberia, mainly the Minusinsk Basin in the Middle Yenisi River during 1400 to 900 BC. Its territory probably expanded to the regions of the Altai (Jettmar 1951). The Karasuk communities are well-known for their stylish bronze artefacts (e.g., single-bladed knives, daggers, adzes, personal ornaments, and bow-shaped object), which share similar features with those from Mongolia, Transbaikal, and northern China (Figure 3.10).

Archaeological information regarding the Karasuk culture mainly comes from burials. Over 2000 tombs have been found and most of them are surrounded by a wall made of stone kerbs. Inside the wall is a single burial pit, either rectangular or trapezoidal in section. In general, a tomb has a cist of stone slabs in a pit, with ceramic vessels next to the head of the dead. A wooden tray carries food offerings mostly from sheep, some from cows or horses. Dog remains is present during the later period. Grave goods have generally been severely looted, so most of Karasuk bronzes are chance finds. Few

undisturbed burials preserved some metal ornaments on the dead bodies. This informs us of Karasuk people's custom of wearing adornments.

In terms of the date of the Karasuk culture, scholars traditionally estimated its chronology by the pottery typology. The early phase (13th to 11th centuries BC) was marked by hand-made ceramic vessels that have a bottom with a flat base or foot-ring, thin wall, and burnished surface. Bronze single-edged knives and adzes belong to this period. By contrast, the pottery style in the later phase (10th to 8th centuries BC) tended to be equipped with a taller pedestal and the overall appearance is coarse and heavy with a large mouth and deep body (Wu 1986; Shao 2007). Bronze artefacts at this stage manifested a diverse assemblage, including daggers, singled-bladed knives, bent knives, socketed axes, bow-shaped objects, and pick-axes.

The latest results of radiocarbon dates contradict the traditional Karasuk chronology, which provide the evidence for the influence of the Karasuk-style metals on northern Chinese single-bladed knives (Legrand 2004 & 2006; Chernykh 2008, 48, fig. 10). Twenty-eight radiocarbon dates from the Karasuk sites fall in a range between 1350 and 750 BC within 68% probability (Chernykh 2008; Svyatko *et al.* 2009). This implies that the emergence of the Karasuk culture was at least synchronous with or perhaps earlier than the late-Shang culture in central China. It is likely that Shang China had been shaped by the Karasuk culture in terms of the taste of steppe metal use.

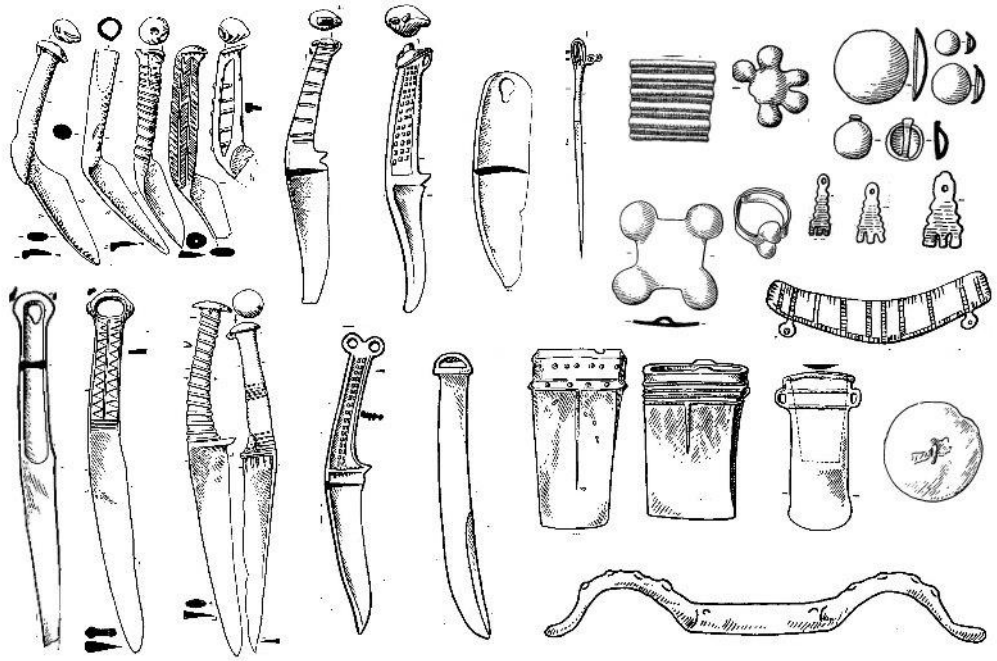


Figure 3.10 Metal artefacts from the Karasuk culture. From Chlenova (1972).

(3) Semirech'e region (Kuzmina 2007 & 2008)

The Semirech'e roughly corresponds to the present-day southern Kazakhstan and northern Kyrgyzstan, including the steppe area of south of Lake Balkhash and the mountainous region around Lake Issyk Kul. During the Final Bronze Age, this region was occupied by the Andronovo groups practicing transhumant pastoralism in the Tian Shan Mountains. Settlements and domestic dwellings are still ill-studied and most archaeological information comes from funeral data. In mountainous region, kurgans were built with pebble and earthen banks, enclosed by rectangular stone slabs. Both cremation and inhumation were practiced. The dead were buried in a pit, in flexed positions, on the left side and head to the west. Vessels with applied-rollers are associated with pottery-making traditions in central Kazakhstan.

The Semirech'e also served as an important metalworking centre during the Final Bronze Age. A large number of metal artefacts have been recovered from chance finds and hoards, including a wide range of bronzes: shaft-hole axes with a butt, chisels, sickles, socketed axes, knives, spearheads, arrowheads, double-edged daggers and typical Andronovo-style adornments (Figure 3.11). As a result, Kuzmina (2007:246) considered Semirechye metalwork as the part of Andronovo metallurgical tradition.

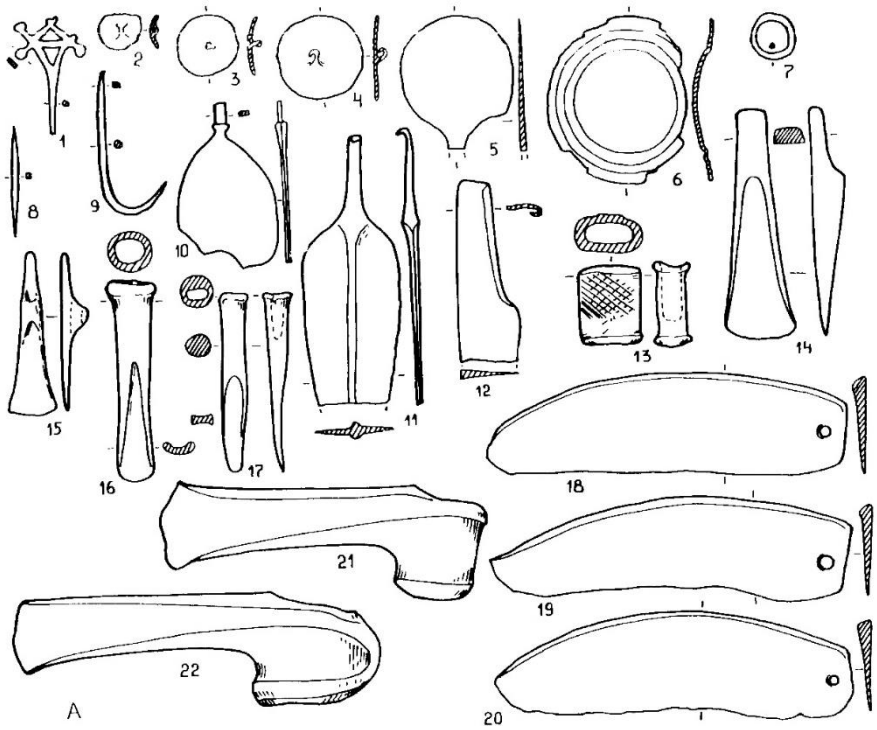


Figure 3.11 Metal artefacts from the Semirech'e region. From Chernykh (1992: 245, fig. 83A).

(4) Fergana Valley (Kuzmina 2007 & 2008)

The Fergana valley is a river basin in central Asia, enclosed by the Tian-Shan Mountains in the north and the Gissar-Alai ranges in the south. The branches of the Syr Darya— the Naryn and the Kara Darya run through the valley to form fertile lands for agriculture. During the Final Bronze Age, the Fergana was inhabited by two groups of peoples: steppe communities of the Kairakum culture and the agricultural Chust culture.

The Kairakum culture was mainly distributed over the semi-desert zone along the banks of Syr Darya in the western Fergana valley. Around seventy settlements, cemeteries and metalworking sites have been discovered. In general, settlements are small, between 1000 and 3000 m². Although most of settlements are heavily eroded due to severe environmental conditions, remains of stone hearths suggest typical rectangular Andronovo-type dwellings.

Burials usually contain stone cists constructed from edgewise-placed slabs, with the dead lying on their sides and head oriented towards the west. Grave goods are composed of hand-made ceramic vessels with a textile pattern and bronze personal adornments of Andronovo type from western Kazakhstan and Semirech'e region (Figure 3.12).

The economic activity is mainly based on cattle-breeding: horses, cows and sheep or goats. Farming and hunting play a secondary role. Metalworking activities might have served as an important part among the Kairakum communities. Ores were probably extracted from deposits in the Kara Mazar Mountains. Raw material was transported to the vicinity of settlements where excavators have found numerous products related to copper smelting: slag, pieces of ores and copper droplets. Kuzmina (2007:249) argued that the Kairakum metallurgy belonged to the wider Andronovo metalworking traditions due to the shared metal assemblage (such as lop-headed axes with a cock-comb, picks, celt-spades, arrowheads, trumpet-shaped earrings and bracelets with conical spirals).

The Chust communities primarily lived in the northern and eastern parts of the Fergana valley. Settlements were typically large villages and some of them were protected by fortified walls made of earth, clay and mud-bricks. The domestic architecture mainly consisted of mud-brick dwellings and small semi-subterranean huts. Among the most striking features in settlements are numerous storage pits for grains. Cemeteries were

built near the settlements. The deceased were buried in flexed positions, lying on their sides, with varied orientation.

Dry farming served as the primary subsisitence strategy of the Chust culture. Wheat, barley and millet were cultivated. Many tools were employed for agricultural processing: hoes, sickles, querns, pestles and grindstones. Livestock-breeding played a secondary role, including cows, sheep, horses, donkeys, dogs and pigs in domestic settings.

The Chust pottery is all hand-made and mainly contains two types. 18% of recovered sherds belong to coarse kitchen ware of grey clay. 73% of the sherds are thin-walled vessels coated with red slip. Diverse motifs and décor on ceramics suggest the multiple cultural relations with other regions. Researchers have recognised similar pottery forms and decorations in Bactria, Turkmenistan, Xinjiang, Afghanistan and central India.

Metallurgy is another important component among the Chust culture. Slag and casting stone moulds were found in settlements. The metal assemblage is extremely diverse, including socketed spearheads, socketed chisels, arrowheads, singled-bladed knives, knife-sickles, bits and cheek-pieces, mirrors with handles and openwork pendants (Figure 3.12). Kuzmina (2008:81-82) argued that the origin of the Chust peoples might be the local steppe groups who adopted new agricultural economy from southern farmers as a result of cultural emulation.

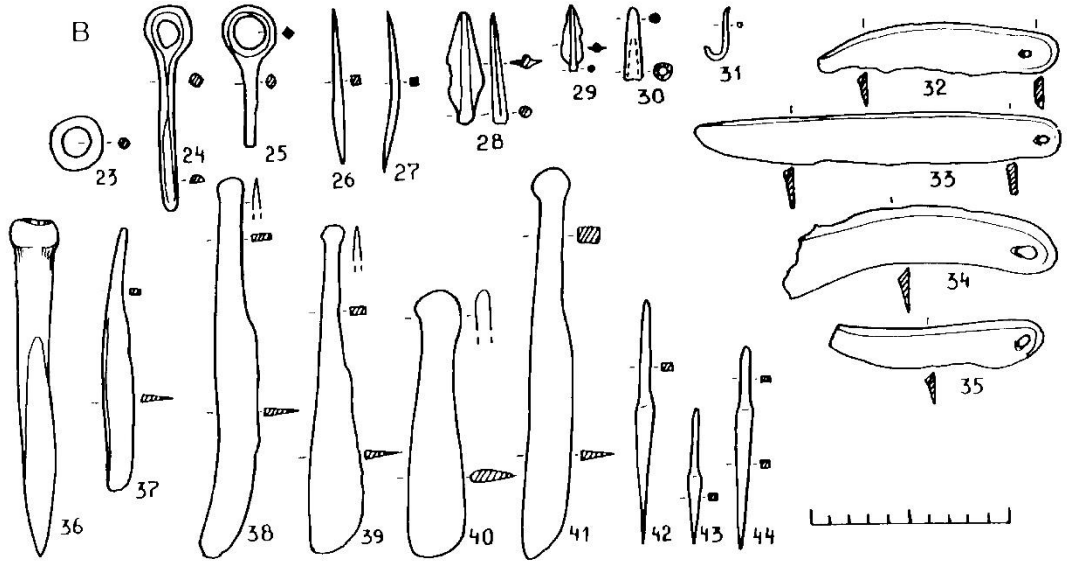


Figure 3.12 Metal artefacts from the Fergana valley. From Chernykh (1992: 245, fig. 83B).

(5) Southern Turkmenistan (Kuzmina 2007 & 2008; Anthony 2007: 421-435)

Southern Turkmenistan had long been the homeland of ancient farming cultures since the fifth millennium BC. During the stages of Namazga IV and V (c. 3000-2000 BC), large fortified towns, sophisticated irrigation systems, and craft specialisations emerged to form a complex settled society. The potter's wheel was used for the ceramic industry and furnaces for making metals were prevalent in settlements. The land travel was hugely facilitated by the application of four-wheeled wagons drawn by oxen or camels.

During the Namazga VI (c 1800-1300), there was a decreasing economic power in southern Turkmenistan. Large walled towns were abandoned and small-size settlements became more common. Although irrigated agriculture still played an important role, there was an increasing live-stock herding in this area, including cattle, sheep or goat, pigs and camels. Domesticated horses first appeared during this time. Metalworking was closely linked to western Asian traditions, especially for the production of bronze seals.

The Namazga VI period was also marked by an increasing contact with northern steppe communities, especially with Andronovo and Karasuk cultures. Hand-made pottery with geometric incised patterns and bronze singled-bladed knives, sickles and double-edged daggers of Andronovo type were frequently encountered in the settlements (Figure 3.13).

By the 12th century BC, the Namazga VI culture ceased to develop and a new culture focusing on animal husbandry took over the lands of southern Turkmenistan. Although where these people came from was still debated, the huge amounts of steppe elements, such as the hand-made pottery, singled-edged knives, socketed arrowheads and the use of iron objects indicate a possible total replacement of agricultural populations by the northern herders.

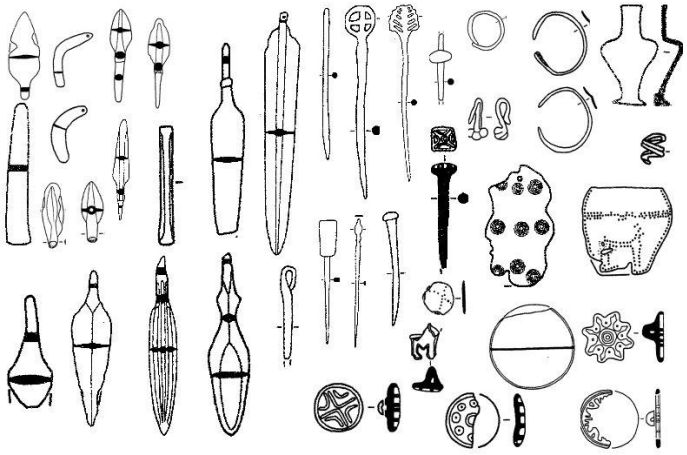


Figure 3.13 Metal artefacts from southern Turkmenistan. From Ruzanov (2013).

(6) Bactria (Kuzmina 2007 & 2008; Anthony 2007: 421-435)

Bactria is the historical region referred to as the territory between the Hindu Kush Mountains and the Amu Darya river. It includes modern-day southern Uzbekistan, the Mughab delta of Turkmenistan, Tajikistan and northern Afghanistan. During the Bronze Age, there were a series of large, fortified settlement sites thriving along the Upper Amu Darya. This archaeological culture is known as the Bactria–Margiana Archaeological Complex (BMAC) or the Oxus civilisation (Masson 1992; Baumer 2012).

Like the Namazga culture, ancient Bactria was inhabited by agro-urban communities relying on irrigated farming in oases. The heyday of this culture lay between 2200 and 1700 BC, and still continued to develop until 900 BC (divided into Spalli, Jarkutan, Juzali, Molai phases, see Baumer 2012: 114). Settlements are square, rectangular and round fortifications guarded by corner towers. The interior designs feature multi-room houses, temples with alters and a central palace indicating certain religious or political authority.

Material culture in Bactria demonstrates a close relationship with southern Turkmenistan. Both areas embark on oasis agriculture, wheel-made pottery, sophisticated settlement complexes, and metal artefacts with western Asian style (Figure 3.14). Likewise, both regions during the second half of the second millennium BC were experiencing the significant changes brought by steppe peoples who introduced hand-made ceramics, livestock herding, and steppe-style metal objects into southern Central Asia (Litvinsky & Pyankova 1992).

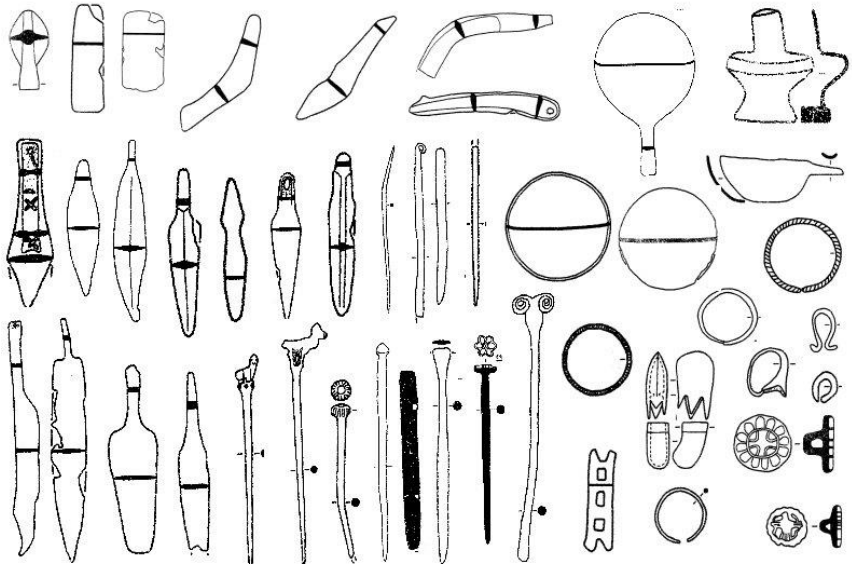


Figure 3.14 Metal artefacts from Bactria. From Ruzanov (2013).

3.2.4 The Early Iron Age (c. 900-300 BC)

The Early Iron Age pastoral societies mainly occupy the steppe and forest-steppe zones of Eurasia. This thesis will only deal with the eastern part of the Eurasian steppe, including the regions of the Altai-Sayan Mountains (the Upper Ob, the Altai, the Minusinsk and Tuva), modern-day Kazakhstan, Mongolia, and Lake Baikal. People living in this territory were well-trained horsemen performing periodical herding strategies. Due to their highly mobile migration-based economic lives, their relics are overwhelmingly dominated by funerary monuments. Typical burial practices are the construction of burial mounds (kurgans) marked by stone-built fences or circles, animal sacrifices, and accompanying artefacts with zoomorphic motifs.

Beyond this pastoral sphere we encounter semi-sedentary societies engaging in animal husbandry alongside cereal cultivation. They have relatively more permanent settlements and, in addition to kurgan burials, they perform various funeral practices such as catacomb or pit-grave types. Their habitation includes the Northern Zone of China, the Hexi Corridor, the Hami Basin in Xinjiang, the forest-steppe zone of western Siberia, and the oasis areas in central Asia (Koryakova & Epimmakhov 2007, Ch.8; Wu 2007, 2008; Moskova & Rybakov 1992, Ch.1 to Ch.3).

(1) Tuva

By the first millennium BC, the territory of Tuva began to be densely populated by pastoral groups in terms of increasing numbers of kurgans and metal artefacts over the entire Early Iron Age. In general, Tuvinian-type barrows were constructed on the high ground near river banks. They were arranged meridionally in chains or along the river bank. The main body of the funerary structure is stone construction but with different burial chambers and arrangements of stone slabs. According to Grach (1971) and Gryaznov (1984) who have studied mortuary rites and artefact types of Tuvinian kurgans, there are three stages of development of archaeological cultures in Tuva: the Arzhan phase (9^{th} to mid-7^{th} c. BC); the early Uyuk culture (Aldy Bel' phase, mid-7^{th} to 6^{th} c. BC); the late Uyuk culture (Sagly phase , 5^{th} to 3^{rd} c. BC).

The burial practice in the first phase is reflected by a dome-shaped structure which covers the deceased in a cist (Bokovenko 1995: 265-267). The tomb is encompassed by a circular stone fence. Skeletons tend to lie on their sides with their legs and arms bent. The most famous examples are the Arzhan I and Arzhan II kurgans found in the

Usinskaya Basin. The Arzhan I kurgan is an enormous burial complex with a cylindrical stone structure measuring 120 m in diameter and 4 m in height. The kurgan consists of a circular building complex made of 70 large wooden chambers, each divided by large larch logs. This complex was built upon stone foundations. In the centre chamber we found human remains of a "king" and "queen" in log coffins, accompanied by six horse skeletons and other attendants. The Arzhan kurgan yields a lot of steppe-style artefacts which can link to the mobile pastoralists in Europe. The radiocarbon dates for the Arzhan I fall between the 9th and 8th cal. BC, which is earlier than the Scythian remains found on the northern shore of the Black Sea.

The scale of kurgans in the Aldy Bel's phase tend to be more modest than the previous stage (Moskova & Rybakov 1992: 185-192). In addition to burials with a circular stone fence, a new rectangular stone fence was used. The dead were placed in either a stone cist or a wooden log coffin. The bottom of the tomb was covered with stone slabs or pebbles.

The Sagly phase marked the continuous development of funerary practices (Moskova & Rybakov 1992: 185-192). The kurgans now were dug deeper and surrounded by rectangular stone fences. The use of log coffins increased in number and we also encounter many collective burials. The most apparent change of material culture during this period were the increasing numbers of iron products and the diversity of clay vessels.

Above all, the burial structures in Tuva demonstrate a certain uniformity except for the variations of the containers for the dead. Categories of steppe-style artefacts basically share a similar trend with the Tagar bronzes in the Minusinsk Basin (Figure 3.).

(2) Altai

The Altai region composes of two major groups relying on different subsistence strategies. The southern part features mountainous valleys suitable for the vertical migration of herding activities. The northern Ob river basin has more settlements engaging in both primitive agriculture and cattle breeding (Moskova & Rybakov 1992: 161).

The main chronological sequences are suggested by Bokovenko (1995:259) as follows: the early stage (8th to 6th c. BC) and the Pazyryk stage (5th to 3rd c. BC). The early stage

of burials in mountain ranges is represented by small kurgans surrounded by a circular stone fence. The deceased were covered with stone and placed in the cist. The bodies were laid on their left sides, with arms and legs contracted. Horses were buried near the human remains. The grave goods include steppe-style daggers, knives, horse bridles, pick-axes, arrowheads, and unique crescent-shaped breastplates worn by male warriors (Figure 3.15). Deer stones and numerous petroglyphs are also discovered in the early stage.

The subsequent period was marked by the well-known Pazyryk culture named after the rich Pazyryk kurgan. Burials during this stage basically inherit the structure of the early phase: small kurgans were surrounded by a circular stone fence. The burial mound is up to one metre in height. Harnessed horses were sometimes buried to the north of the deceased who were placed either in log coffins or stone boxes. The Pazyryk kurgans are the largest burials during this period. They were enclosed by stone rings measuring between 40 to 60 m in diameter and more than 2 m in height. Tombs were reinforced by wooden frameworks and the dead were placed in log coffins. Due to the frozen soil, plenty of organic artefacts such as wood, leather, fur, felt, wool, and silk are well-preserved. Judging from the grave inventory, Altaian peoples were in close contact with ancient Persia and China (Figure 3.).

Burials in the Ob valleys can be divided into two phases corresponding to the chronologies of kurgans in the Altai Mountains (Moskova & Rybakov 1992: 177-178). The tombs consist of an oval pit about half a metre in depth. The deceased ware laid in a crouched position on the side. The grave inventory tends to be very poor, with occasional finds of copper articles (Figure 3.15). The residents in the Ob regions may have been subject to raids from their nomadic neighbours. One example shows a bronze arrowhead embedded in the thigh of a male body in a grave.

(3) Minusinsk Basin

The Minusinsk Basin during the Early Iron Age was occupied by the Tagar culture (Chlenova 1967). It is believed that this culture had evolved from the previous Karasuk culture (Teploukov 1929; Gryaznov 1968). Burials from transitional periods between Karasuk and Tagar cultures (10^{th} to 9^{th} centuries BC) exhibit the traits of the different groups involved. Based on object typology, Gryaznov (1968) divided the Tagar culture into four phases: Bainovo (7^{th} to 6^{th} c. BC);

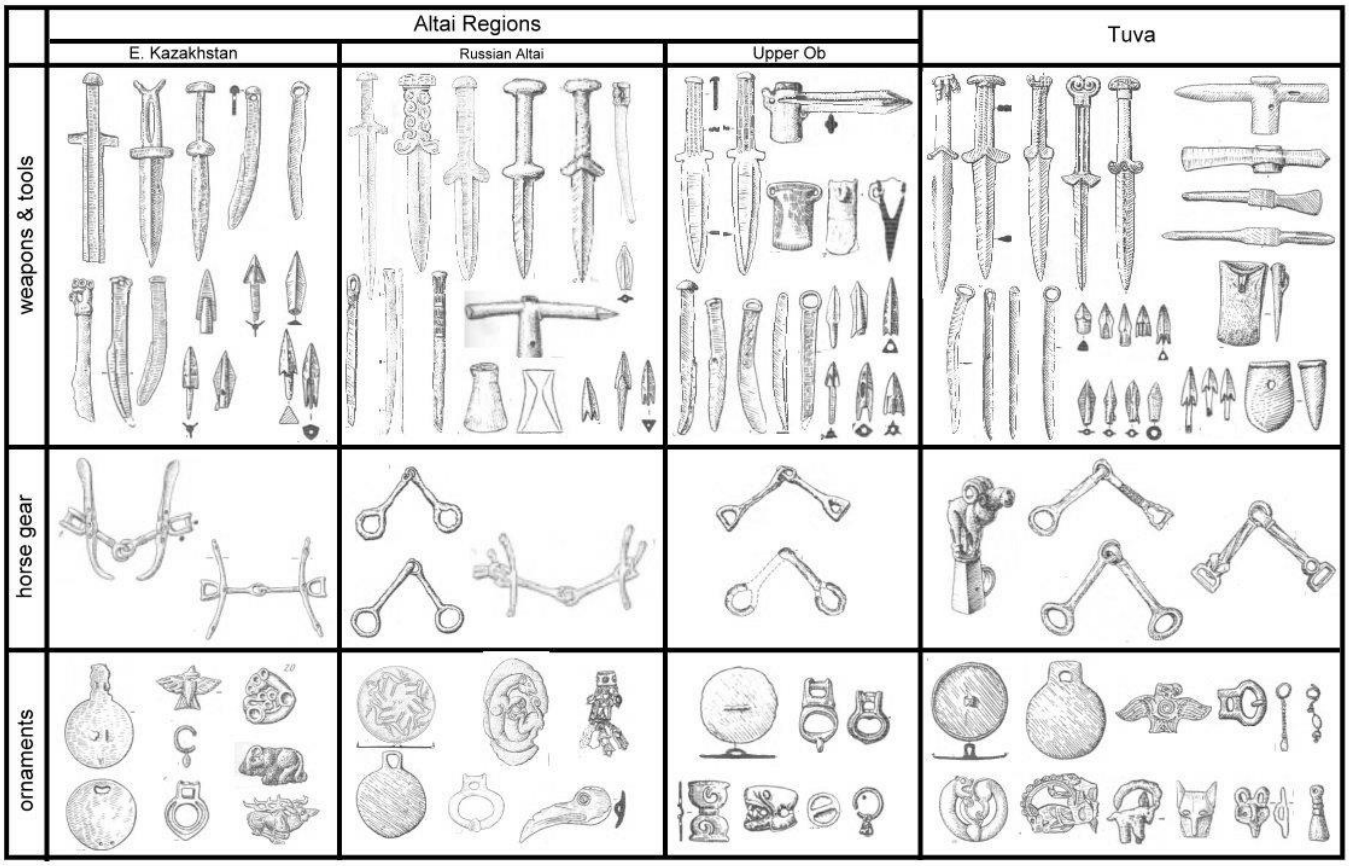


Figure 3.15 Metal artefacts from the EIA Tuva and Altai. From Moskova & Rybakov (1992).

Podgornovo (6th to 5th c. BC); Saragash (4th to 3rd c. BC); Tes (2nd to 1st c. BC). However, radiocarbon dates suggest a range from 10th c. BC to 1 c. AD (Svyatko *et al.* 2009).

In general, the burial is constructed with vertical stone slabs forming the enclosure on the surface (Bokovenko 1995 & 2006). The stone fence, reinforced by several stelae as corner stones, encompasses a raising pyramidal mound. In the early phases, the grave contained only one or two deceased buried inside the stone cist. The single burial gradually gave way to the collective burial interred with up to 200 people. The stone-cist practice also changed to timber-frame structures with multi-layered floors. Meanwhile, the tombs increased in size and depth over time and some burials contained above-ground structures.

In the male tombs drinking vessels, perhaps containing liquid, were placed by the deceased's heads and some meat by their feet. A dagger and a battle axe were set nearby the male body, along with a knife on the left side of the belt and a quiver with arrows adjacent to the feet (Chlenova 1992: 211). A dead woman usually carries a mirror and a comb in a small bag. The clothes are adorned with numerous beads and pendants.

The most remarkable legacy of the Tagar culture is its bronze inventory. A variety of copper-based artefacts with vivid zoomorphic ornament witness the sophisticated bronze metalwork in the Minusinsk Basin, including daggers, battle-axes, arrowheads, single-bladed knives, horse harnesses, and animal-style adornments (Figure 3.16). These "steppe-style" artefacts were also widespread in the regions of the eastern Eurasian steppe.

Overall, the tomb structure, grave furnishing and funerary rituals in the Tagar communities followed a continuous local development. The changes in material culture are due to internal adjustment rather than external pressure from immigrants (Bokovenko 2006: 877).

(4) Western Mongolia

During the early phase of the Early Iron Age, funeral practices in the western part of Mongolia resembled those found in Tuva and Altai: the construction of kurgan burial, stone cists as coffins, and the deceased in crouched position with the head towards the west or northwest (Volkov 1995: 324). Unfortunately, there are almost no grave goods inside the burials, which makes it difficult to investigate their material culture further.

By the second half of the first millennium BC, a metal-producing community arose in western Mongolia, named as the Ulangom culture (Novgorodova 1989:257-286). It was discovered in the vicinity of Ulangom city in northwestern Mongolia, near the border of the Tuva Republic. Burials are pit-grave type without surface makers. The coffins are in the forms of the log chamber or stone cists. The body was placed in a crouched position with the head towards the northwest. The distribution of grave items seems to follow a certain order. Daggers and battle-axes were found near the hip of the dead. Mirrors, awls, and single-edges knives were placed adjacent to the waist (Figure 3.16). The southeastern corner of the burial chamber was reserved for the ritual practices associated with bones of sacrificial animals (sheep, dogs, and horses), traces of ashes, and clay pots with food remains. After comparing recovered metals and ceramic assemblage with those in Tuvinian kurgans, the Ulangom cemetery can be roughly dated to around the 5th to 3rd centuries BC (Volkov 1967).

(5) Transbaikal, Cisbaikal, and eastern/central Mongolia

Mobile pastoralists in the Lake Baikal regions and eastern/central Mongolia are different from those of Eurasian steppes in terms of osteological evidence. It is believed that early Iron Age populations in these areas were based on the preceding Bronze Age hunter-gatherers with Mongoloid features, unlike the Europoid type of Scythians (Moskova & Rybakov 1992).

During the Early Iron Age these regions were occupied by the so-called "Slab-Grave Culture" (Moskova & Rybakov 1992: 247-254). This name derived from its unique stone-built burials. The surface of the tomb is vertically placed with flat stone slabs. The deceased are buried in the pit underneath, mostly in a supine position with their heads oriented towards the east. The pit is usually dug in a rectangular shape and filled with numerous irregular stones. The dead are sometimes put in stone cists and the skulls of sheep, horses, and cows laid nearby the heads or feet of corpses.

The majority of tombs are very poor in burial contents. Tsybiktarov (1998) has reported that 295 out of 542 graves are without grave goods. When artefacts are present, they are mostly ceramics, bronze articles, and beads made of argillite, pyrophyllite, glass, turquoise, carnelian, malachite, cowrie shells, and gold. Ceramic vessels are characterised by two types: flat-bottomed containers and cordoned tripods with snake-like decorations. Bronze objects include daggers, single-bladed knives, horse harnesses, cauldrons, socketed axes, mirrors, plaques and belt ornaments (Figure 3.16). Known settlements of this culture are quite few but there are metallurgical remains of copper and iron production. Another remarkable feature of this culture is the depiction of deer stones. They usually served as the cornerstones of tombs, depicting deer images and warriors' weaponry.

This culture is also extended to eastern and central Mongolia and the eastern part of Inner Mongolia (Hulunbuir plateau) where similar structures of burials have been reported (Davis-Kimball *et al.* 1995; Erdenebaatar 2002; Wu 2008: 56-57). As far as the origin of this culture is concerned, current archaeological evidence does not yet provide a certain answer.

The chronology of this culture seems to last for quite a long span. Radiocarbon dates suggest the range between the 11th and 3rd centuries BC (Tsybiktarov 1998: 103-104; Wu 2008: 402-416).

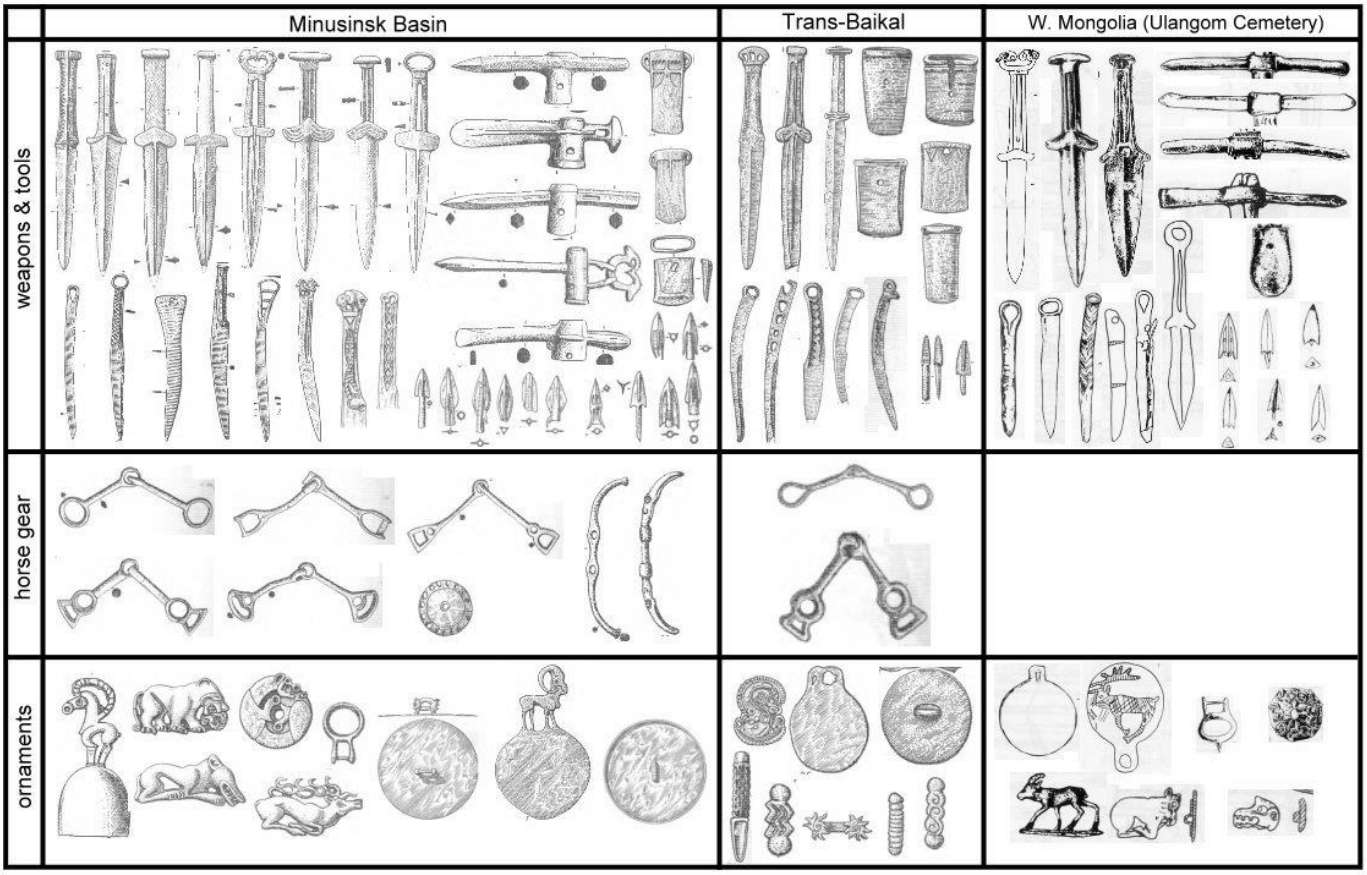


Figure 3.16 Metal artefacts from the EIA Minusinsk, Trans-Baikal and W. Mongolia. From Moskova & Rybakov (1992); Novgorodova & Volkov (1982).

(6) Kazakhstan and Transurals

The material culture of pastoralists in these regions is manifested by numerous kurgan cemeteries known as "Tasmola" type, dated to around the 7th to 3rd c. BC (Kadrybayev 1966). The cemeteries generally consist of 10 to 15 kurgans and each of them is encompassed by a circle of stone with a single pit-grave underneath. The burial mounds are normally under 10 m in diameter and 0.2 to 1 m in height and the deceased buried inside are covered with stone slabs.

The most remarkable burial ritual is represented by the kurgans "with mustache" (Kadrybayev 1966: 431-432). This type of funeral monument is composed of a large kurgan, two satellite kurgans, and two lines of stone arrangement connecting the large to small mounds. While large kurgans are interred with deceased persons, small accompanying burials usually contain horse skeletons and ashes indicating some sort of fire cult.

Accompanying metal artefacts primarily include arrowheads, horse harness, single-bladed knives, and animal-style ornaments (Figure 3.17). Bronze arrowheads are the most frequent finds, either designed as socketed or tanged types. The next major metal

assemblage is the horse harness including bridle bits, cheek-pieces, decorative strap plates and buttons. Horse bits with either stirrup-shaped or ring ends demonstrate the variety of horse-riding cultures. Zoomorphic representations are popular themes for personal adornments such as belt plaques, costume decorations, or horse trappings.

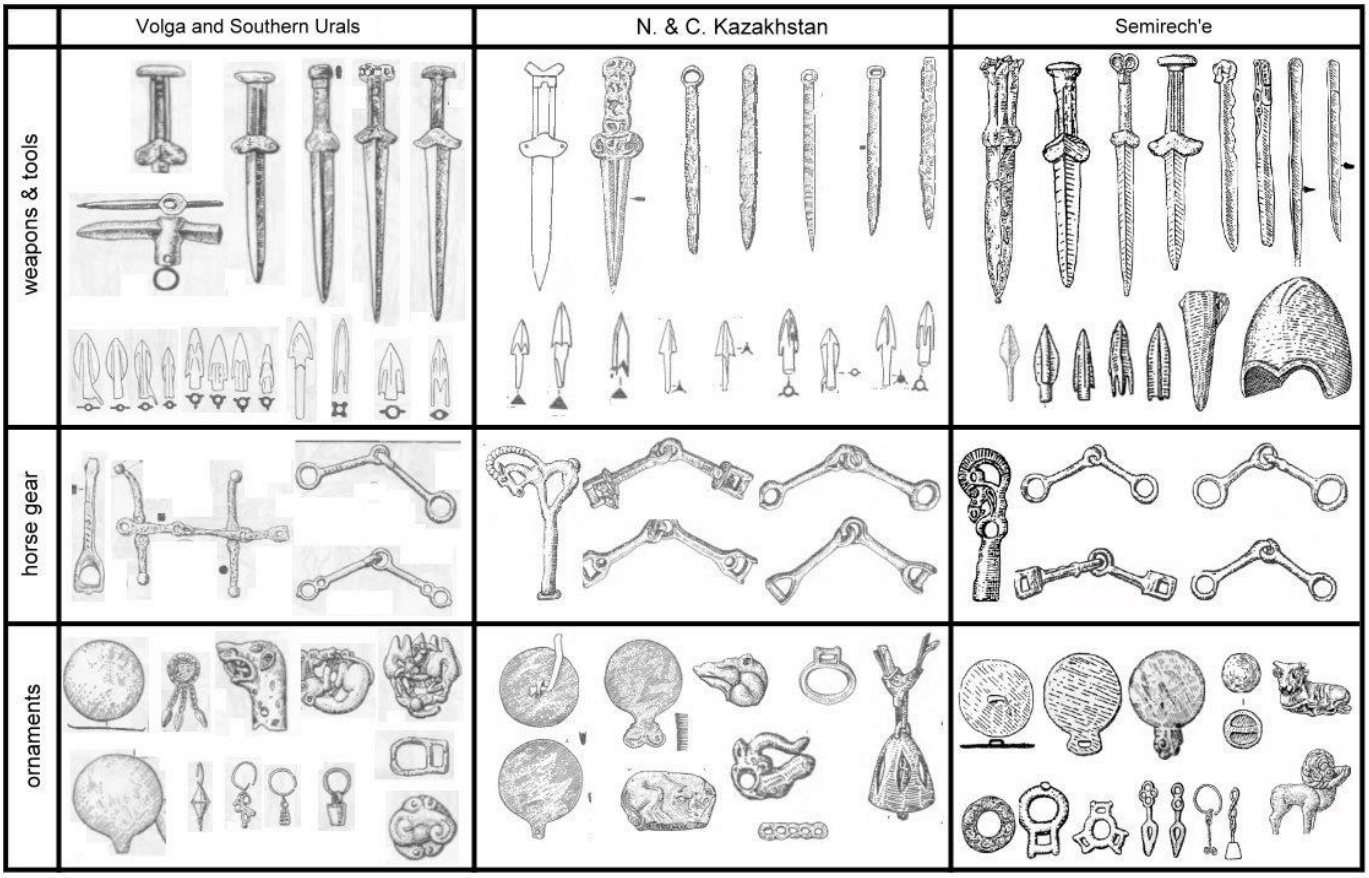


Figure 3.17 Metal artefacts from Kazakhstan and southern Urals. From Moskova & Rybakov (1992).

(7) Northern Zone of China

The "Northern Zone" is situated along the border provinces of present-day northern and western China (Watson 1971; Lin 1986). It is the contact zone between mobile pastoral groups in the Eurasian steppe and settled agricultural Chinese dynasties in the Central Plains. This transitional area was inhabited by several semi-sedentary groups during the Early Iron Age. Presented below are a general overview of the Northern Zone cultures summarised by Wu (2007 & 2008).

The Upper Xiajiadian culture occupies the eastern part of Inner Mongolia and northeastern China. It is dated to between the 11th and 7th centuries BC on the basis of both radiocarbon dating and the typology of central Chinese bronze vessels (Wu 2007:

170). Most of our knowledge about these peoples come from their burials, yet few settlements and ritual relics are known. General burial grounds consist of three types: stone-structured tombs; stone-slab tombs, and pit graves.

In the stone-structured tomb, a vertical pit was dug out and the dead were placed inside wooden frames. One stone slab was put on the top and the other on the bottom to form a rectangular coffin with frames. The space between the wall and coffin was filled with stone blocks. This type of burial usually yields abundant accompanying artefacts, considered as the high-ranking cemetery. The stone-slab tomb contains a rectangular pit lined with several large stone slabs, covered with stone slabs. The final type of grave is a simple pit with timber structures.

The economic life of the Xiajiadian people is quite diverse. They were settled agriculturists, raising pigs and poultry. Animal husbandry and hunting played a minor role. They might have exploited the copper deposits in Linxi to produce a variety of bronze assemblage, including daggers with leaf-shaped blades, helmets, shields, arrowheads, pick-axes, knives, horse bits, and zoomorphic ornaments (Figure 3.).

The Shieertaiyingzi culture is mainly situated in Liaoning, Northeast China, dated to the 10^{th} - 4^{th} centuries BC in terms of archaeological stratigraphy and the cross-comparison with Chinese bronzes. The burials contain shaft-pit and stone-structured graves. People engaged in a sedentary lifestyle supplemented by animal herding, fishing and hunting. Typology of metal objects highly resembles the Upper Xiajiadian parallels, suggesting their affinity of bronze-making traditions (Figure 3.18).

Distribution of the Upper Zhangjiayuan culture focusses on northeast Hebei Province. According to the dates of central Chinese bronzes found in their burials, its chronology ranges from the 11^{th} to the early 8^{th} centuries BC. In the early stage, the tomb contains a rectangular pit with wooden boards on the bottom. The dead were placed in a supine position, accompanied by a dog skeleton. These funerary rites are similar to western Zhou rituals, but abundant steppe-style grave goods suggest other influences from the steppe (Figure 3.18). The tombs in the later period feature slightly raised mounds and stone-slab coffins underneath. Zhangjiayuan people were also settled farmers who raised pigs and cows.

The Yuhuangmiao culture, disseminated over northern Hebei, developed immediately after the Upper Zhangjiayuan culture. According to the unearthed central Chinese

bronze artefacts, its dates are placed between the 8th and 5th centuries BC. The burial structures consist of a rectangular pit with either timber frames or stone slabs as coffins. The practice of animal sacrifices is prevalent including horses, sheep, cows, pigs, and dogs. Only the large-scale graves are buried with horse remains. Every cemetery contains several dozens to hundreds of burials. Typical steppe-style daggers, knives, and personal adornments are found in the grave assemblage (Figure 3.18).

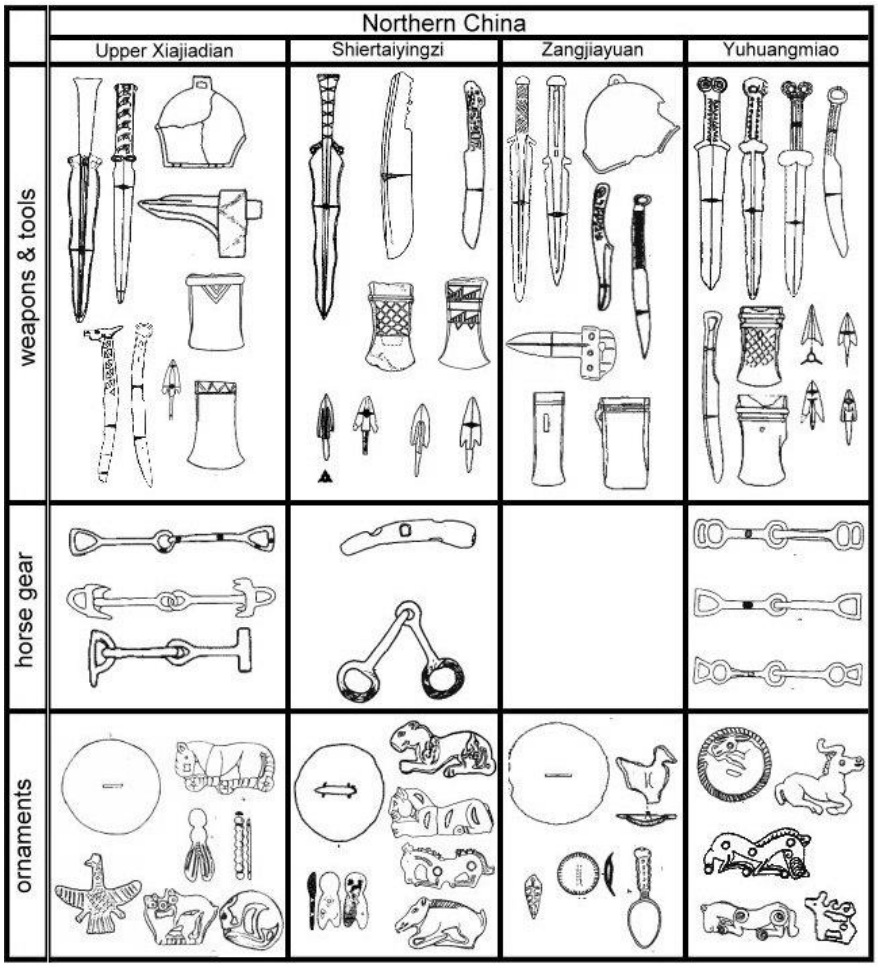


Figure 3.18 Metal artefacts from the Northern Zone (eastern part). From Wu (2008).

The Maoqingqou culture is located in the middle part of Inner Mongolia. Radiocarbon dates and typology of Chinese bronzes suggest a time span from the 7th to 3rd centuries BC. Two major burial types are documented: east-west oriented and north-south oriented tombs. The E-W graves consist of rectangular pits without any coffins. A large amount of steppe-style bronzes, along with heads or hoofs of horses, cows, and sheep, constitute indigenous elements. The N-S tombs usually have wooden coffins interred with bronze or iron belt hooks. Such different burial practices imply that several communities co-existed in the Maoqingqou culture. New types of steppe bronzes

started to emerge during this period, especially the daggers with antenna-style handles, zoomorphic bronze plaques, and small symmetric animal-style fittings (Figure 3.19). In the later stage of this culture, some iron artefacts, such as daggers, pick axes, and plaques, made their appearance. Maoqingqou people were mainly pastoralists judged from their species of animal sacrifices.

The Taohongbala culture refers to a series of the Early Iron Age burials uncovered from the Ordos region in the central part of Inner Mongolia. Radiocarbon dates and grave goods suggest a chronology between the 7th and 3rd centuries BC. The mortuary practice is represented by a simple rectangular pit buried with skulls and hoofs of horses, cows, and sheep. The dead were laid on their back with their head towards north and limbs stretched. Artefacts bear the typical steppe features: bronze antenna-pommelled daggers, plaques with animal combat scene, deer figurines with coiled antlers, zoomorphic pole finials, and the extraordinary gold headdress (Figure 3.19). Taohongbala people were nomadic pastoralists because no pig remains (related to sedentary lifestyle) or settlements have been found in this culture. Abundant horse and sheep remains suggest the active role of animal herding.

The Yanglang culture mainly concentrates in Ningxia and eastern Gansu. According to the cross comparison with central Chinese bronzes, it is dated to between the 7th and 3rd centuries BC. This culture differentiates itself with other Northern Zone communities due to its unique funeral arrangement. The tombs are constructed in the form of a catacomb, with additional space dug into the wall of a rectangular or square pit. Most of the grave goods and animal remains are placed in the pit. The Yanglang bronze assemblage consists of typical steppe-style artefacts, yet no Chinese bronze ritual vessels have been found (Figure 3.19). The artefact types resemble those found in the Taohongbala and Maoqinggou cultures. The economy relies heavily on animal husbandry including domesticated horses, sheep, and cows. Material evidence associated with the sedentary lifestyle (e.g. agricultural tools, pig skeletons, or settlements) have not yet been discovered.

In sum, archaeological cultures in the Norther Zone are extremely diverse. Each cultural group seems to perform varied funerary rituals and subsistence strategies suitable for their specific natural environments. For instance, communities living in a more humid climate, such as northeastern China, tended to engage in more cereal cultivation and

their material culture was mixed with central Chinese burial and bronze-producing traditions. In contrast, societies in the arid part of Inner Mongolia developed a more mobile lifestyle based on livestock raising.

Despite these differences, the production of steppe-like bronze artefacts seems to be commonly shared by northern Chinese groups. Offensive weapons, tools, and animal-style adornments are widespread in the bronze assemblage among all cultures. Meanwhile, influences from central Chinese metalwork are also visible in the eastern part of northern China. Therefore, the Northern Zone has a great potential to demonstrate the metallurgical interaction between mobile pastoralists and settled farmers.

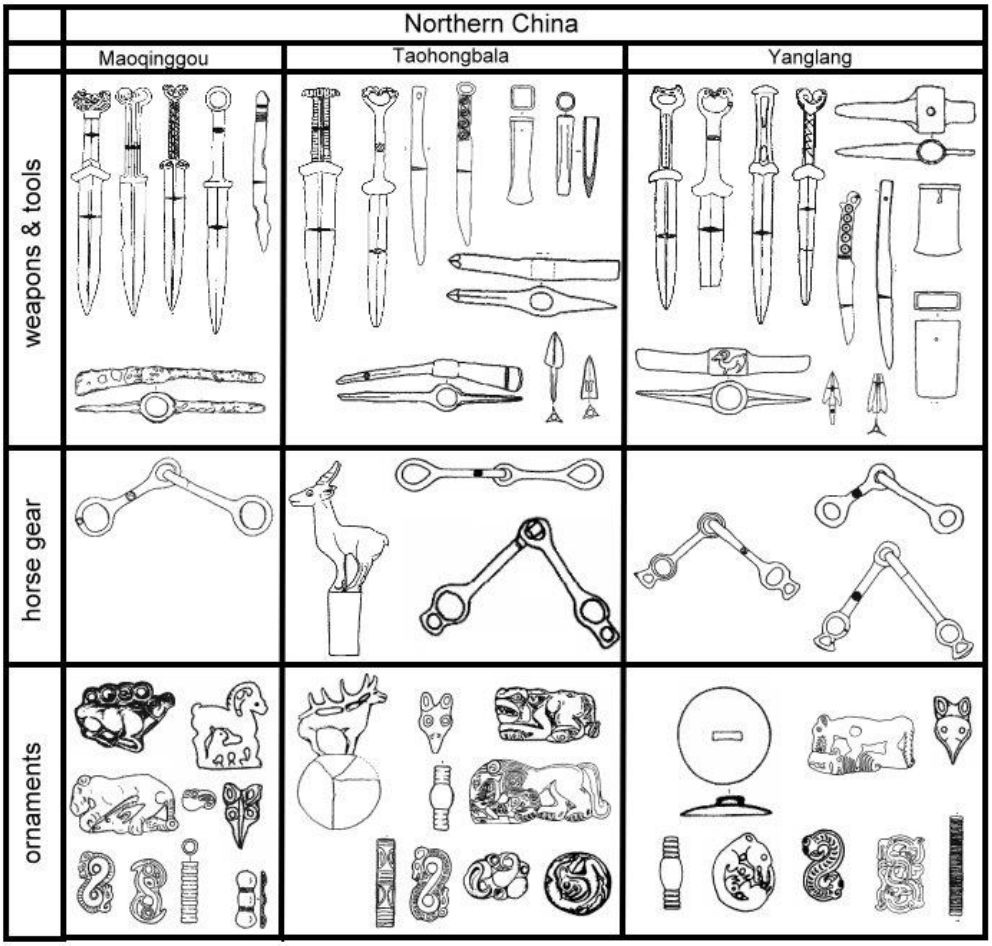


Figure 3.19 Metal artefacts from the Northern Zone (central and western parts). From Wu (2008).

3.3 Mining and smelting in the prehistoric Eurasian steppe

Even though this thesis primarily deals with changes in artefact chemistry to answer the question regarding metal circulation, it is essential to highlight probable ancient mining and smelting sites and relevant techniques that serve as the basis of metal production in the Steppe. Figure 3.20 plots the distribution of mining sites with traces of ancient workings. A quick look at it shows four concentrated regions for copper extraction in antiquity: the Ural Mountains, central and northern Kazakhstan, the Altai Mountains and the Yenisei River basin (Minusinsk and Tuva). This can help us be aware of possible ore sources that contribute to the flow of metals. Furthermore, remains of possible smelting debris (e.g. slags, furnaces, tuyères, or crucibles) recovered from many Middle and Late Bronze Age settlements may witness multiple settlement-based primary metal productions across the Steppe (Figure 3.21 & 3.22). However, without the detailed scientific examinations, it is often very difficult to draw a firm conclusion whether they are actually products of smelting activities or simply the remains of copper melting.

Compared to abundant chemical data of finished artefacts, the analyses of ores and slags from archaeological sites are still limited and occur only occasionally in some archaeometallurgical reports (e.g. Sunchugashev 1969 & 1975; Kiriushin & Tishkin 2003; Kuznetsova &Teplovodskaya 1994). By far the most informative and extensive research into steppe smelting technologies is conducted by Grigor'yev (2015). He has analysed 2331 specimens of slags and ores throughout the Bronze Age steppe cultures, by means of detailed mineralogical and chemical examinations. The following discussions are chiefly based on his research outcomes.

3.3.1 Mining and smelting in the Sintashta and Petrovka cultures

Grigor'yev (2015) has undertaken chemical and mineralogical studies on 113 ore samples from both Sintashta and Petrovka settlements, including specimens from adjacent ancient copper mines in the Urals (e.g. Tash Kazgan, Miley-Yurt and Ust-Kabansky). He concludes that Sintashta metallurgy is primarily characterised by the smelting of oxidised ores from ultrabasic rocks, mostly malachite in a serpentine matrix (Ibid. 107). This type of deposits in the Urals can be found in Vorovskaya Yama, Ishkininskoye, Ivanovskoye, Dergamyshskoye, and Elenovka on the southeastern slope of the Ural Mountains (Zaykov *et al.* 2005). (Ibid. 154).

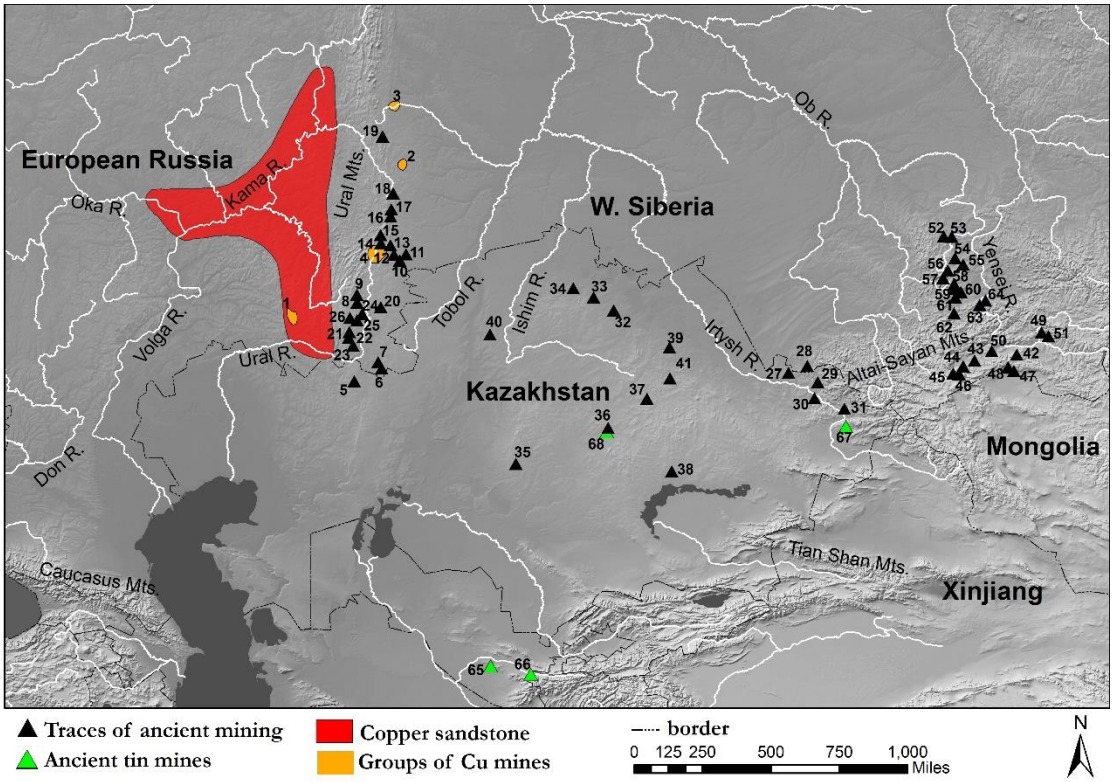


Figure 3.20 Map showing distribution of ore deposits and ancient mining sites on the Eurasian steppe. Data from Chernykh (1970, p. 37, fig, 32); Grigor'yev (2015, p.101, fig. 3-1, p. 357, fig. 8-1, p. 561, fig. 11-4).

1. Kargaly. 2. Blagodatnyi. 3. Verkhoturinsky. 4. Kiryabinskoye. 5. Dzhengana. 6. Ush-Katta. 7. Elenovka. 8. Kamyshly-Uzyak. 9. Bakr-Uzyak. 10. Polyanovskoye. 11. Kichiginskoye. 12. Tash-Kazgan. 13. Nikolskoye. 14. Mednaya Gora. 15. Berezovaya Gora. 16. Soimonovskoye. 17. Sugurskoye. 18. Gumeshki. 19. Mednorudyanskoye. 20. V orovskaya Yama. 21. Ivanovskoye. 22. Dergamyshskoye. 23. Ishkininskoye. 24. Sibauskiy. 25. Baymaksiy. 26. Yuluk. 27. Zmeinogorskiye. 28. Kolyvanovskiye. 29. Charyshsko-Anuyskaya. 30. Irtshskaya. 32-34. Kochetavskogo. 35. Dzhezkazgan. 36. Kenkazgan. 37. Uspensko-Spasskogo. 38. Balkhash. 39. Ekibastuzsko-Bayanaul'skogo. 40. Atbasar-Tersakkanskogo. 41. Karkaralinskiye. 42. Khovu-Askv. 43-44. Mining along the river. 45. Sukhom Logu. 46. River Ak-Khem. 47. River Yubyur Ungeshu. 48. River Kadvoy. 49. Stream Terektyg. 50. Arguzun-Ak-Durug. 51. Kzyzl-Torg. 52. Pechishche. 53. Chulym. 54. Itkul. 55. Yulinskoy. 56. Ulen. 57. Temir. 58. Uzui-Zhul'. 59. Lake Bulan-Kul'. 60. Bol'shoy & Malyy Syry. 61. Baza. 62. Butrakhty. 63. Mayna. 64. Sunery.

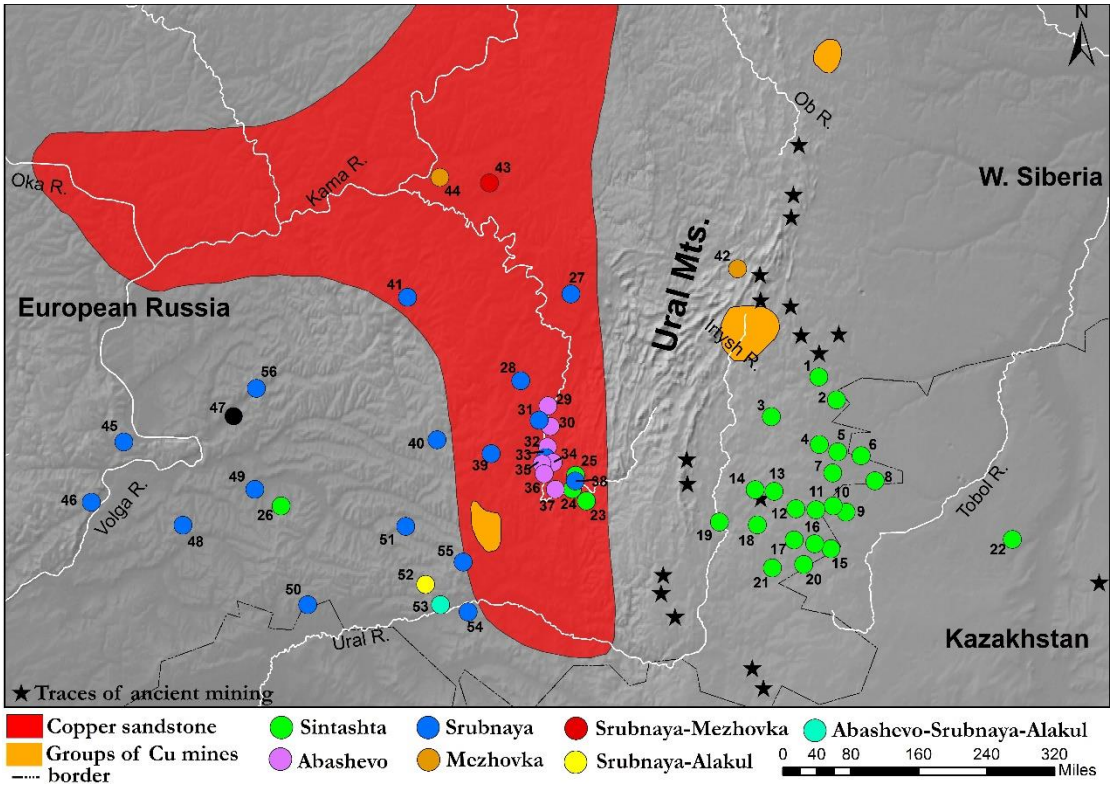


Figure 3.21 Map showing distribution of the Bronze Age smelting sites on the Volga-Ural regions. Data from Chernykh (1970, p. 37, fig, 32); Grigor'yev (2015, p.101, fig. 3-1, p. 357, fig. 8-1, p. 420, fig. 9-1).

1. Stepnoye. 2. Chernorech'ye III. 3. Bakhta. 4. Parizh. 5. Ust'ye. 6. Chekatay. 7. Rodniki. 8. Iseney. 9. Kamysty. 10. Kamennyy Ambar. 11. Zhurumbay. 12. Konoplyanka. 13. Sarym-Sakly. 14. Kuysak. 15. Andreyevskoye. 16. Sintashta II. 17. Sintashta. 18. Arkaim. 19. Kizil'skoye. 20. Bersuat. 21. Alandskoye. 22. Semiozerki. 23. Tyubyak. 24. Beregovskoye I. 25. Beregovskoye II. 26. Utevka. 27. Baygil'dino. 28. Chishminskoye. 29. Balanbash. 30. Urnyak. 31. Novobaryatino. 32. Yumakovo I. 33. Yumakovo II. 34. Yumakovo III. 35. Beregovskoye I. 36. Beregovskoye II. 37. Tyubyak. 38. Verkhnebikkuzino. 39. Sergeyevskoye. 40. Aitovo. 41. Sasykul. 42. Yukalekulevskoye. 43. Novokizganovo. 44. Kakrykul-Rudniki. 45. Shigonskoye II. 46. Lipovyy Ovrag. 47. Popovo Ozero. 48. Mikhaylo-Ovsyanka. 49. Syezzheye. 50. Kuz'minkovskoye. 51. Tokskoye. 52. Pokrovskoye. 53. Rodnikovoye. 54. Nizhnepavlovskoye. 55. Gorny. 56. Kibit I.

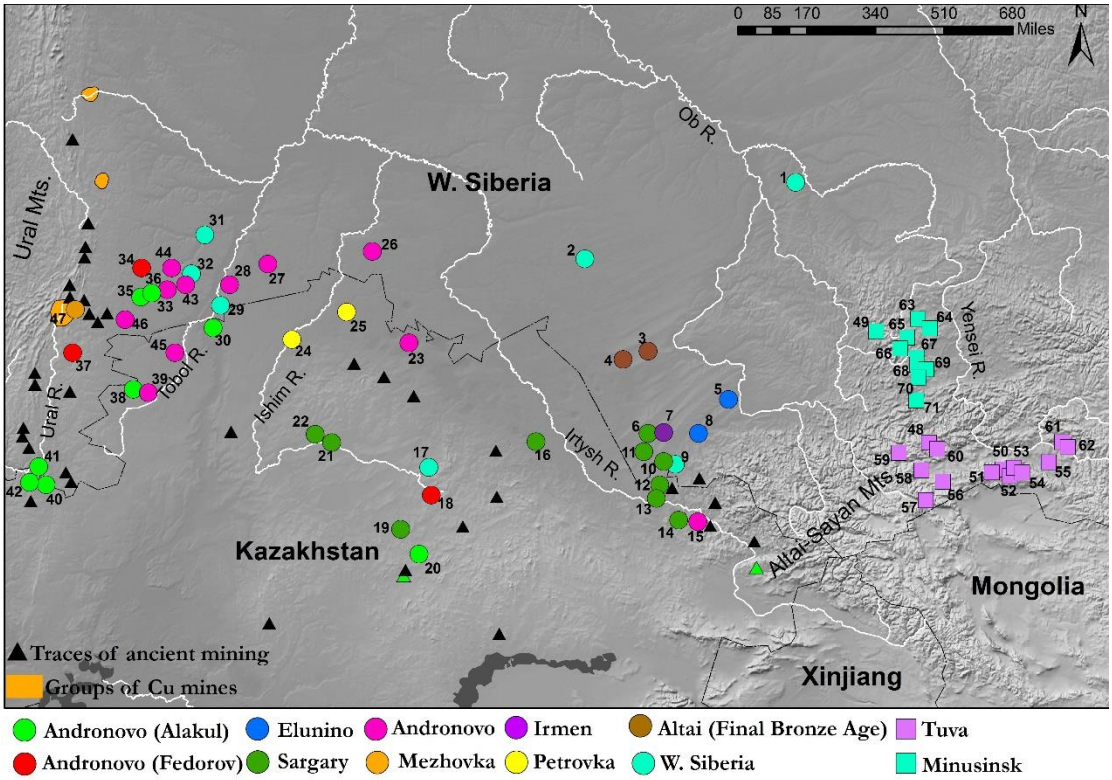


Figure 3.22 Map showing the Bronze/Iron Age smelting sites on the eastern Eurasian steppe. Data from Grigor'yev (2015, p. 561, fig. 11-4); Sunchugashev (1969, 1975).

1. Novokuskovskaya. 2. Markovo-2. 3. Burla-3. 4. Kaygorodka-3. 5. Berezovaya Luka. 6. Kalinovka II. 7. Chernaya Kur'ya VI. 8. Kolyvanskoye I. 9. Noven'koye-6. 10. Sovetskiy Put'-1. 11. Rublevo VI. 12. Chekanovskiy log-1. 13. Gilevo II. 14. Novoshul'binskoye. 15. Chistyy Yar. 16. Kafarka. 17. Vishnevka. 18. Ust'-Kenetay. 19. Kent. 20. Atasu. 21. Tel'mana XVI. 22. Sargary. 23. Stepnyak. 24. Petrovka II. 25. Petrovka. 26. Novonikol'skoye. 27. Kamyshnoye. 28. Yazevo. 29. Berkhnyaya Alabuga. 30. Ubagan. 31. Korshunovo. 32. Tashkovo II. 33. Kipel'. 34. Graurtly. 35. Mochischche. 36. Korkino. 37. Il'yaska. 38. Bersuat XVII. 39. Atamanovka. 40. Kupukhta. 41. Baytu. 42. Shandasha. 43. Malookunevskoye. 44. Novoburino. 45. Nikolayevka. 46. Arkhangel'skiy Priisk II. 47. Novo-Bayramgulovskoye. 48. Karty. 49. Poselytsik. 50-51. Khovu-Aksy. 52-53. On-Kazhaa. 54. River Chumurtuk. 55. Lake Cheder. 56. River Dagyr-Shemi. 57. Bog-Day. 58. River Khemchik. 59. Lake Karakol. 60. Village Kuzhe-Bazy. 61. Kyzyl-Torg. 62. Bay-Syut. 63. Itkul. 64. Yulinskoy. 65. Ulen. 66. Temir. 67. Uzui-Zhul'. 68. Lake Bulan-Kul'. 69. Bol'shoy & Malyy Syry. 70. Baza. 71. Butrakhty.

According to Grigor'yev (2015), slags recovered from Sintashta settlements mainly concentrate on individual household rather than specialised workshops (Ibid. 120). The mineralogical study reveals four types of slags in the Sintashta settlements (Ibid. 128-134, also see Table 3.3). Type I consists of abundant chromite grains with olivine crystals and magnetite, related to ultramafic rocks. It generally bears high arsenic concentration (up to 0.5%). These chromite-containing slags are absent in the subsequent Late Bronze Age specimens. Type II is represented by slags with quartz grains associated with quartz rocks. Its arsenic level is usually lower than 0.03%. Type III features slags with mixture of chromite and quartz, which bears both high and low arsenic content. The Type IV comprises slags with a high portion of cuprite prills reaching as high as 50%.

Figure 3.23 demonstrates the distribution of slag types from the Sintastha to Petrovka periods. It is apparent that Type I and III slags with chromite inclusions, presumably sourcing from ultrabasic ore deposits, are dominant in the Sintashta settlements. Their portions are gradually decreasing as the transition to the Petrovka period takes place. In order to search for possible deposits mined by Sintastha people, Grigor'yev (2015:147-149) compares shapes and chemical composition of chromite in slags with those of ultrabasic deposits in Vorovskaya Yama, Ishkininskoye, and Ivanovskoye, Dergamyshskoye, and considers Ishkininskoye ore field as a possible candidate for the Sintastha metal production.

During the transitional (Sintastha-Petrovka) and Petrovka periods, there was a gradual shift from the use of oxidised ore from ultrabasic rocks to those from quartz rocks .Grigor'yev (2015:142-143) argues that Petrovka metalworkers started to adopt a new source of more refractory quartz-bearing raw material, which requires high-temperature and longer-smelting time. They increased the air flow in order to reach higher temperature in the furnaces, leading to a more oxidising condition and the greater loss of copper being transferred into slags (Type IV). Therefore, Petrovka slags contain more cuprite and the copper content (around 3-5% in the slag samples), which is higher than those of Sintashta slags.

Apart from the direct copper smelting described by Grigor'yev. One may consider the possibility of co-smelting practice given the fact that traces of copper sulphides (mostly

Table 3.3 Mineralogical Types classified by Grigor'yev (2015).

Period	Culture	Mineralogical Type (% of total assemblage)							Total N
		I	II	III	IV	V	VI	uncertain	
MBA	Sintashta	59.2	15.8	22.4					76
	Sintashta-Petrovka	37.1	14.4	29.9	17.6				97
	Petrovka	13	4.4	8.7	65.2				23
	Abashevo (Cisurals)	28.6	21.4	10.7	25	14.3			28
	Elunino		86.7		13.3				30
LBA	Srubnaya (Cisurals)	33.7	26.2	3.3	27.5		9.3		66
	Srubnaya (Orenburg)	1.9	31.4		64.8		1.9		54
	Srubnaya (Volga)	39.1	4.3		21.7		34.8		23
	Alakul	8	4		80			8	25
	Fedorov				4.5		95.5		22
FBA	Sagary	20	40		40				5

Mineralogical Type	
Type I	oxide ores from ultramafic rocks; many chromite, olivine and magnetite inclusions; some secondary copper sulphides (covellite & chalcocite)
Type II	Oxide ores from quartz rocks; lack of iron composition; some secondary copper sulphides (covellite & chalcocite)
Type III	mixture of Type I and Type II
Type IV	many cuptire prills; relatively oxidising conditions
Type V	friable soot slags; oxide ores associated with copper sandstones; formation of cuprite; low temperatures (1050-1200°C)
Type VI	primary sulphide ores (pyrite and chalcopyrite); dendrites of wüstite; formation of fayalite ; high temperatures (1360-1400° C)

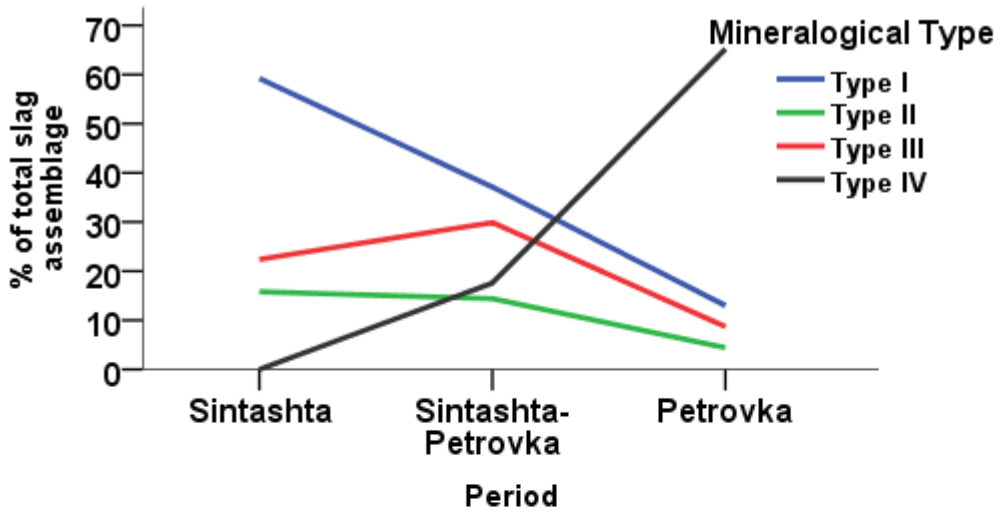


Figure 3.23 Chronological change in slag types from Sintashta to Petrovka periods. Data from Grigor'yev 2015:231, tab. 5.21).

covellite and chalcocite, some bornite, chalcopyrite, and tennarite) in slags. In practice, it is entirely feasible to use sulphur as a reducing agent to obtain metallic copper from oxide ores (Rostoker *et al.* 1989). Co-smelting carried out by Sintastha people may not be deliberate as it is common to have copper oxide ores with sulphide minerals. The Ishkininskoye mine, identified by Grigor'yev (2015) as one of major copper sources during the Sintashta time, is actually characterised by pyrite-pyrrhotite, chalcopyrite-prite-pyrrhotite and sulfoarsenic-sulfidic ores.

Another unique feature of the Sintashta metallurgy lies in a settlement-based smelting strategy (Donnan, personal communication). In studying the slags from the Stepnoye site, Hanks and Donnan (2009) conclude that they are mostly derived from refining or secondary processing step rather than primary smelting because Stepnoye slags do not contain any ore mineral or gangue inclusion. Such site differences are also implicitly suggested by Grigor'yev (2015: 108): that statistically copper ores from the Ust'ye settlement comprise higher concentrations of Mn, Pb and Ba, and ores from Arkaim are distinguished by higher arsenic. Consequently, it is not entirely correct to generalise the smelting technologies of Sintashta communities.

3.3.2 The presence of arsenic in Sintashta metallurgy

Arsenical copper/bronze no doubt plays an essential role in the steppe metalwork. Unlike tin bronzes in which tin can be added as the metallic form, copper-arsenic alloys are often associated with the introduction of arsenic-bearing minerals into the copper

smelt. To understand the manufacture of arsenical copper, one should explore the copper smelting process that is responsible for the potential alloying of arsenic.

Sintastha material, with ores, slags and finished products, provides the necessary evidence to study the appearance of arsenical copper in the Steppe. As a portion of Sintashta metals are represented by arsenical copper and arsenic-nickel copper, the emergence of copper-arsenic alloys becomes a popular topic in Eurasian prehistory (see Chapter 4 for more detail). Grigor'yev (2015: 108) notes that only eleven Sintashta ore samples (roughly 10% of the total assemblage) show relatively high concentration of arsenic (>0.1%), including three samples from the Tash Kazgan mines, two from the settlement of Ust'ye, one from Burli, two from Sergeevka, and three from Arkaim. Although Chernykh proposed that arsenical copper originated from the Tash Kazgan ore deposit in the Transurals (Chernykh 1992: 202), Grigor'yev casts doubt on this statement due to higher zinc content (>0.1%) within Sintashta ores than those from the Tash Kazgan mine. Furthermore, Tash Kazgan is a deposit developed from quartz rocks, contradicting most Sintashta ores with ultramafic rocks in origin. Tash Kazgan is therefore unlikely to have been exploited by Sintashta miners.

Chemical analysis of Sintashta ores and slags reveals an interesting result: arsenic is brought into copper at the stage of ore smelting rather than by direct smelting of copper-arsenic ores (Grigor'yev 2015: 155). According to Grigor'yev, the arsenic content in Sintashta slags is relatively higher than that of the ores (Figure 3.24), which is unlikely to be the result of smelting arsenic-rich copper oxide ores as arsenic is transferred into the raw copper rather than slags (Tylecote 1980). Moreover, the presence of nickel along with arsenic is quite common in Sintashta slags as some copper prills demonstrate high amount of As, Ni and Fe (Grigor'yev 2015, Tab. 5-4). In analysing Sintashta metals, Degtyareva (2010:87) observes around 20% of analysed objects with nickel concentrations from 0.2 to 0.96% and they also contain elevated arsenic content. Thus, Sintashta arsenic/nickel copper may originate from the addition of an arsenic-nickel mineral, possibly as nickel arsenide or nickeline (Grigor'yev 2015:157). Another possibility, in my opinion, is the recycling of high-arsenic copper objects from somewhere else as the majority of Sintashta metal artefacts do not have more than 2% arsenic (see Chapter 4).

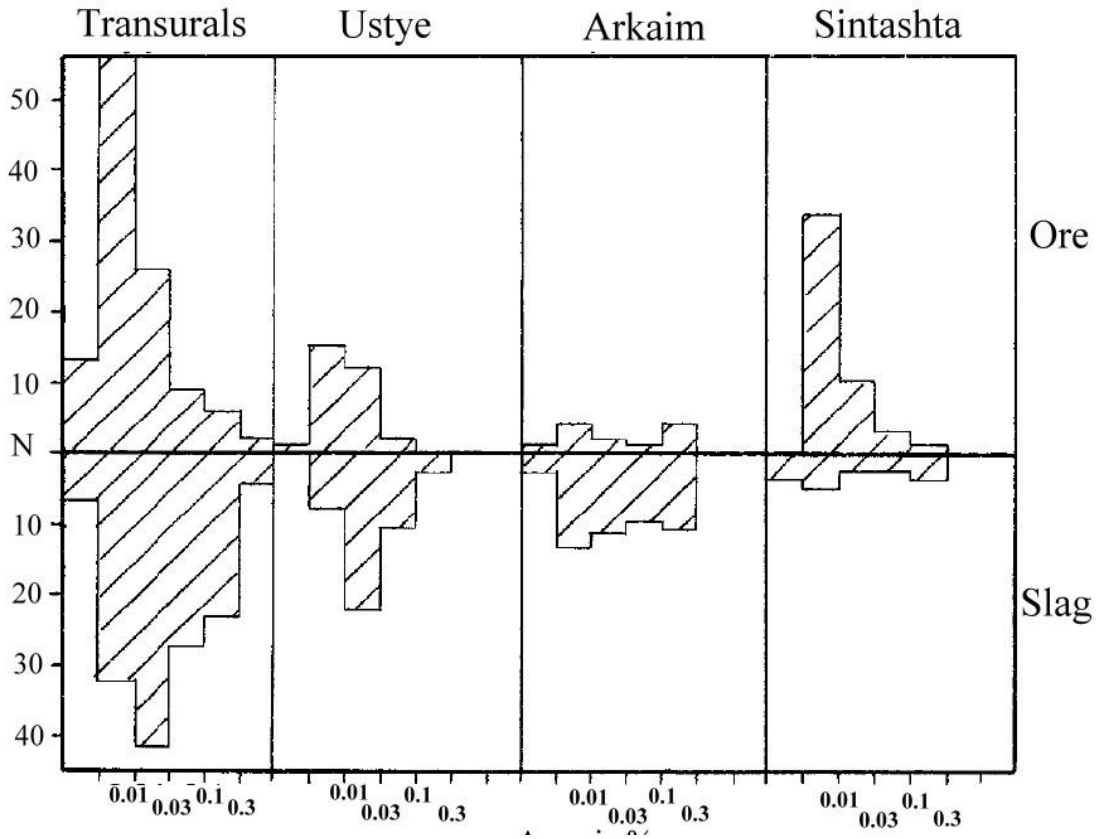


Figure 3.24 Comparison between arsenic concentrations in Sintashta ores and slags. It shows that slags contain relatively more arsenic than ores. From Grigor'yev (2015, Tab. 5-47).

3.3.3 Mining and smelting in the Abashevo culture

Abashevo settlements in the Cisurals (known as Balanbash type along the Belaya River) are situated in large copper sandstone deposits along the western slopes of the Ural Mountains. The primary ore minerals are malachite and cuprite, followed by chalcocite, covellite and bornite. Abashevo slags are similar to those of Sintashta in terms of their microstructures (Grigor'yev 2015:324, also see Table 3.3). Type I and Type II are marked by the presence of chromite inclusions associated with the origins of ultramafic rocks, and Type II is related to the sources of quartz rocks. Despise the use of different ore sources, these three slag categories were produced from similar smelting technologies, with a temperature of 1200-1300°C under reducing conditions (Ibid. 326). Type IV, corresponding to slags during the Sintashta-Petrova period, contains a number of cuprite grains suggesting a rather more oxidising atmosphere during the copper smelting (Ibid. 326).

The unique feature of the Abashevo smelting is the presence of Type V slags. They are relatively friable and possibly smelted from very pure oxidised ores related to silicate rocks with low iron content. The major ore inclusions are malachite, chrysocolla and cuprite. Grigor'yev (2015: 327) argues for the sandstone origin of Type V slags.

3.3.4 Mining and smelting in the SrubnayacCulture

According to Grigor'yev (2015), the Srubnaya slags come from three geographical areas: Cisurals, Orenburg (southern Urals), and Middle Volga, and each region engages in different copper smelting schemes. Slags from the Cisurals inherit the Sintashta-Abashevo traditions, represented mostly by the use of serpentinized ultramafic rocks (Type I and III), and secondary quartz-bearing rocks (Type II) (Grigor'yev 2015: 333-337). However, there is an increase in the use of chalcocite, bornite and chalcopyrite ores, indicating a transition to a new smelting technology of the sulphide ores (Ibid: 339-340). A new type of slags (Type VI) appears in the Srubnaya settlements of the Cisurals. According to Grigor'yev (2015: 339), these slags include dendrites of wüstite (FeO) and grains of pyrite. Some reduced iron is observed. Unlike other types of slags, quartz particles are extremely rare, which gives way to the formation of fayalite (Fe_2SiO_4) These pieces of evidence indicate the smelting of chalcopyrite from quartz rocks within a temperature 1360-1400°C under a reducing condition (judging from the molten surface of wüstite dendrites, Ibid. 339).

Smelting ores from sandstone deposits is evident in the Orenburg regions. Settlements in this area yield slags containing fragments of sandstones, smelted under rather oxidising conditions (Grigor'yev 2015:412). Both chemical analysis and microstructures of these slags resemble those from the Late Bronze Age Kargaly mining complex. Unlike the Orenburg areas, slags from the Volga are primarily smelted from the ultrabasic or quartz rocks (Ibid. 412).

Overall, moving from the Abasevo-Sintashta to the Srubnaya periods, copper smelting had gradually shifted from using copper oxide/carbonate ores to copper sulphide ores. This change brought forth new pyrometallurgical practices with control of atmospheres and high-temperature techniques. However, regional variations were quite apparent as metalworkers conducted copper smelting according to the properties of accessible ore sources (Grigor'yev 2015:419). This leads to different "expertise" of the Srubnaya metalworking preferences, such as the chalcopyrite smelting in the Cisurals and sandstone smelting in the Orenburg.

3.4 Mining and smelting in the Asian part of the Eurasian steppe

3.4.1 Elunino culture in the Upper Ob River Basin

One of the most important ore mineralisation in the eastern Eurasian steppe is situated in the Altai Mountains. Copper mineralisation is generally associated with intrusions of quartz proprieties forming from granite magma (Grigor'yev 1934). Copper deposits are represented by polymetallic ores with accompanying lead and zinc. The oxidised zone is well developed, marked by a depth of 30 to 60 meters (Roslyakov 1970: 59-66). Many of these deposits were probably exploited in ancient times, but the traces of ancient workings have been severely destroyed by modern mining industry so the actual dates of opening of mines cannot be determined (Chernikov, 1949; Rozen, 1983). Copper metallurgy came into existence in the Altai regions during the Afanasievo time dated to the first of the third millennium BC (Svyatko *et al.* 2009). Unfortunately, the lack of slags or other smelting remains does not allow for the reconstruction of Afanasievo smelting technologies. It is only after the second millennium BC (Middle Bronze Age) that we have enough material to investigate the smelting traditions in the Altai (Grigor'yev 2015:478).

Elunino settlements during the Middle Bronze Age (c. 1800-1600 calibrated BC) have yielded the remains of copper ores and slags as the evidence of primary production. Grigor'yev (2015: 486) has analysed 67 samples from the settlement of Berezovaya Luka) and asserts that Elunino metalworkers utilised a mixture of copper oxides and secondary sulphide ores (chalococite and covellite) to produce raw copper. Chemical analysis of ores and slags suggests the possible origins of quartz rocks with trace amount of lead and zinc, a characteristic of mineralisation in the Altai Mountains (Ibid. 488).

3.4.2 Copper smelting in western Siberia

The earliest examples of copper smelting in western Siberia belonged to slags from settlement (Upper Alabuga; Korshunovo; Vishnevka). These sites are roughly dated to the Alakul period (c. 1700-1400 BC). According to Grigor'yev (2015: 493), the settlements performed the chalcopyrite smelting from quartz rocks, producing slags with high iron content. The presence of the molten wüstite (FeO) indicates high smelting high temperatures under a reducing atmosphere.

3.4.3 Copper smelting in the Andronovo culture

The Andronovo culture consists of two major sub-groups: Alakul and Fedorov variants (Kuz'mina 2007). Slags from Alakul sites in Transurals and central Kazakhstan have been subject to chemical and mineralogical analysis (Grigor'yev 2015: 513-21). The results show that slags were mainly formed by oxide ores from quartz rocks or quartz-bearing sandstones, with some mixture of sulphide ores. Many cuprite inclusions are present in the samples, indicating a relatively oxidising atmosphere during smelting. Copper smelting was possibly conducted at a rather high temperature (up to 1470 °C) and a great amount of copper was lost and passed into slags (Ibid. 518).

Fedorov slags, on the other hand, are mainly smelted from primary sulphide ores (chalcopyrite and bornite) associated with quartz rocks (Grigor'yev 2015: 522-526). Inclusions of iron oxide are prevalent and some of them might be introduced from the use of iron fluxes. Smelting is carried out under a reducing atmosphere, with temperatures ranging from 1300 to 1400 °C.

3.4.4 Copper smelting in the Dandybai-Sargary culture

The numbers of analysed slags from this culture are fairly small (only 6). The preliminary study shows that slags are chiefly sourced from oxide ores of quartz rocks, with minor secondary sulphides (Grigor'yev 2015:529-532). The smelting condition is mildly oxidising, which leads to a number of cuprite inclusions in the specimens. Generally speaking, copper smelting in the Dandybai-Sargary culture resembles Alakul technologies (Grigor'yev 2015:532).

3.4.5 Copper smelting in the Cisbaikal and the Transbaikal

The most informative survey of ancient mining and smelting sites was undertaken by Sergeeva (1981). According to her research, in Cisbaikal the most probable indigenous copper sources come from copper sandstones in the Lena River basin. They have been exploited since the Imperial Russian period but left no traces of any Bronze Age workings.

Transbaikal contains multiple copper deposits and silver-lead-zinc mineralisation. In the west, now present-day Buryatia, copper or polymetallic deposits are widespread in the Sayan-Baikal ore belt. The largest oxidation zone is located in the Namaminskom field where copper, arsenic and antimony exist in the ores. In the east of Transbaikal, the largest copper mine concentrates on the north of the Chita region. Alluvial tin ores

are found in the Onon River. Transbaikal metals possibly use oxidized and sulphide copper ores, in particular, fahlores of polymetallic deposits. Unfortunately, traces of ancient mining are not preserved in most deposits.

3.4.6 Copper smelting in the Minusinsk Basin

Sunchugashev (1975) had investigated ancient mining and smelting activities in the territory of the Minusinsk Basin. His study pointed out that this region is rich in the polymetallic deposits and there are more than 100 copper deposits with a strong oxidation zone. Ancient copper extraction had begun in the Yulinskoy mine during the Karasuk period and the Tamir mine during the Tagar period. The majority of copper was smelted from oxide ores (Sunchugashev 1975:114). According to Sunchugashev, quite significant arsenic content is detected in the copper ingots from these two deposits (up to 6.3%), while slags contain no more than 0.89% arsenic. Although he suspected the artificial addition of arsenic-rich mineral when casting those ingots, high-arsenic content in raw copper could also result from the partitioning of arsenic during the copper smelting.

3.4.7 Copper smelting in Tuva

The Khovu-Aqsa mine is the best-studied copper deposit in ancient Tuva, dated to the 12th century BC and became very active during the Uyuk culture (c. 7th to 3rd centuries BC) (Sunchugashev 1969). It contains copper-cobalt-nickel mineralisation with a strong oxidised zone of malachite and azurite. Nearly 300 ancient workings have been found, which contain either open-surface quarries or underground tunnels. Stone tools for the copper extraction and fragments of slags and clay moulds remains are also uncovered in this mining district. Another rich copper deposits are situated in the Hemchik river basin, western Tuva. There are many ancient workings showing the exploitation of surface oxide/carbonate ores (malachite and azurite). However, no archaeological evidence has been found to confirm their chronologies.

Remains of copper smelting in Tuva are usually found near copper mines or along riverbanks. They include copper slag heaps, fragments of fire clay, clay moulds, models, tuyeres, crucibles and ceramic wares and domesticated animal bones. It seems like the copper smelting was carried out when seasonal migration took place in summer (Sunchugashev 1969).

3.5 Importance of copper-smelting research and its limitations

Research on smelting technologies of Eurasian steppe indeed reveals the variations of raw material being used in different cultures, regions and time periods. Different smelting conditions will also affect the final composition of copper and copper-alloy artefacts (Pollard *et al.* 1991). Grigor'yev's examinations on ores and slags conclude a dramatic difference between ore sources used by Sintastha-Abashevo and Srubnaya-Andronovo people. The former relies on copper oxides from ultrabasic rocks and the latter on copper oxidises or mixed oxide and sulphides ores from quartz rocks. This is a vital discovery to suggest a change in ore supplies and smelting technologies during the transition from the MBA to LBA in the central Eurasian steppe. Nonetheless, as Grigor'yev still focuses on identifying the ore sources, he overlooks or seldom discusses the influence of mixing and recycling from multiple origins. This leads to his conclusions that the shift from the production of arsenical copper to tin-bronze in the Steppe was mainly due to the change of ore sources from copper oxides to sulphide ores from quartz rocks. He argues that higher temperatures and longer smelting time required by this new type of smelting result in the losses of arsenic and other impurities. In order to maintain the quality of copper alloys, ancient metalworkers started to adopt the tin alloying, which is much easier to be controlled by melting metallic tin.

Although his explanations about changes in alloying preferences sound probable, it is inappropriate to assume that ancient people were aware of mechanical properties of arsenical copper (Budd 1991). In fact, most Sintastha metal objects contain less than 2% arsenic (see Chapter 4), which is difficult to argue for a huge physical improvement on copper alloys. It is more likely that ancient smiths simply smelted local copper ores with accidental arsenic-bearing minerals (by co-smelting). Arsenic-free copper (pure copper) during the Late Bronze Age may not be a consequence of using sulphide ores, but alternatively arsenic can be lost through the recycling or mixing.

3.6 Difficulties in synthesising data from different sources

3.6.1 Problems of using different analytical techniques

Before using any chemical dataset, one of the most important questions needs to be asked is how reliable it is. As can be seen in Figure 3.25, our chemical data is drawn from different laboratories employing a wide range of analytical techniques: wet chemical, OES, AAS, AES, ICP-AES, NAA, XRF, SEM-EDS, EPMA and ICP-MS.

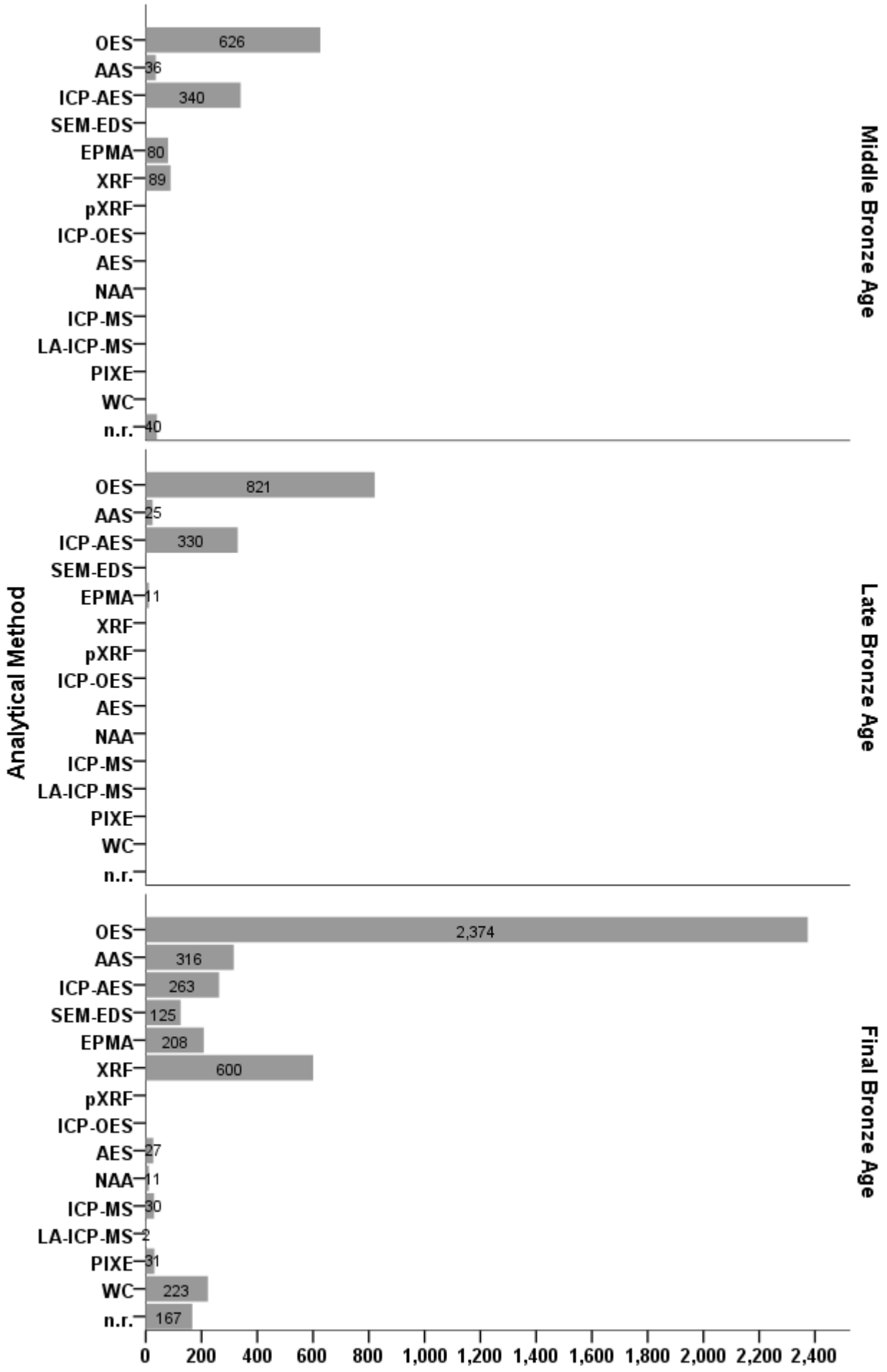
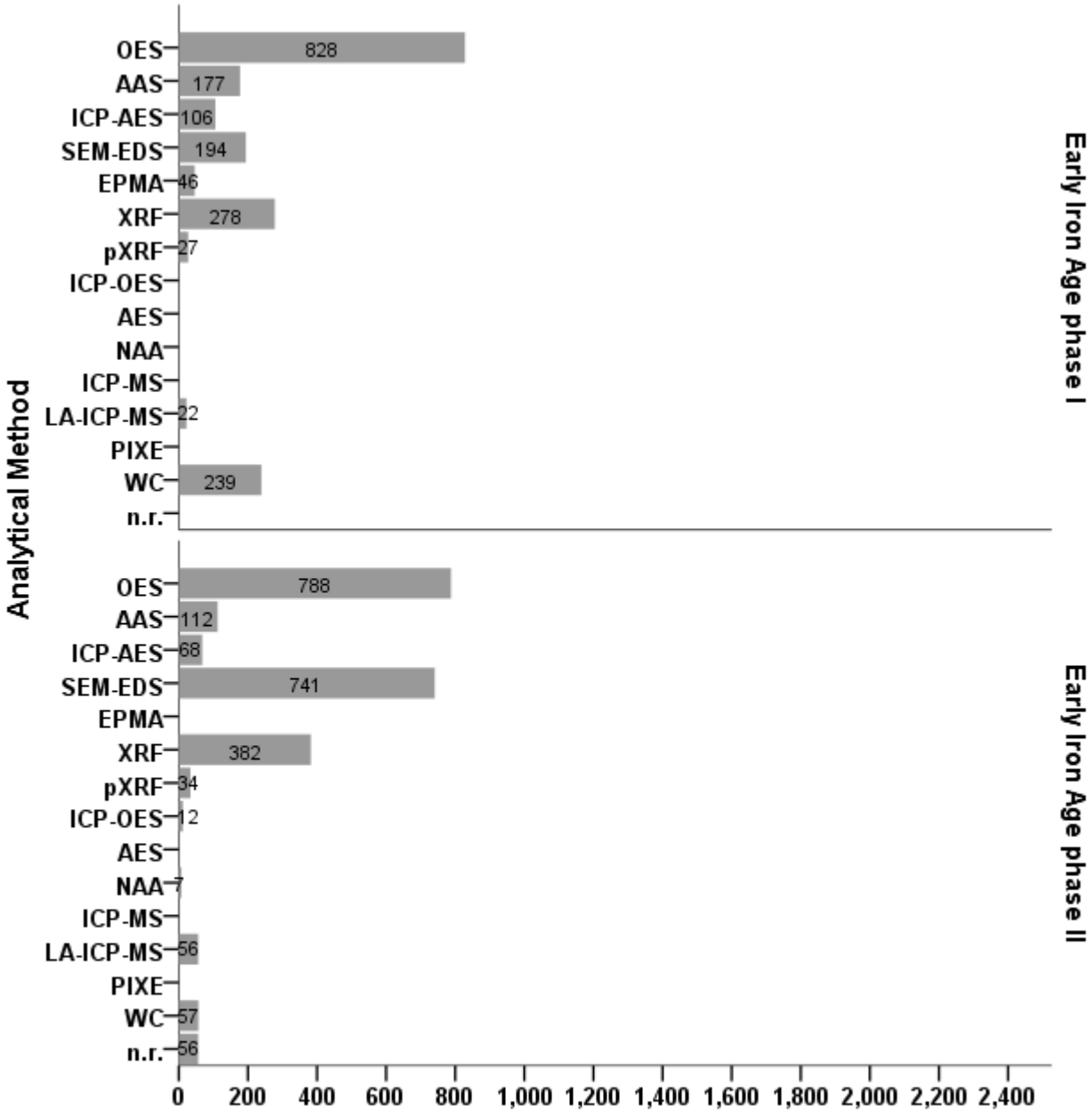


Figure 3.1 Diagrams showing analytical methods used in the database



Abbreviations are noted as follows:

OES—optical emission spectroscopy AAS—atomic absorption spectroscopy

AES—atomic emission spectroscopy NAA—neutron activation analysis

XRF—X-ray fluorescence spectroscopy EPMA—electron probe microanalyser

pXRF—portable X-ray fluorescence spectroscopy WC—wet chemistry

PIXE—particle-induced X-ray emission n.r.—not reported

ICP-OES (AES)—inductively coupled plasma optical emission spectroscopy

ICP-MS—inductively coupled plasma mass spectrometry

LA-ICP-MS—laser ablation inductively coupled plasma mass spectrometry

SEM-EDS—scanning electron microscopy with energy dispersive X-ray spectroscopy

It is not the purpose of this thesis to review each analytical method as it has been done elsewhere (Pollard & Heron 2008). However, it is crucial to assess the data quality and variability in association with techniques to avoid making invalid judgements.

Three concepts deserve a detailed discussion in judging a database from multiple sources: precision, accuracy and the limit of detection. Precision is considered as a measure of repeatability (how well results are replicated under fixed conditions). The uncertainty associated with the precision is called the random error caused by the limitations of an analytical technique (For example, the OES techniques is notorious for the lack of precision). These errors can be estimated by repeated measurements on the same specimen. In the database I collect, this practice is carried out by some laboratories using OES and SEM-EDS methods. They usually analyse multiple spots for each sample to obtain average bulk measurements. This undertaking can also reduce the variability caused by segregation of elements within the objects. Furthermore, the random errors will tend to minimise given a large sample size, thus the issue of the precision is slightly less critical in this thesis.

The accuracy of results can be referred to as the closeness of a measurement to a "true" value. The errors related to accuracy are systematic errors, resulting from bad analytical protocols or certain technique-related biases between different methods. Evaluating the accuracy of each data source becomes impossible in this study because most publications do not provide information about whether their instruments were calibrated with appropriate certified reference materials. To that end, in the following section I will evaluate other papers dealing with data from different analytical methods and see whether "legacy data" can be integrated for a comparative study.

The detection limit is usually defined as the smallest amount of an analyte that can be detected in a specimen. It is equal to three times the standard counting error above the mean background intensity (known as lower limit of detection). This calculation is based on normal distribution in which there is a 99.87% probability that a measurement does not belong to the background signal (Potts 1987: 16).

To assess the quality of chemical data, one should investigate these three essential factors (accuracy, precision and LoD) through the measurements of primary and secondary reference standards, settings and procedures of analytical methods, and systematic and random errors. Unfortunately, virtually none of literature provide full

information necessary for a decent judgement. The OES data comprises the largest portion of the legacy chemical dataset. Most of them were measured by Chernykh and his team at the Laboratory of the Institute of Archaeology in Moscow. OES is often a technique of choice for metallurgical studies and it is a routine practice for trace element measurements (Potts 1987:206). It was the commonest technique up to the 1980s but was replaced by AAS and the ICP methods from then on. Chernykh (1966) briefly reported the analytical protocol on the analysis of ancient copper-based objects. Their laboratory employed the arc-OES method to excite an electrical discharge with the use of photographic plates for measuring the intensity of emission lines. 40 copper-alloy standards were used, covering a wide range of concentrations of element (Table 3.4). In order to reduce the errors from the inhomogeneity of the objects, drilled samples were taken from two to seven locations on one object at different depths. The precision of the OES measurements on a copper-alloy standard is documented in Table 3.5. Even though Chernykh did not record the limit of detection for each element, a study of arc OES method shows high sensitivity for many trace elements down to ppm levels (Table 3.6). However, the very serious drawback is the saturation of the signal at high concentrations (e.g. Sn>10%).

Table 3.4 Concentration ranges of copper-alloy standards used in the Moscow lab. From Chernykh (1966: 30).

Element	Range%
Sn	0.0003-25
Pb	0.0003-20
Zn	0.001-13
Ag	0.0001-5
Bi	0.0001-2
Fe	0.0005-4
As	0.005-17
Sb	0.001-13
Co	0.001-1
Ni	0.0001-3
Mn	0.001-1

The OES method has the inherently poor precision and repeatability of measurements due to unstable excitation conditions and uncertainties from the development of the photographic plates (Pollard *et al.* 2007: 48). This causes a problem to combine the old OES data with analyses from other new techniques. Pernicka *et al.* (1997) compared their NAA results with Chernykh's data of the same copper artefacts from Chalcolithic

Bulgaria. It shows that in spite of certain disagreements, most of data points fall into the respective concentrations within a factor of three (Ibid. 89, Figure 3.26). Most importantly, both NAA and OES measurements share the similar distribution of chemical groups defined by Chernykh. The old OES data can be used to characterise metal artefacts but some precautions are necessary (see Section 3.6.3).

Table 3.5 Precision of OES measurements in the Moscow lab. From Chernykh (1966: 33)

Concentration	Sn=2.3	Pb=0.17	As=4.9	Sb=0.16	Ni=0.76	Bi=0.001
10 measurements	2.5	0.2	6	0.13	0.7	0.0008
	2	0.18	5	0.23	0.9	0.0007
	2.2	0.14	5	0.22	0.8	0.0009
	2.3	0.13	4	0.15	0.65	0.002
	1.9	0.16	4.5	0.16	0.6	0.001
	2.7	0.25	4.7	0.11	0.85	0.0013
	2.5	0.13	4.2	0.22	0.75	0.001
	1.9	0.17	4.5	0.17	0.5	0.0015
	2.1	0.1	5	0.18	0.7	0.0016
	2.6	0.16	4	0.14	0.65	0.001
Absolute error	0.26	0.032	0.49	0.031	0.0104	0.0003
Relative error	11.30%	18.80%	10%	19.40%	13.70%	30%

Table 3.6 LoDs of elements measured by the arc-OES method. Reported by Potts (1987, p. 237). Highlighted elements are most relevant to archaeological metals.

Element	**ppm**	**Element**	**ppm**	**Element**	**ppm**	**Element**	**ppm**
Si	20	Cd	50	La	20	Sc	5
Al	10	Ce	200	Li	200	Sn	10
Fe	8	Co	5	Lu	100	Sr	2
Mg	5	Cr	1	Mo	5	Sm	100
Ca	50	Cs	20000	Nb	10	Ta	200
Na	500	Cu	1	Nd	100	Tb	1000
K	7000	Dy	50	Ni	3	Te	1000
Ti	2	Er	50	Os	100	Th	200
P	2000	Eu	500	Pb	10	Tl	100
Mn	2	Ga	2	Pd	3	Tm	100
Ag	1	Gd	50	Pr	500	U	500
As	1000	Ge	10	Pt	30	V	10
Au	20	Hf	100	Rb	100000	W	100
B	20	Hg	10000	Re	50	Y	10
Ba	2	Ho	100	Rh	50	Yb	5
Be	1	In	10	Ru	100	Zn	200
Bi	10	Ir	100	Sb	100	Zr	10

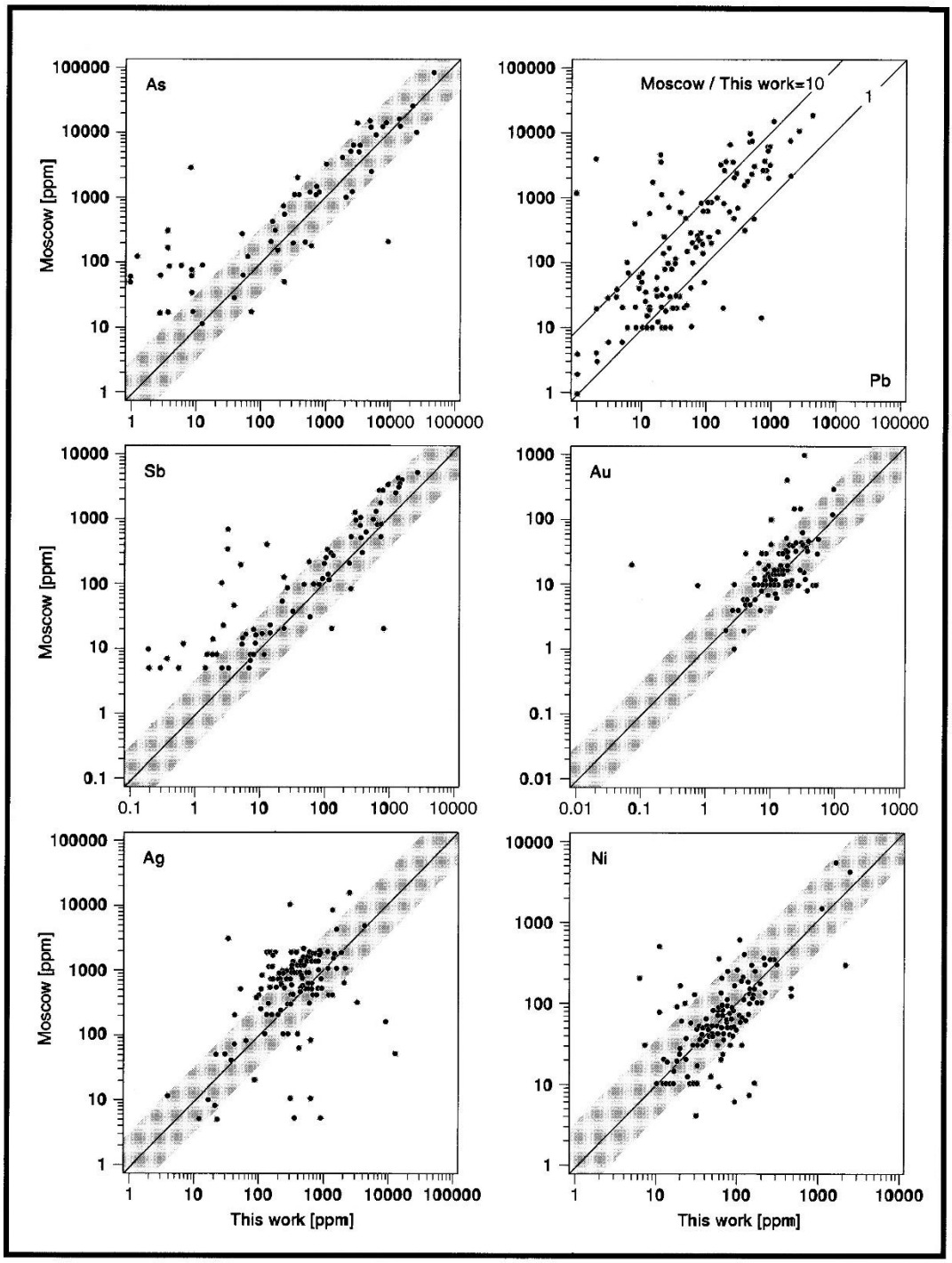
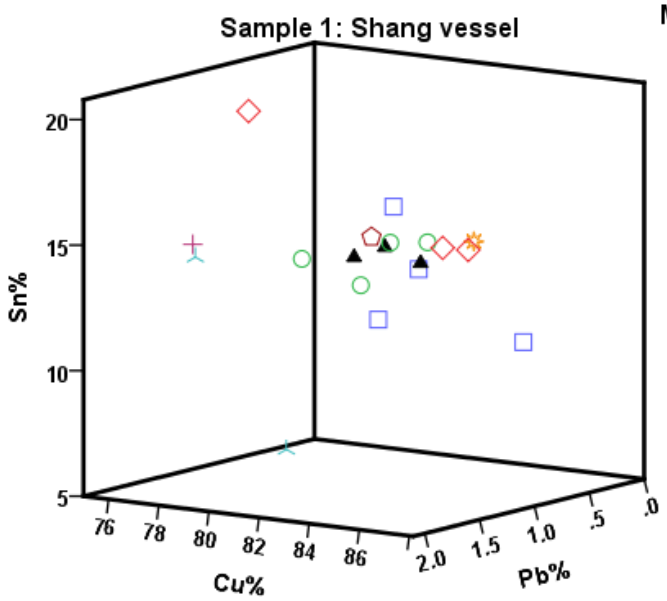


Figure 3.26 Comparison of chemical composition of the identical Bulgarian artefacts analysed by the optical emission spectroscopy (Moscow, y axis) and neutron activation analysis (German, x axis). The shaded band indicates the respective concentrations in agreement within a factor of three. From Pernicka (1997, fig. 15).

3.6.2 Evaluation of inter-laboratory analyses

The first large-scale inter-laboratory project to compare the reproducibility of ancient copper alloys composition was pioneered by W. T. Chase (Chase 1974). He selected a Chinese Shang vessel, an Iranian Luristan spearhead and an artificially-made standard

to be analysed in thirty-six laboratories employing a wide range of techniques. Only 21 of them had returned the results and as many as forty-eight elements were examined. The outcome showed that for major elements copper, tin and lead, the mean standard deviation was around 14.8% but for some trace elements the error often reached 100% due to the selected specimens with very low concentrations. Figure 3.27 & 3.28 display the re-plotting of Chase's data in a three-dimension representation. Chase concluded that although variability of chemical analyses from different methods indeed exists, for major elements the majority of them can still correctly characterise the composition of objects. Thus, the Shang container is a moderately high tin-bronze (Sn≈ 15%) with about 1% lead, and the Luristan sample is a low-tin bronze with trace amounts of lead less than 0.5%.



AAS= atomic absorption spectroscopy
WC= wet chemistry
ES= emission spectrography
XRF= x-ray fluorescence spectrometery
MS= spark souce mass spectrometry
NAA= neutron activation analysis
POL= polarography
EL= electrolysis (wet chemical)

Figure 3.27 3D-plots showing composition of a Shang sample analysed by different methods. Data from Chase (1974).

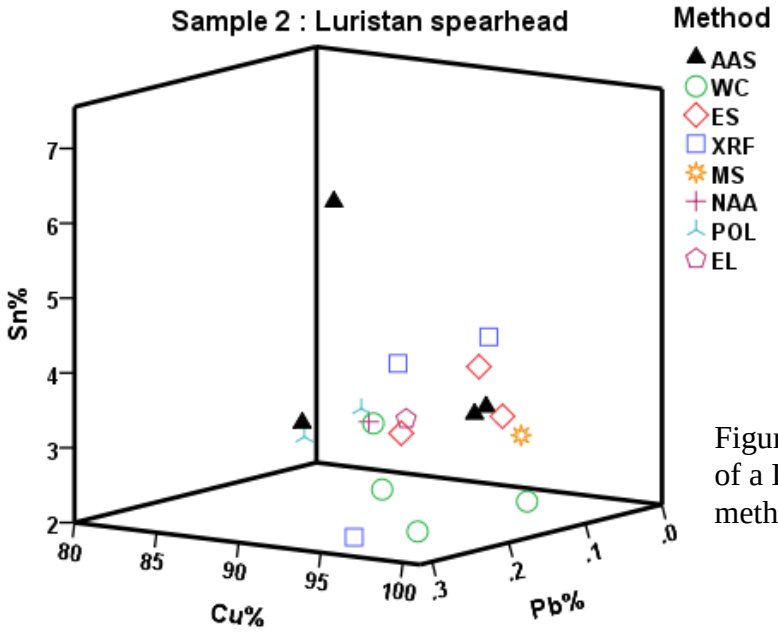


Figure 3.28 3D-plots showing composition of a Luristan sample analysed by different methods. Data from Chase (1974).

Northover & Rychner (1998) extended this cross-comparison of bronze analysis to twenty-one laboratories and eleven analytical methods. Seven real copper-alloy artefacts with up to 1% of impurities are prepared for the analysis. They all come from Auvernier, dating to the Hallstatt B2-B3 period. The data from one of collaborative laboratories (British Museum) where atomic absorption spectroscopy is used as the standard to measure the variability of analyses between different methods. The results show that for major alloying element (tin) presents the best measurement with the mean standard deviation below 10%. However, the standard deviations tend to become larger for trace elements or elements with severe segregation properties (such as Pb). The measurements of each method against the AAS results are plotted in a series of scatter diagrams (Figure 3.29 to 3.35) Generally speaking, analytical results derived from different techniques are in agreement with each other (points falling on the line), but sometimes they fall short in certain elements such as wet chemical for Sn, Pb and Ag, OES for Ag, XRF for Sn, Pb and As, and EPMA for Pb and As.

Cuénod's research on the ancient Iranian metalwork also attempted to address the question of variability of analytical methods (Cuénod 2013). She examined the data from four sites (Tepe Hissar, Mesopotamia, Selme in Oman and Susa). The results show that even if the datasets were obtained from different methods, they are generally in good agreement except for the data from Susa (Figure 3.36). This tells us that one should not deal with absolute values of analysed objects as they are potentially biased due to the technique used, it is more appropriate to search for the general trend of chemical composition over a large assemblage.

3.6.3 Precautions when dealing with multiple datasets

Overall, the past studies have shown although the variations existing between different laboratories, the datasets can still provide similar chemical characterisations that can be used interchangeably if they are treated with caution.

Having understood the potential problems of using the legacy data, all, I will comply with the following protocol to minimise the issues of the precision, accuracy and the limit of detection.

1. I do not comment on the chemistry of isolated artefacts as the discussion can be biased due to the inhomogeneity of the objects or random errors of measurements. We will investigate chemical data within a whole metal assemblage.

2. I do not use the averages to compare chemical composition of objects from different periods or regions as the variations between them may derive from the bias between different analytical methods. Instead, it is preferable to use the distribution of elemental concentration over the assemblage to explore the broad trend of metallurgical behaviours.

3. Due to varied analytical techniques in the database, I will simply use the concept of presence or absence of elements to characterise copper-alloy objects via the threshold of 0.1 % for four elements (As, Sb, Ag and Ni). Even though it is not an ideal solution to avoid technique-related discrepancies, this presence/absence approach is less affected by the variability of techniques (Figure 3.37).

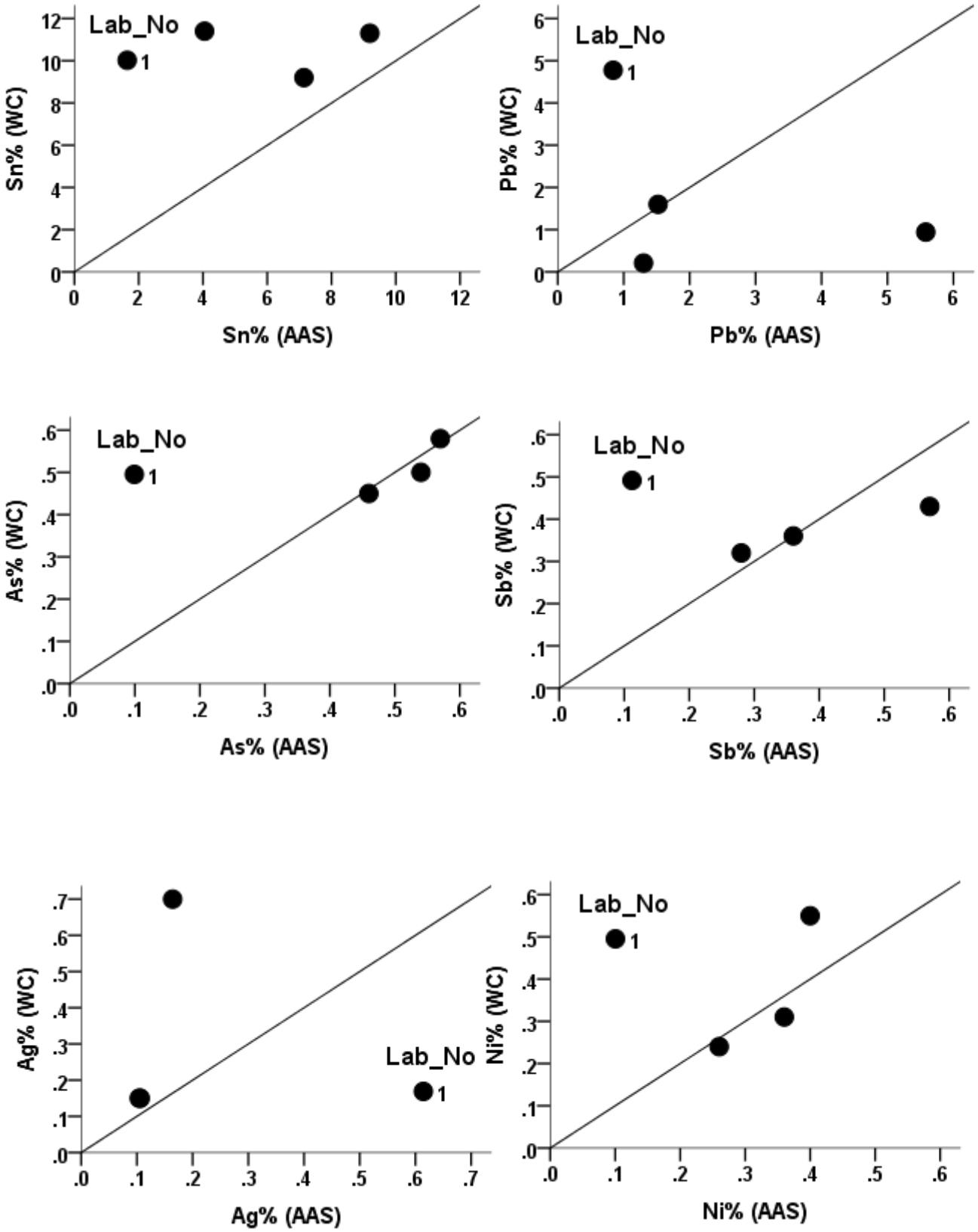


Figure 3.29 Comparison of analytical results between wet chemical and atomic absorption spectroscopy. Data from Northover & Rychner (1998).

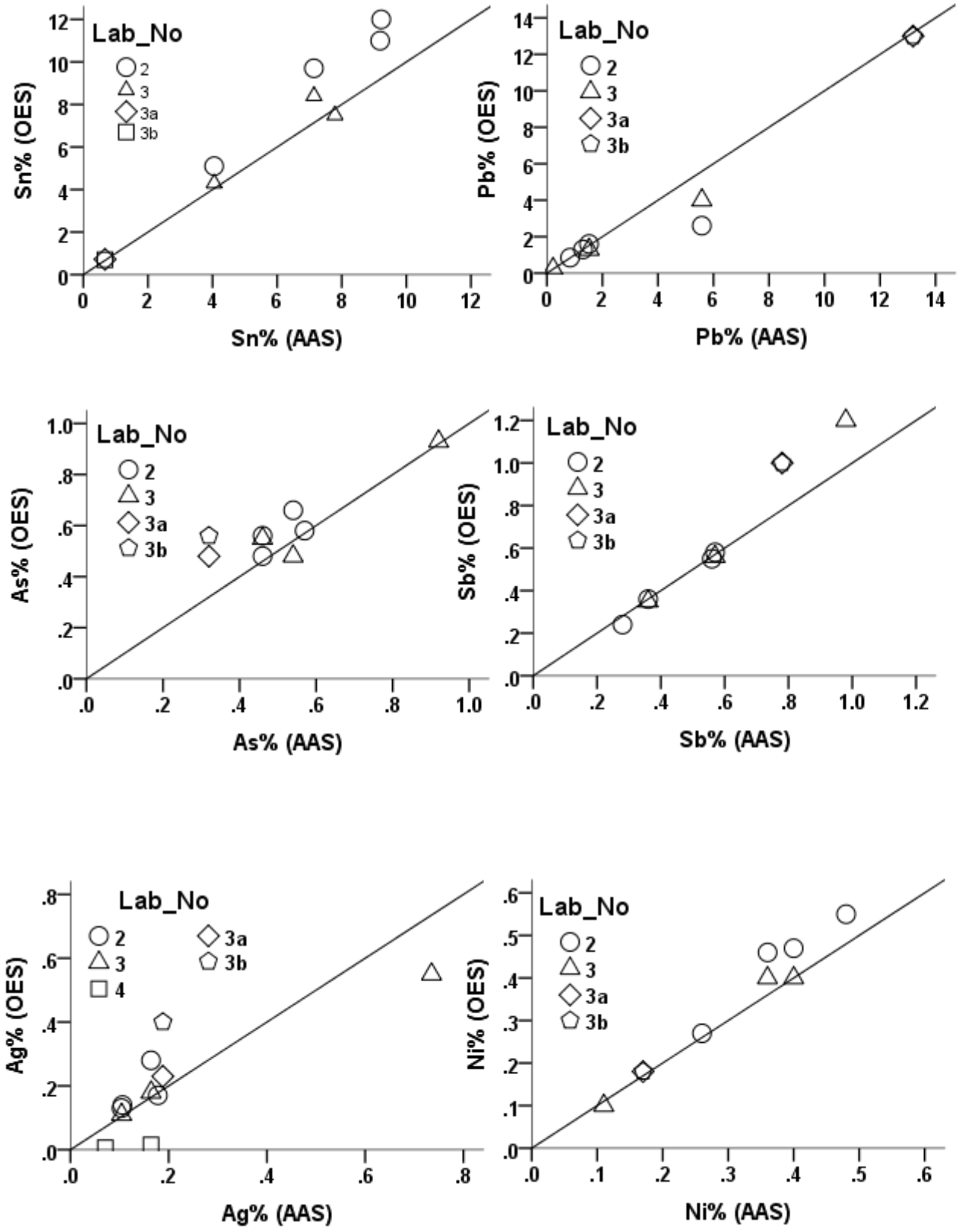


Figure 3.30 Comparison of analytical results between optical emission spectroscopy and atomic absorption spectroscopy. Data from Northover & Rychner (1998)

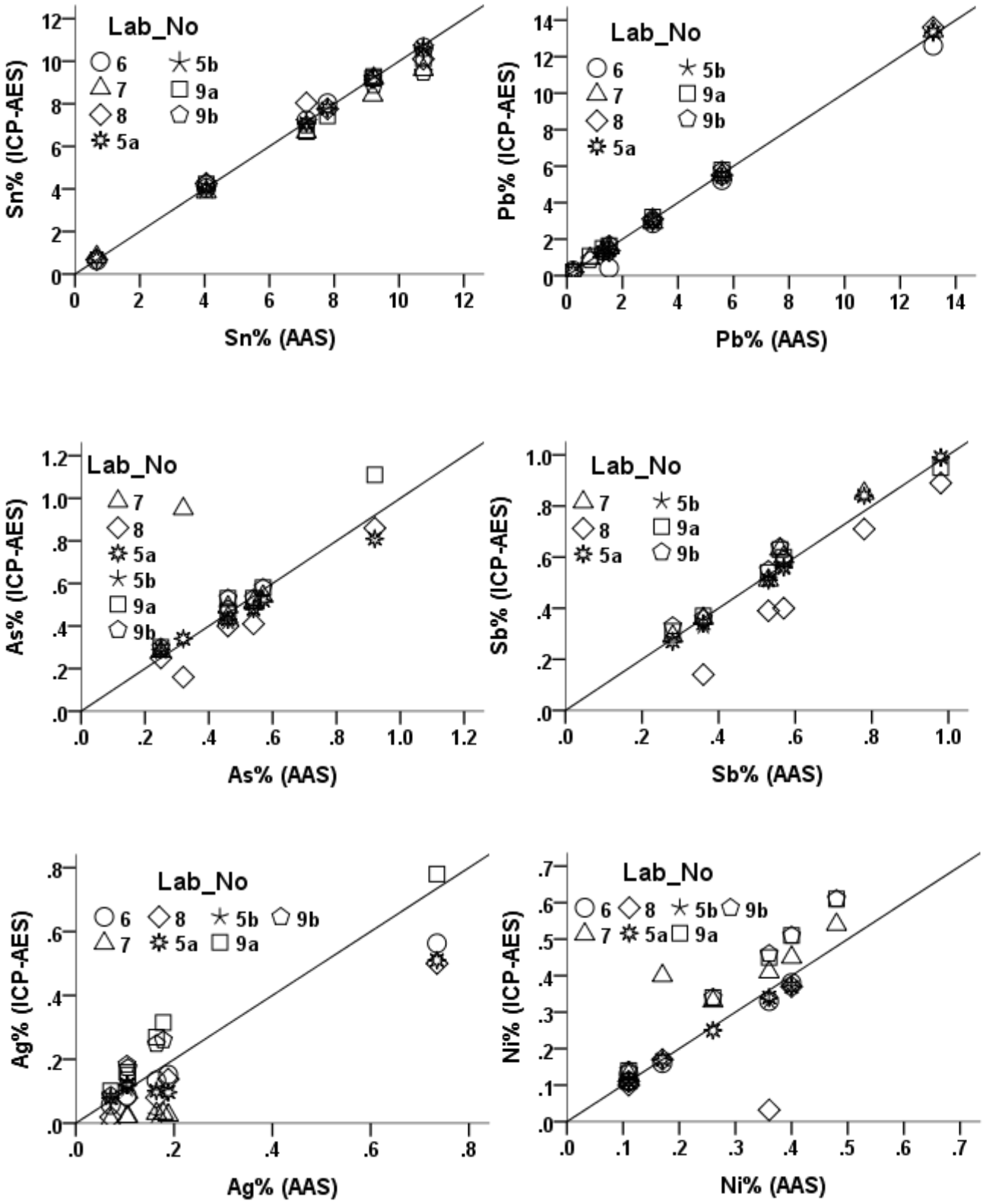


Figure 3.31 Comparison of analytical results between inductively coupled plasma atomic emission spectroscopy and atomic absorption spectroscopy. Data from Northover & Rychner (1998).

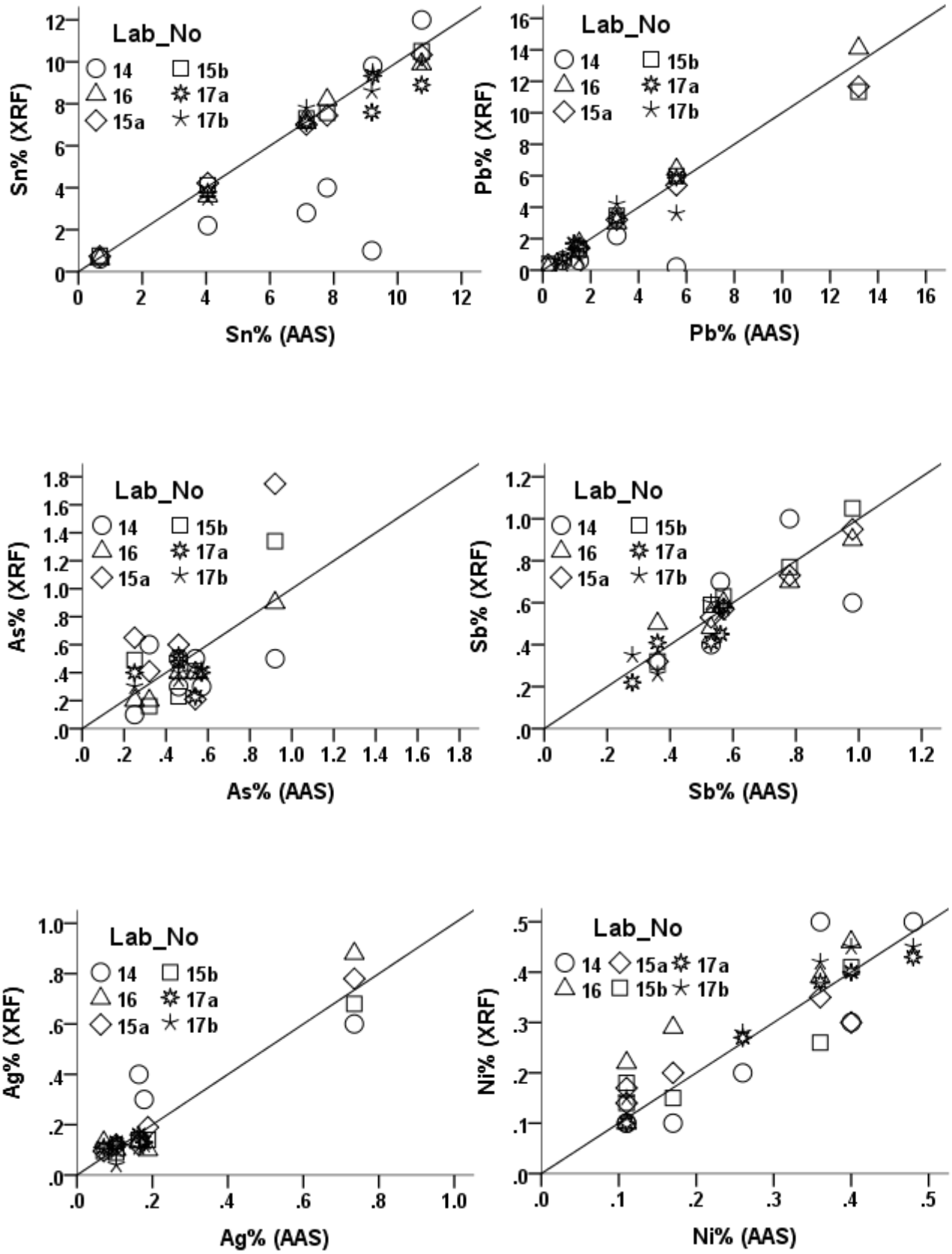


Figure 3.32 Comparison of analytical results between X-ray fluorescence spectrometry and atomic absorption spectroscopy. Data from Northover & Rychner (1998)

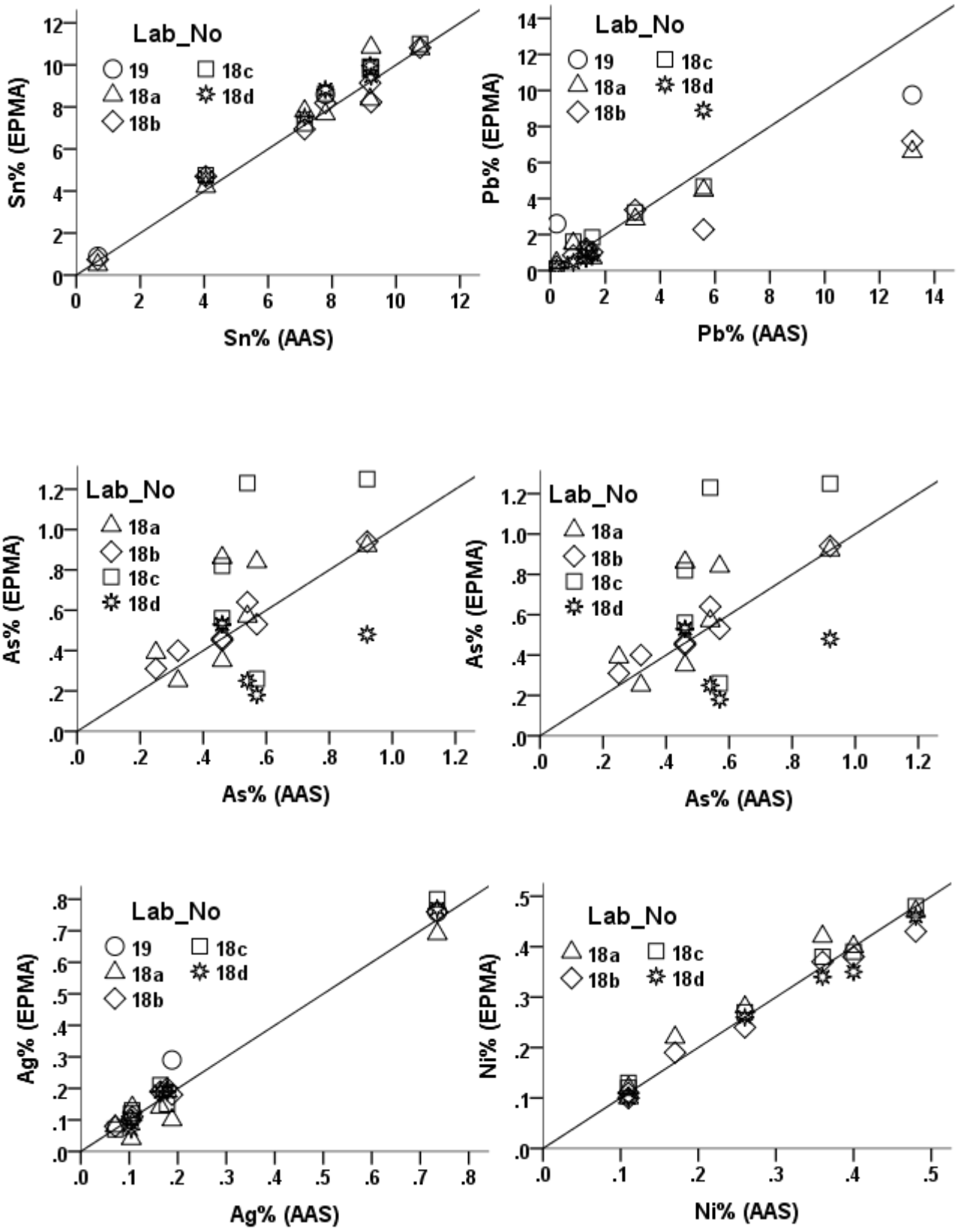


Figure 3.33 Comparison of analytical results between electron microscopy and atomic absorption spectroscopy. Data from Northover & Rychner (1998)

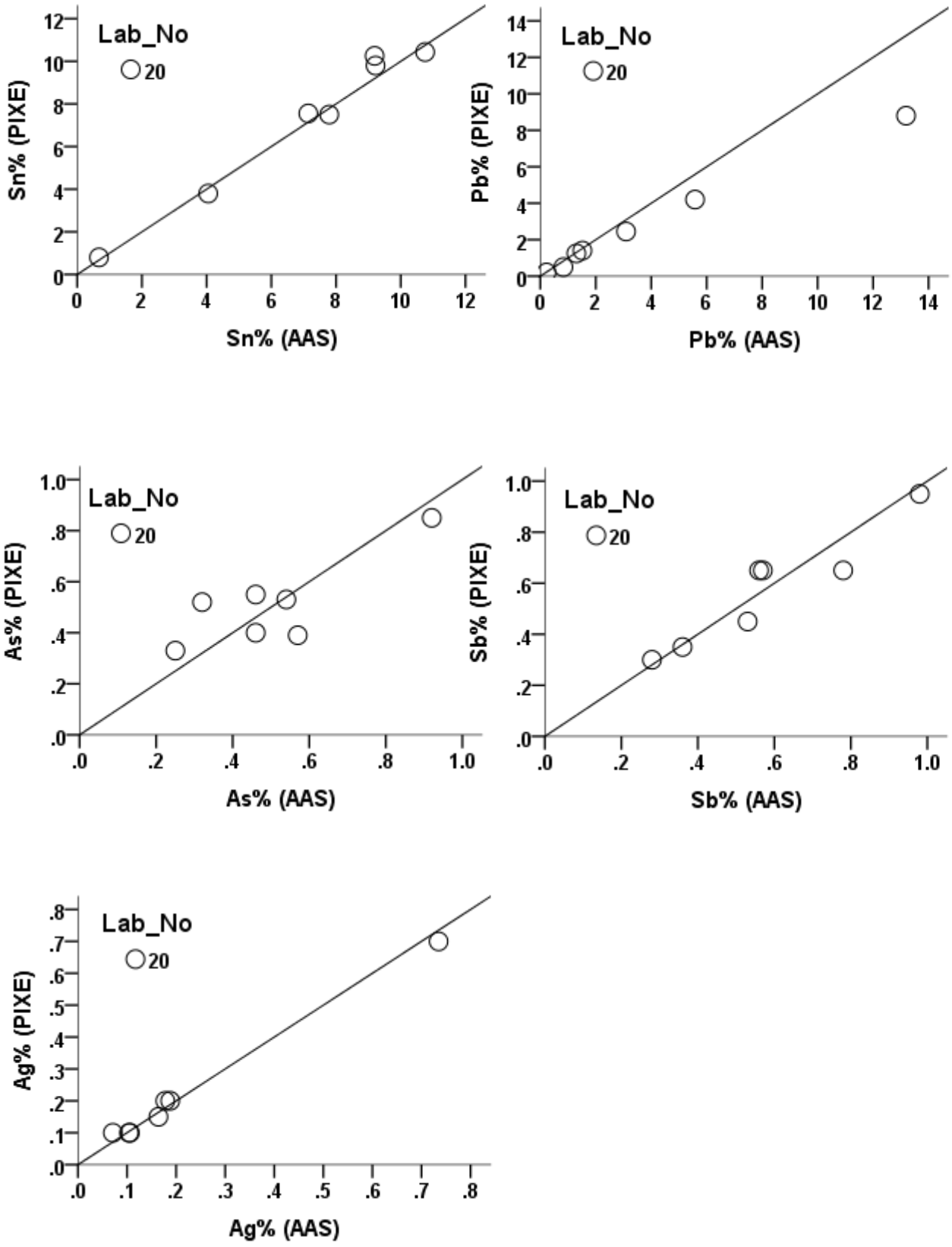


Figure 3.34 Comparison of analytical results between particle induced X-ray emission and atomic absorption spectroscopy. Data from Northover & Rychner (1998).

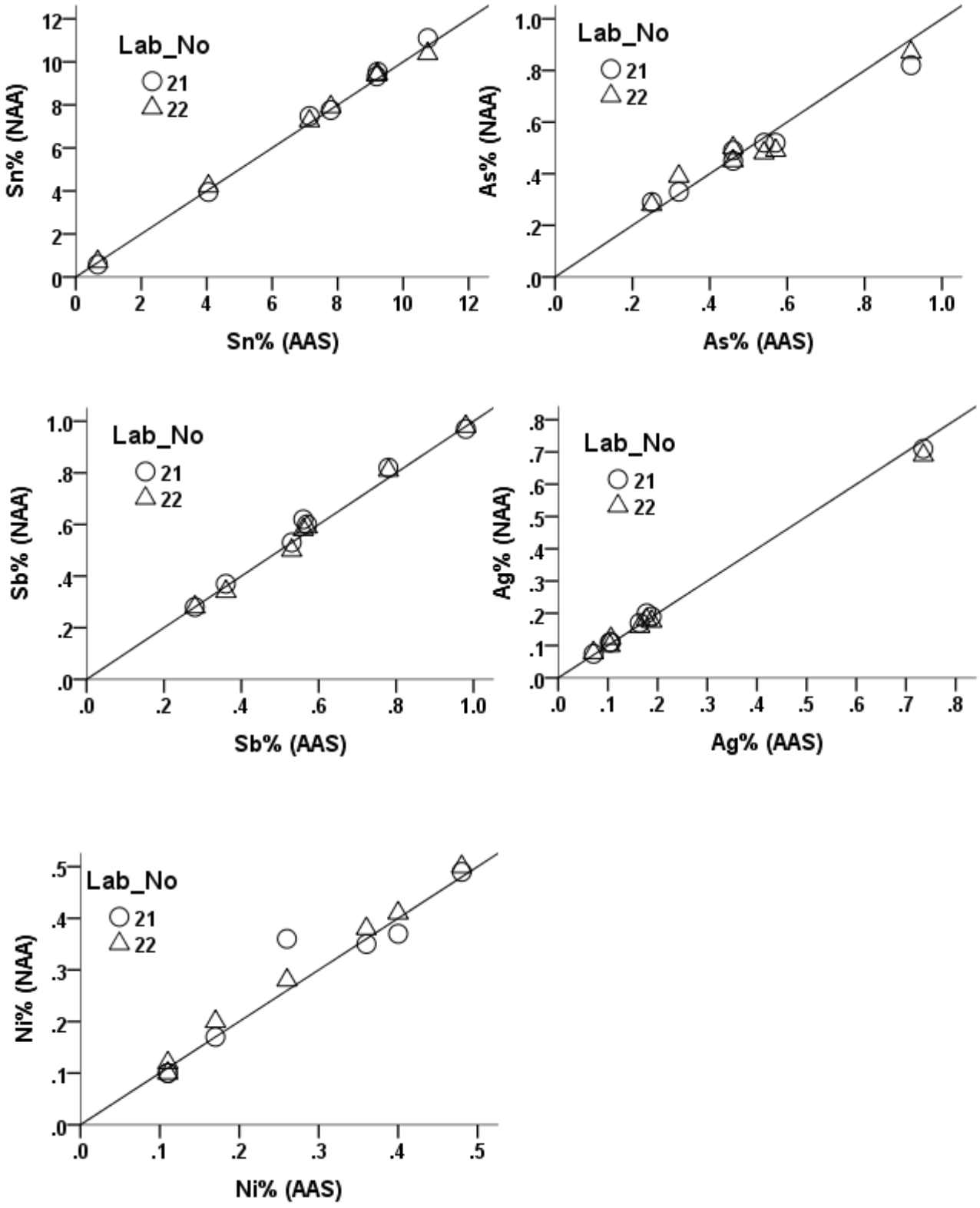


Figure 3.35 Comparison of analytical results between neutron activation analysis and atomic absorption spectroscopy.Data from Northover & Rychner (1998).

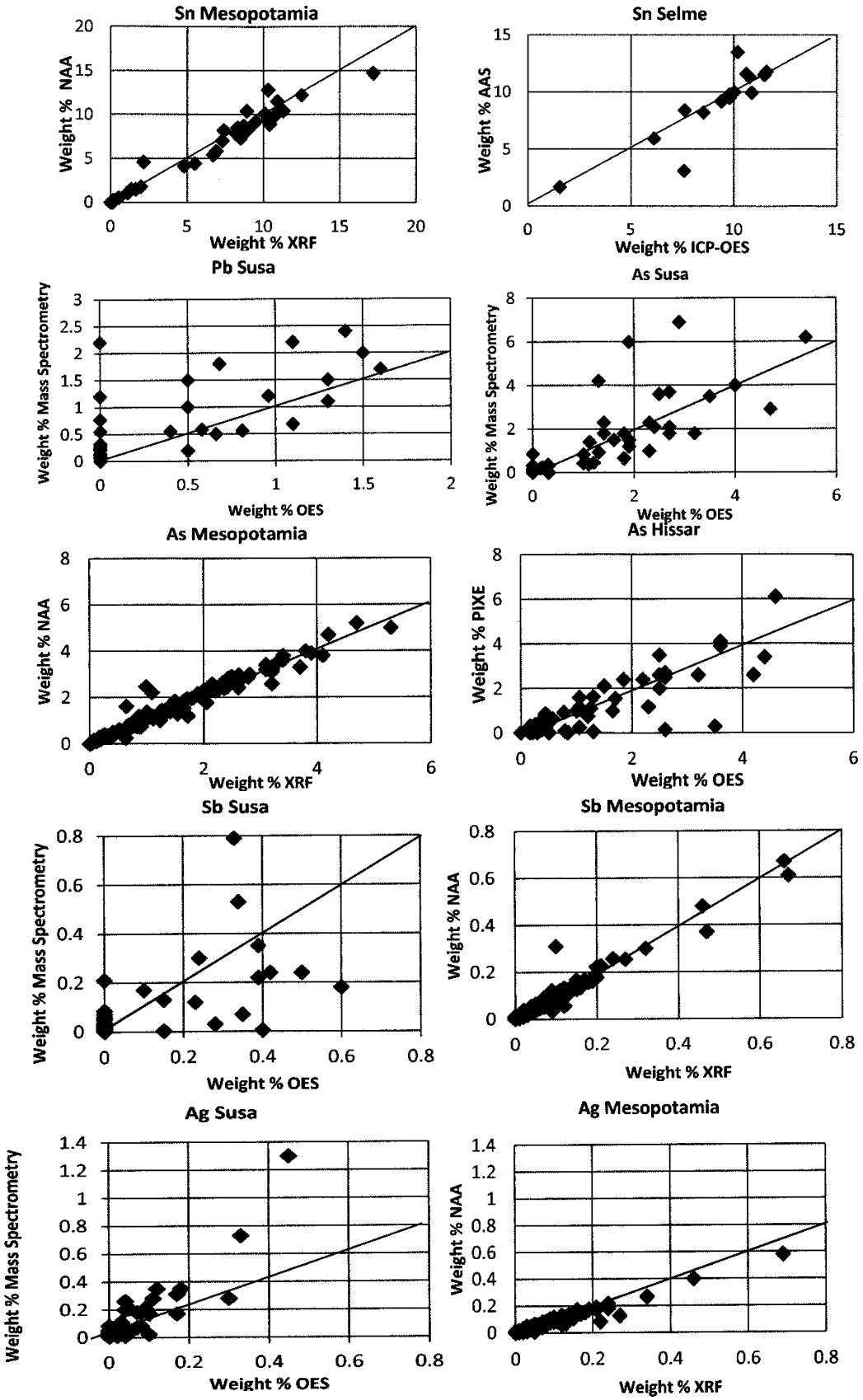


Figure 3.36 Comparison of analysed Mesopotamian and Iranian objects between different methods. From Cuénod (2013, fig III-10,11, 13, 14, 15, 16, 18 and 19).

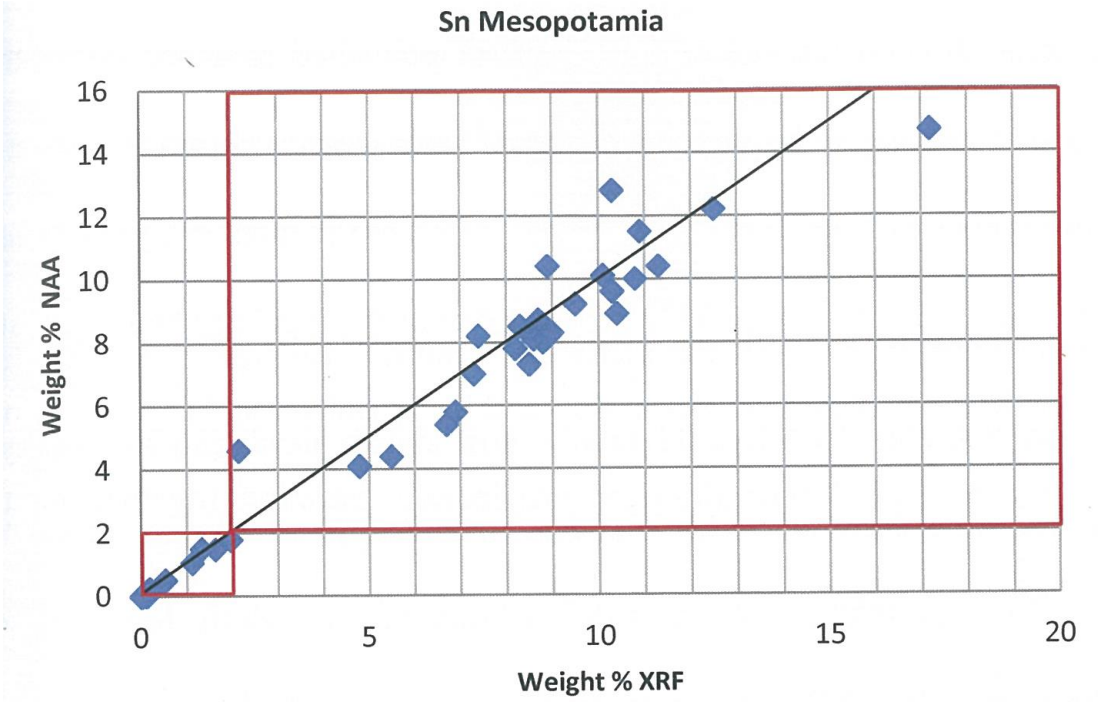


Figure 3.37 Tin measurements for the Mesopotamian artefacts by different analytical methods. Red boxes represent the presence or absence of tin at the 2% cut-off. From Cuénod (2013, fig. III-20).

4. The Middle Bronze Age: the Seima-Turbino Trans-Cultural Phenomenon and its Impact on Eurasian Metallurgy

4.1 Introduction

By the second millennium BC, the Circumpontic Metallurgical Province (CMP) was transformed into a new metal exchange system known as the Eurasian Metallurgical Province (EAMP) (Chernykh 2008:46). It covered the vast territory of the steppe and forest-steppe zones of European Russia and Siberia and reached as far as the desert areas of central Asia and Xinjiang. Drawing from compositional data of copper-based artefacts, this chapter aims to explore the circulation of metal during the first phase of the EAMP (c. 2200-1800/1700), which features the interactions between the Seima-Turbino phenomenon (denoted as ST) and the Abashevo-Sintashta-Petrovka archaeological complex (Figure 4.1).

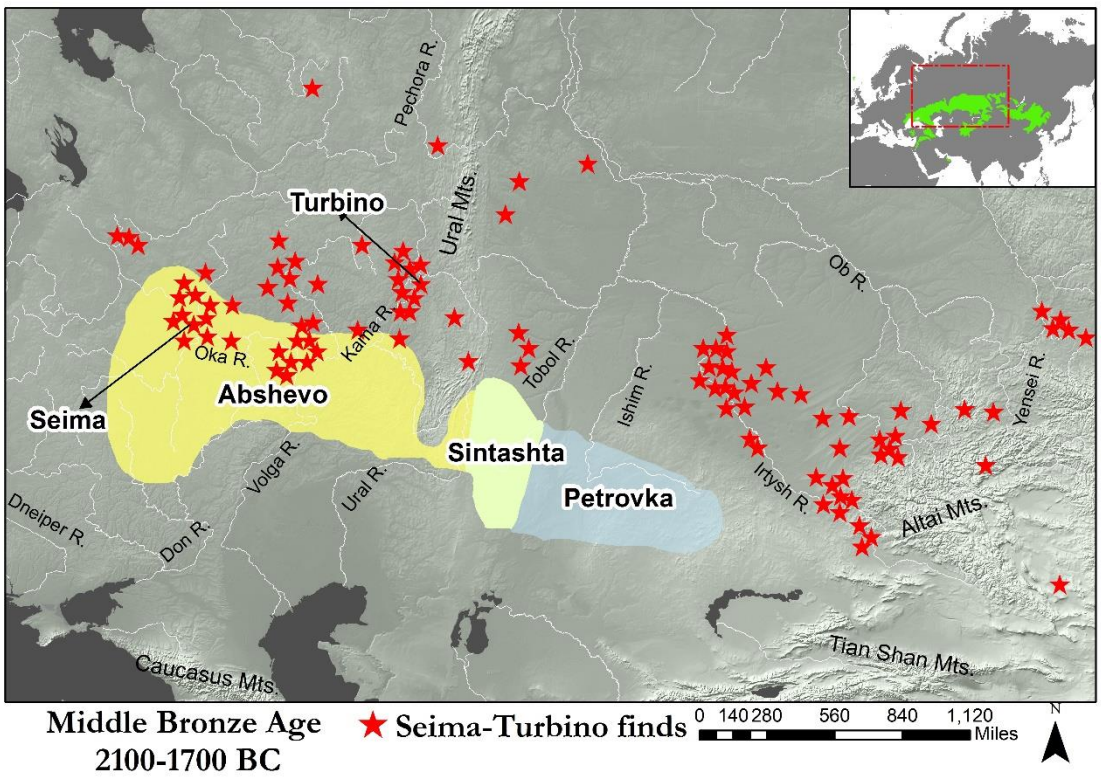


Figure 4.1 Distribution of ST and Abashevo-Sintashta-Petrovka sites. Modified from Chernykh (2008: 47, fig. 9)

Steppe metallurgy during the MBA was represented by two distinctive metalworking traditions (Table 4.1). The emergence of ST bronzes signified a breakthrough of metal technologies. New types of bronze weaponry were invented in favour of thin-walled hollow casting with a suspended core, standardised copper-tin alloying, and exquisite

casting-on or lost-wax techniques (Sherratt 2006:43). These new innovations are in contrast with the southern steppe cultures within the domain of the previous CMP, where the use of unalloyed copper and arsenical copper was prevalent, treated by cold working or hot forging. Another different metalworking system, derived from the CMP, was characterised by the Abashevo culture in the forest-steppe zone of eastern Europe as well as the rise of new metallurgical centres in the Transurals, known "Sintashta-Petrovka pattern" (Hanks & Doonon 2009). This new change coexisted with the increasing social complexity fuelled by the construction of fortified settlements, elaborate mortuary practices, enormous animal sacrifices, and horse-driven chariot technologies (Anthony 2007:371-374). The increasing intensity of metal production was witnessed by the construction of cupola-shaped furnaces, copper ores, slags, pestles, and metal droplets from Sintashta-type sites. This was also the first time that we have sufficient metallurgical evidence to outline the nature of metal production in the Eurasian steppe (Grigor'yev 2015).

Table 4.1 Comparison between the ST and steppe metalworking traditions. Summaries from Chernykh and Kuz'minykh (1989a) & Chernykh (1992).

	Seima-Turbino	**Southern Steppe Communities**
Alloy type	Tin-bronze	Arsenical copper/bronze
Metalworking	No mining and smelting evidence	Many remains associated with primary smelting
Technique	Hollow, thin walled casting with a suspended core. Casting-on or lost wax casting	Casting with hammering and annealing
Artefact type	Weapons and tools	Ornaments and tools
Archaeological context	Burials, sanctuary places, or chance finds	Settlements and cemeteries
Metal movement	From East to West along the forest-steppe and forest zones of Eurasia	From West to East along the steppe

One of the biggest puzzles in the study of Eurasian prehistory is the sudden rise of a full-blown tin-bronze metallurgy in the Seima-Turbino context. Based on the diffusion model, tin-bronze was first used extensively in Mesopotamia from the third millennium BC. In this regard, one would expect the initial adoption of tin-bronze should have taken place in the Pontic-Caspian steppe via the Caucasus or the Balkan. However, the regular use of tin-bronze actually initiated in the Seima-Turbino complex along the northern edge of the steppe zone. This rather odd phenomenon generates a great deal of debates concerning the homeland of the Seima-Turbino bronzes and their routes of distribution.

Chernykh & Kuz'minykh (1989a) dedicated a volume to explore these issues through the combination of chemical and typological studies. The purpose of this chapter is to re-examine their data and provide some new information by using the new methodology. The particular focus will be on the flow of the ST metals and their interactions with southern steppe communities. Before going further, it is necessary to review the past scholarly perspectives on this subject.

4.2 Previous archaeometallurgical research

4.2.1 Seima-Turbino metalwork

Chernykh and Kuz'minykh (1989a) geologically divided the Seima-Turbino bronzes into Siberian (eastern) and European (western) groups, separated by the Ural Mountains. The eastern group is referred to metal artefacts from Siberian forest zone, western Siberia, and the Altai. The western group mainly contains objects from the Kama, Volga, and Oka River basins. There is also an isolated metal hoard (Kaninskaya Cave) in the Pechora River.

What makes the Seima-Turbino metallurgy a single entity is the share of the strikingly similar form of bronze artefacts, represented by cast spearheads, socketed axes, double-edged knives, daggers and single-bladed knives. These artefacts, despite local variations in decorative motifs, are present in both Siberian and European ST communities. According to Chernykh and Kuz'minykh (1989a:178-179), ST metal artefacts can be further classified into four typological categories: eastern type (primarily found in the east of the Ural Mountains), western type (primarily found in the west), common type (found both in the east and west) and Eurasian type (imported items from the southern steppe), as shown in Figure 4.2.

The compositional analysis of 353 Seima-Turbino bronzes (76 from the east and 277 from the west) reveals the distinctive alloying preferences in Siberian and European groups. Chernykh & Kuz'minykh (1989a) pointed out that more than 95% (66 out of 76) of Siberian bronzes belong to tin bronzes (Sn >1 %) or tin-arsenic bronzes. By contrast, the composition of European metals demonstrates a wide range of variations, including pure copper (30 out of 277), arsenical copper (82), arsenic-antimony copper (40, As+Sb >0.5%), tin-bronzes (55), and tin-arsenic bronzes (48). Such contrasting metal composition between Siberian and European specimens reflects the availability of raw material, especially for tin (Chernykh & Kuz'minykh 1989a: 175). For instance,

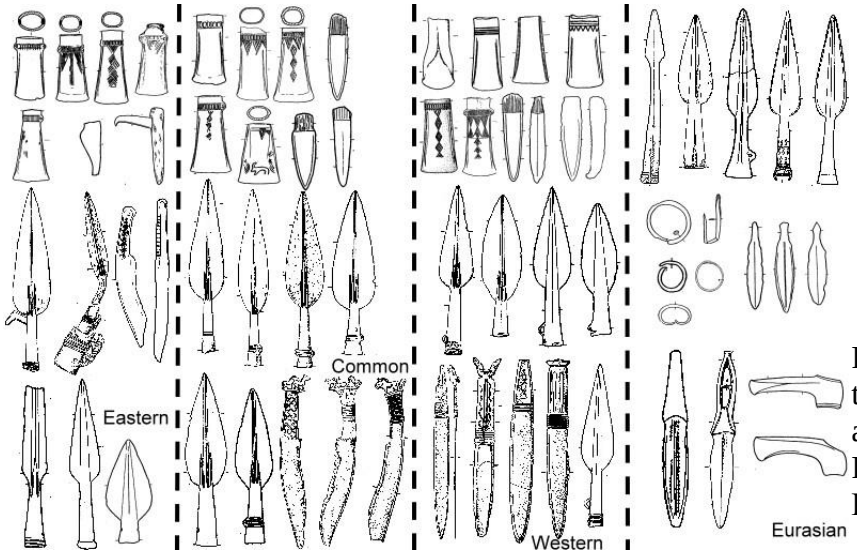


Figure 4.2 Examples of the ST metal artefacts arranged by typology. From Chernykh & Kuz'minykh (1989a).

the ST objects from western Siberia and the Altai are mainly composed of tin bronzes or copper-tin-arsenic alloys (up to 70-80% of the total assemblage). The ratios of these two alloy types drop significantly to 30% among the European group. This trend indicates tin of eastern origin and the most likely source comes from tin deposits in the Altai Mountains (Chernykh & Kuz'minykh 1989a:175-176). Altaian tin sources were first investigated by Chernikov (1948 & 1949), who identified several Bronze Age tin mines in the Kalba-Narym ridges of eastern Kazakhstan.

Chernykh & Kuz'minykh (1989a: 167-170) also contended that ST metalworkers in eastern Europe began to exploit Uralian ores with certain characteristic impurities. These include copper sandstone deposits in Cisurals, and arsenic-rich (Tash-Kazgan) and silver-rich (Nikolskoye) copper mines in Transurals.

4.2.2 Abashevo metalwork

Metal production in the Abashevo communities concentrated in two areas: (1) the Volga, where metal objects were mostly recovered from burials and (2) the Urals (known as Balanbash-type), where a number of settlements show signs of primary smelting activities using the local copper ores (Chernykh 1992:202). 80% of the Volga objects feature clean copper objects with low impurities (MP) and remaining metals are of arsenic-rich copper (TK) (Chernykh 1970:31). Some objects contain silver as the chief trace element, which might be sourced from a silver-rich copper mine (Nikolskoye) in Transurals (Chernykh & Kuz'minykh 1989a: 174). On the other hand, while the Uralian variant of the Abashevo metals also contains pure copper (MP) and arsenic-rich copper (TK), Chernykh (1970:109-111) considered Balanbash-type settlements as the primary metal suppliers due to the presence of copper smelting infrastructures on

sites (including fragments of ores, slags and melting crucibles). These Balanbash sites are close to rich copper deposits in the Urals, and primarily produce arsenical copper to be used within the domain of the Abashevo culture.

4.2.3 Sintashta-Petrovka metalwork

As discussed in Chapter 3, recent research on chemistry and microstructures of Sintashta ores and slags has revealed some informative outcomes (Grigor'yev 2015, Ch. 3 & 4). The compositional analysis of Sintashta metal artefacts has also provided some important characteristics of Sintashta metal production. Degtyareva (2009) investigated 95 copper-alloy objects from Sintastha cemeteries and concluded that over 80% of them are arsenical copper with arsenic ranging between 0.1 and 0.3%. Some copper-arsenic objects contain nickel up to 1%. She suspected that arsenic is derived from the mixing of oxidised ores and copper arsenide, and this smelting practice was introduced to neighbouring Abashevo and Potapovka societies and to less degree in the Petrovka culture (Ibid. 38-39). Apart from arsenical copper, pure copper and tin-bronze objects are less numerous, responsible for 6.2% and 5.3% of the total specimens respectively. The presence of tin-bronze in the Sintastha sites bears the testimony to the contact with the Seima-Turbino and Petrovka communities (Ibid. 38).

Vinogradov *et al.* (2013) examined copper-alloy objects from the fortified settlement Ustye I in the Transurals. Both Sintashta and Petrovka materials were unearthed, accompanying with numerous metallurgical items and infrastructures associated with metalworking activities, including ores, slags, tuyeres, crucibles, moulds, and furnaces for copper smelting and casting. 118 analysed objects are composed of tools, ingots, bars, staples, and some personal ornaments. The authors statistically grouped the analytical results into several alloy types: pure copper, arsenical copper (0.1-2% As), tin-bronze (0.4-8% Sn), and tin-bronze with arsenic (0.3-8.4% Sn; 0.15-0.54% As). They argued that Sintashta metals are represented principally by arsenical copper, and secondly by pure copper and the copper-tin-arsenic alloy. By contrast, Petrovka metals mainly feature pure copper followed by tin-bronze and tin-arsenic bronze. Chernykh (2007:81) argues that arsenical copper in both Abashevo and Sintastha contexts shares a common origin of arsenic-rich copper deposits in Tash-Kazgan.

Petrovka metals in the Transurals, on the other hand, are chemically different from the Sintashta metalwork. Based on the analytical data from settlement Kulevchi 3,

Degtyareva *et al.* (2001) identified two major metallurgical groups associated with the Petrovka context: pure copper and tin-bronze (Sn≥3%). The former consists of 76.9% of the total assemblage, and the authors believed that this clean copper corresponds to the chemical group EU, defined by Chernykh (1970). This specific copper group may source from the Elenovka and Ush-Katta deposits in Transurals and they are the principal component of the subsequent Andronovo metallurgy (Chernykh 1970:111-112). The occurrence of tin-bronze in the Petrovka assemblage might suggest a certain connection with the East (E. Kazakhstan), since its western neighbours, namely Sintashta and Abashevo communities, lack copper-tin alloys.

4.2.4 Other Eurasian metalwork during the Middle Bronze Age

Although the initial intention of this chapter was to investigate interactions between ST and Abashevo-Sintastha-Petrovka metalwork, it soon becomes obvious that in order to comprehend such a complicated metallurgical network, it is necessary to extend the research areas into neighbouring metal-using cultures. They are northern Caucasian cultures, Potapovka in the Middle Volga, Elunino in the Upper Ob River, Okunevo in the Minusinsk Basin, and Glazkovo in the Baikal (Figure 4.3).

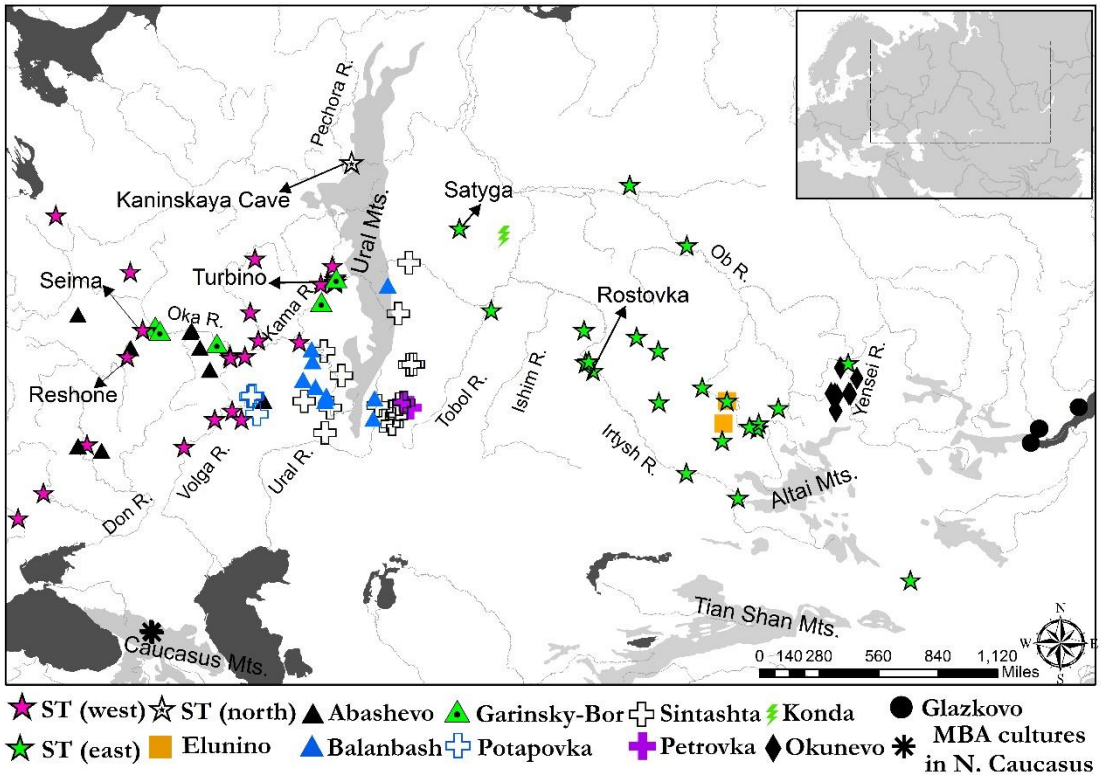


Figure 4.3 Distribution of analysed objects during the Middle Bronze Age.

The Elunino culture is situated in the Ob River near the Altai Mountains (Kiriushin 2002 & 2005). Elunino burials and settlements have yielded a number of Seima-

Turbino type tools and weapons so that this culture has been considered to play an important role in shaping the formation of the ST phenomenon (Chernykh & Kuz'minykh 1989a: 251-253; Kiriushin 2002; Kiriushin *et al.* 2004; Grushin 2002; Grushin *et al.* 2009). Analysis of metal objects from the Berezovaya Luka settlement suggests the widespread use of tin-bronze (Kiriushin & Tishkin 2003). Some artefacts show the presence of lead (0.2-1%), and recovered copper ores are also marked by lead and zinc as the chief minor elements. This Pb-Zn pattern may indicate the possible exploitation of polymetallic ores (Cu-Pb-Zn) in the Altai (Stöllner *et al.* 2011:235). The compositional analysis undertaken by Degtyareva *et al.* (2010) also revealed similar outcomes: copper-tin alloys are predominant, with occasional pure lead and tin-lead objects.

The Potapovak culture centred on the Middle Volga region, along the Samara River. According to Anthony (2007:386), it was a contemporary sister of Sintashta, featuring similar funeral practices, metal assemblage, horse sacrifices and chariot-related implements. Agapov and Kuzminykh (1994) have analysed 48 metal objects from the Potapovka I cemetery. The results show that 65% of them are made of clean copper, 13% of arsenical copper and 8 % of tin-bronze, corresponding to the Chernykh's copper groups MP, TK and VK respectively. Peterson *et al.* (2015) also explored the composition of 67 articles from the same cultural group and identified a probable recycling pattern due to the depletion of arsenic. He also noticed a positive correction between arsenic and nickel content within arsenical copper (R=0.55). He proposed that Potapovka metalwork employed a variety of ore sources in which the Kargaly ore field in the southern Urals played a vital role.

The Okunevo culture in the Minusinsk Basin was a metal-using community dated to 25th to the 20th centuries cal. BC (Svyatko *et al.* 2009). Chernykh has noted that this culture was capable of producing hollow-cast spearheads, a typical technique used by the Seima-Turbino metalworkers (Chernykh 1992: 185). Compositional studies on the Okunevo metals have been summarised by Khavrin (1997 & 2006), who suggested that they are mostly clean copper followed by tin-bronze items. Unfortunately, he did not go further to explain the patterns of trace elements.

The initial use of copper and copper alloys in the Cisbaikal region was operated by the hunter-gatherer community, known as the Glazkovo culture dated to 3400/3000 to 1000

cal. BC (Weber *et al.* 2011). The connection between the Glazkovo culture and Seima-Turbino phenomenon is evidenced by the discovery of similar nephrite rings, and the Baikal region has long been recognised as the source of Siberian jade (Chernykh & Kuz'minykh 1989a:245). Another indirect long-distance contact is manifested by the cranial trauma on the Glazkovo deceased. The breakage of skulls can only be created by the strike of sharp metal tools. Such metal implements are completely absent among the Glazkovo assemblage but they are typical for the Seima-Turbino spearheads or daggers (Schulting, person. com.).

The analysis of metal objects conducted by Sergeyeva (1981:65) demonstrated that the early stage of the Glazkovo metallurgy was marked by the manufacture of leaf-shaped knives made of pure copper in contrast with the emergence of copper-tin-arsenic alloys in the later stage. Nevertheless, Goryunova & Pavlova's (2008) research on metal objects from the Kurma XI cemetery showed that both pure copper and tin-bronze items coexisted in the same funeral context without any chronological lag. Another cemetery (Shamanka II) yielded a dozen of decorative items made of tin-bronze. Most of them contain less than 15% tin, but some up to around 20-30% tin (Tishkin 2010). This is an interesting sign to suggest the independent development of tin-bronze in the Baikal. Unfortunately, the author did not report which analytical method was employed for the measurements of those high-tin bronzes. If it was the surface analysis by the XRF spectrometry, tin concentrations can be exaggerated by the corrosion or tin enrichment (caused by inverse segregation during casting) near the surface (Meeks 1993).

4.3 Potential problems of traditional interpretations

Although previous studies can definitely foster our understanding of the prehistoric metallurgy in the Eurasian steppe, some of their arguments based on the provenance rationale are potentially flawed. The authors neglect the possibility of recycling or mixing of metals from different sources, which could wipe out any "fingerprints" left in object chemistry, making the provenance study invalid. It is problematic to employ Chernykh's chemical groups to characterise metal production since his grouping purely depends on direct links with ore deposits in the Urals. Of course, copper ores from the Urals were likely to have been exploited by the MBA societies from the analysis of ore and slag chemistry (Grigor'yev 2015, also see Chapter 3). However, this does not imply that copper after being smelted was directly transferred into different regions without any further processing. In order to better understand the life histories of artefacts, we

have to link object chemistry to ancient metalworker's preferences rather than to the geological sources.

Another important issue is the emergence of tin-bronze across the Eurasian steppe. The adoption of copper-tin alloys had long become a pan-Asian technological phenomenon (Pigott 2011: 273). Chernykh & Kuz'minykh (1989a) considered that the ST phenomenon was the driving force for the spread of bronze metallurgy in the Steppe, but they did not specifically argue how tin-bronze affected the trajectories of metallurgy in other steppe communities due to the lack of chemical analysis of metal objects in relevant archaeological cultures. Recent archaeometallurgical studies have turned this situation around by providing new compositional data from many contemporary bronze-using societies (e.g. Petrovka and Elunino). However, no one has ever attempted to utilise these new data to re-evaluate the existing framework proposed by Chernykh and Kuz'minykh (1989a).

Finally, one of the most challenging tasks is to determine the dates of the ST bronzes. Chernykh (2008) has positioned the ST sites in the interval between 2200 and 1700 BC, synchronous with Abashevo-Sintashta-Petrovka cultures, based on pottery typology and few radiocarbon dates (four dates). Recent dating projects in relevant sites from western Siberia and eastern Europe have shed some light on the chronological development of the ST metallurgy (see Section 4.7). This chapter attempts to integrate available radiocarbon dates to address the probable dates of the ST metals in relation to other steppe cultures.

In a word, I will address three main research questions regarding the circulation of the metals, the spread of tin-bronze, and chronological framework during the Middle Bronze Age of the Eurasian steppe.

4.4 Alloying practices in the Eurasian steppe

4.4.1 The tin story

As tin-bronze production is the most crucial element of the ST phenomenon, it is necessary to scrutinise the use of such particular alloying practice across the Eurasian steppe. Table 4.1 provides details of tin-bronze (tin > 1%) used in each culture based on the ubiquity analysis (percentage of the assemblage composed of that particular alloy). As can been seen, the ratios of tin-bronze in the E.ST (Siberian type) and Elunino assemblage (73.9% and 66.7%, respectively) are much higher than those of other

cultures. The only exception is the Pechora specimens containing over 80% of tin-bronze. These bronzes come from a single metal hoard, Kaninskaya Cave (in Pechora River, denoted as N. ST), which is reported as a specific ritual deposition.

Table 4.1 Ubiquity of alloy types across the MBA metal-using cultures.

Metal-Using Culture						
N=1181	Caucasus	Abashevo	Potapovka	Sintashta	Petrovka	
Cu	100.0%	100.0%	91.0%	93.3%	79.1%	
Cu-Sn	—	—	**7.5%**	**5.8%**	**20.3%**	
Cu-Sn-Pb	—	—	—	—	—	
Total N	36	185	67	224	153	
	W. ST	N. ST	E. ST	Elunino	Okunevo	Glazkovo
Cu	70.8%	16.7%	18.2%	7.4%	62.5%	48.9%
Cu-Sn	**29.2%**	**83.3%**	**73.9%**	**66.7%**	**29.5%**	**43.6%**
Cu-Sn-Pb	—	—	8.0%	14.8%	5.4%	5.1%
Total N	226	24	88	27	112	39

The non-primary tin-bronze production consists of Okunevo, W. ST (European type), and Petrovka cultures, situated in the periphery of the primary production centres (E. ST and Elunino), presenting 20-30% tin-bronze in their assemblage. By contrast, cultures located even further away from the potential tin-rich areas (Altai) show very little or a complete absence of copper-tin alloys such as Potapovka, Sintashta, Abashevo and N. Caucasus. In this regard, these patterns of tin-bronze distribution are in agreement with Cherynkh's argument that tin was likely to originate from the East, particularly the Kalba-Narym deposits in the Altai Mountains which are geographically close to the E. ST and Elunino sites. Recent fieldworks undertaken by Deutsches Bergbau-Museum Bochum have uncovered several tin mines from eastern Kazakhstan, although they are all dated to the later Andronovo culture (c. 1700-1400 cal. BC) (Stöllner *et al.* 2011:246-247).

Apart from the possible tin sources in the Altai, one may argue another tin-bronze centre in the Glazkovo communities of Cisbaikal. Despite relatively few metal objects uncovered from the Glazkovo cemeteries, over 40% of them can be categorised as tin-bronze. Tin concentrations in these objects demonstrate the prominent peak at a high level, a pattern of primary production rather than recycling or mixing (see later discussion).

When plotting ratios of alloy types on the map, we can perceive a striking feature that the proportion of tin-bronze decreases when moving further away from the source (Altai). Figure 4.4 displays such a correlation in the subdivisions of the ST metals. The copper-tin alloy has the highest proportion in the Altai and it slightly decreases in western Siberia. Further west we observe a decline in tin-bronze ratios from the forest zone to Kama-Volga-Oka river basins, where tin-bronze approximately consists of a quarter of the individual assemblage.

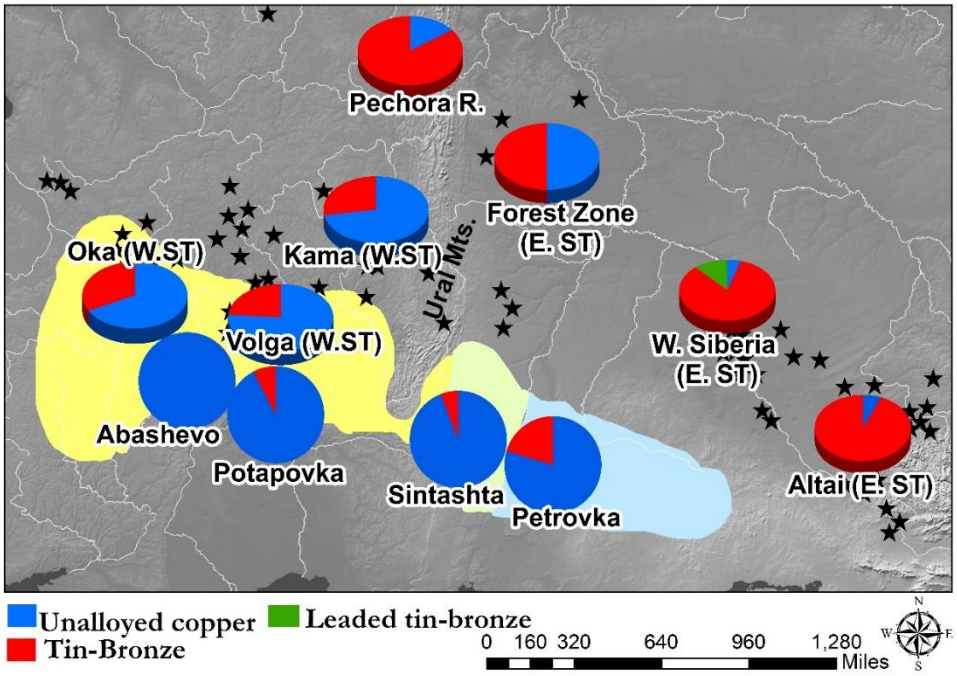


Figure 4.4 Ubiquity of alloy types in ST and Abashevo-Sintashta-Petrovka complexes. Distribution of cultural groups corresponds to Figure 4.1.

Incidentally, outside the ST phenomenon, the ratio of tin-bronze also diminishes from the East to West. It begins with around 25% in the Petrovka culture, then followed by the Sintashta and Potapovka communities, and eventually disappears in the Abashevo culture and N. Caucasus. Although this reduction of tin-bronze production has been pointed out by Chernykh and Kuz'minykh (1989a), this study is the first attempt to include the data from the southern steppe communities to visualise this pattern.

What Chernykh did not explicitly demonstrate is how the actual "quality" of tin-bronze artefacts is used in various cultures. Figure 4.5 presents the distribution of tin concentrations in the ST metals from the Siberian group. Where dramatic peaks occur at the high percentages may suggest the "designed recipe" in the past practices. The ST metals from the Altai are represented by such intentionally added tin with a prominent peak between 10 and 13%. This can be considered as a starting point of the

primary copper-tin alloying. When moving to western Siberia, ST objects display a bi-modal tin distribution, with a principal tin peak identical to the Altaian specimens. A secondary peak in low concentrations (4-7%) may indicate a possible mixture between high-tin bronze with tin-less copper. Further west in the forest zone the tin content is marked by a decreasing pattern suggesting the more drastic recycling/mixing activities.

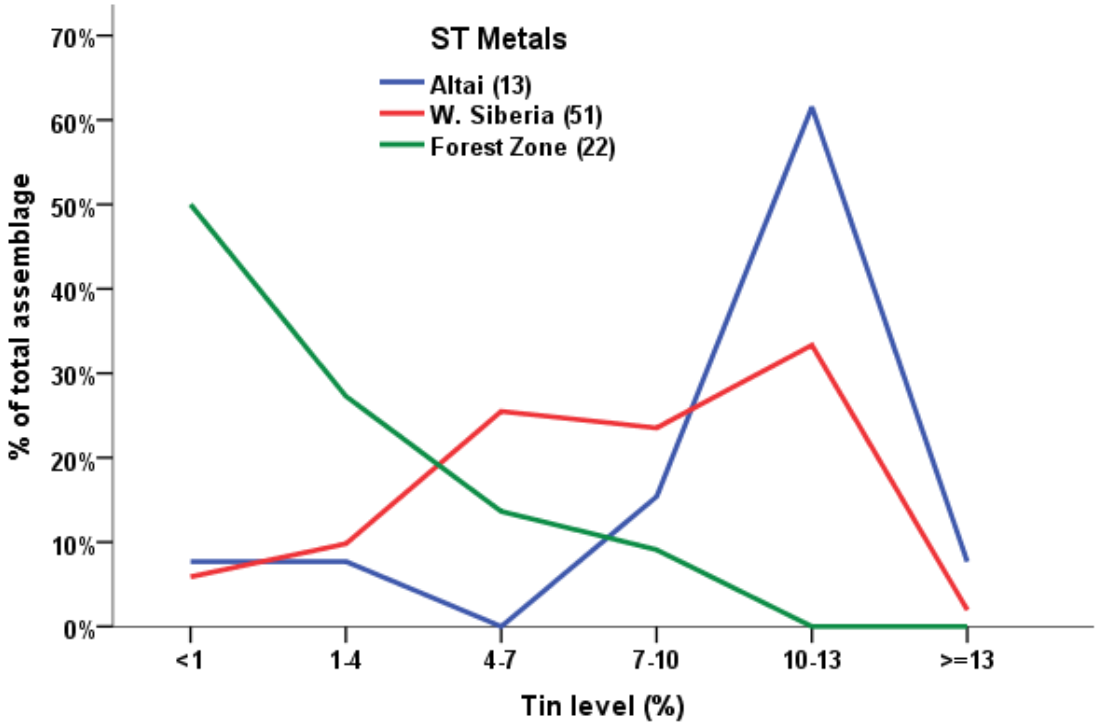


Figure 4.5 Distribution of tin in the E. ST metal assemblage

Copper-tin alloys also occur in the Elunino culture in the Ob, Okunevo culture in the Minusinsk basin, and the Glazkovo culture in the Cisbaikal (Figure 4.6). Compared with the E. ST metal specimens, both the Okunevo and Elunino objects are composed of lower tin concentrations (7-10% and 1-4%, respectively), suggesting the likelihood of using recycled metals from E. ST bronzes. This chemical connection is supported by the typological studies as the Elunino culture contained some imported items of the ST metalwork. Likewise, the Okunevo culture was in contact with the ST people as shown by the use of specific metal implements with bone handles. Another possible candidate for deliberately-made tin-bronze is the Glazkovo culture, where some personal adornments are produced from relatively high tin concentrations (>13%)

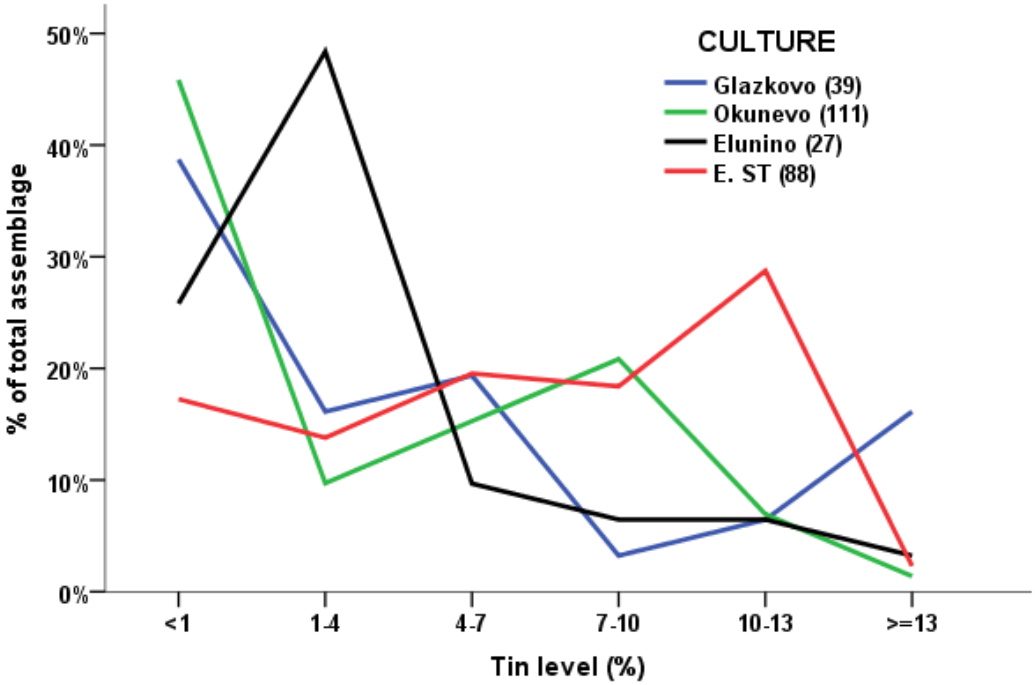


Figure 4.6 Distribution of tin among metals from the east of the Ural Mountains. E. ST bronzes include objects from the Altai, western Siberia and the Siberian forest zone.

In comparison with high-tin production in the East, metals from the Petrovka, Sintashta and Potapovka communities show considerable recycling or mixing as the majorities of them contain less than 4% tin (Figure 4.7). Metalworkers in these cultures probably did not consciously produce tin bronzes. Tin was accidentally brought in by recycling tin-bronze objects from foreign copper-tin alloys (likely from ST metals). The reuse of scrap metals is evidenced by metallurgical remains from the Petrovka sites, where many low-tin fragments and bars are considered as the semi-finished products (possibly as ingots) for further casting (Vinogradov 1982).

Of course, recycling is not the only way to transfer tin bronzes to the west of the Ural Mountains. The data also suggests that a proportion of W. ST specimens serve as the direct imports from the East (Figure 4.8). Tin bronzes from the Kama, Volga and Oka river basins share a similar alloying recipe of the E. ST as shown by tin concentrations ranging from 4 to 13%. These W. ST tin-bronze artefacts actually typologically resemble the E. ST counterparts, including spearheads, socketed axes, and double-edged knives (see Section 4.6). The decreasing tin curves in the W. ST specimens are due to the use of pure copper or arsenical copper from the southern Abashevo-Sintastha metalwork. Those are artefacts with less than 1% tin. As a result, we can observe two separate metalworking traditions in the W. ST metals. One is the unique character of tin bronzes as imported items and the other is the adoption of the southern steppe

alloying practices. W. ST metalworkers seldom mixed up these two distinctive metalwork. Tin-bronze artefacts in the W. ST could either serve as prestigious items (e.g. heirlooms) or reciprocal gifts for tribal, social or political ties. However, as W. ST people did not have access to raw material for bronze casting, they had to develop a new strategy by obtaining metals from their southern steppe communities. This brings out another important aspect of the steppe metallurgy—arsenical copper production.

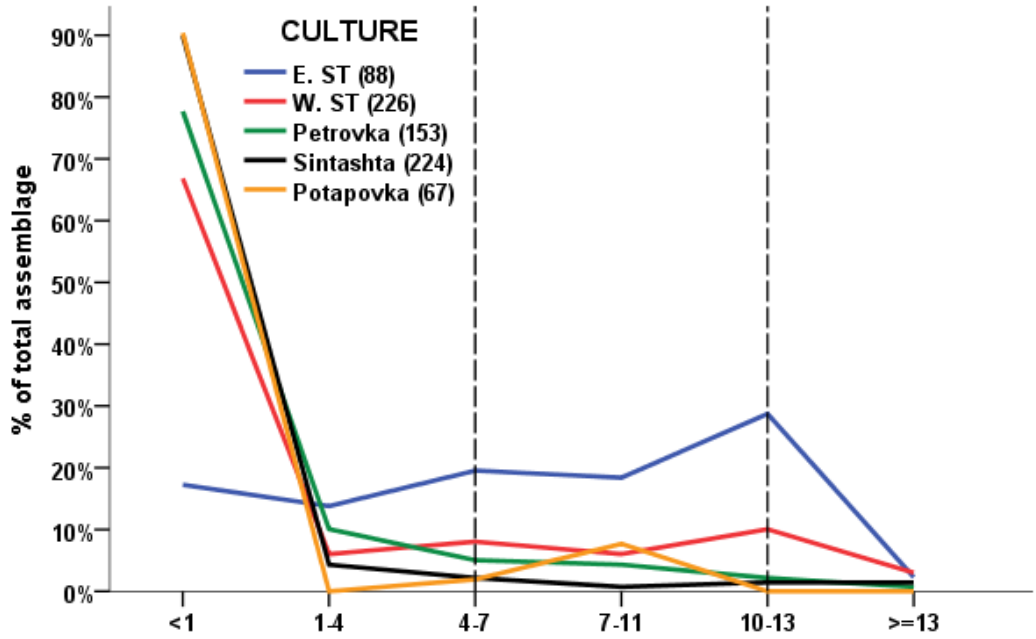


Figure 4.7 Distribution of tin among metals from the west of the Ural Mountains. W. ST includes objects from the Kama, Volga and Oka.

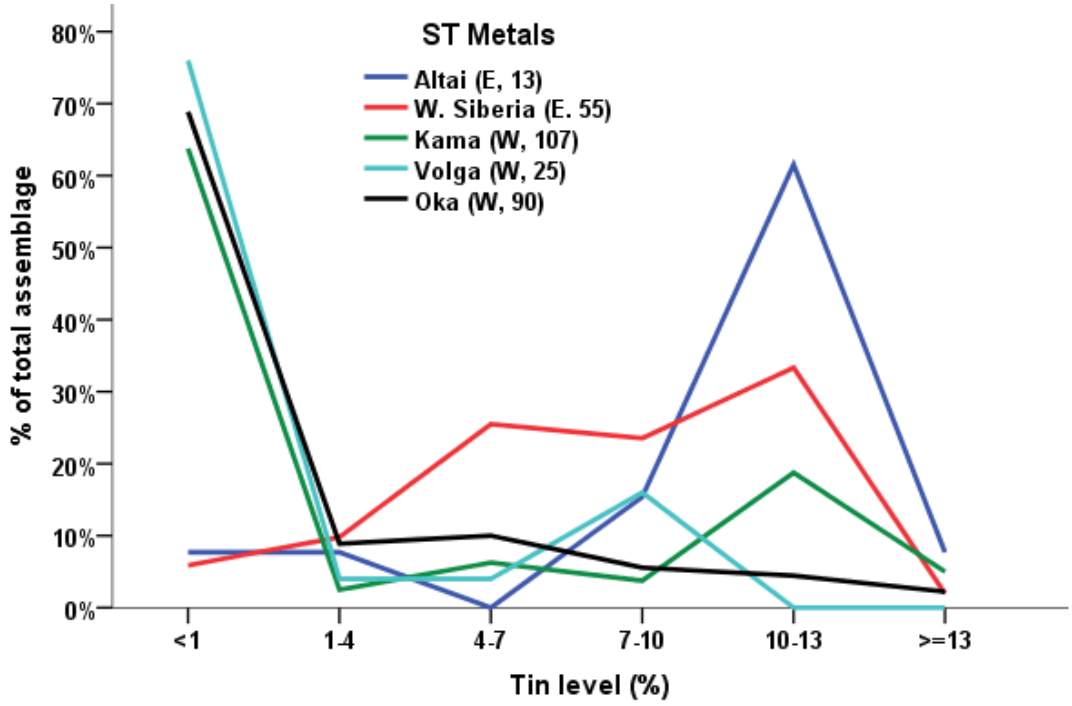


Figure 4.8 Distribution of tin among the ST metals.

4.4.2 The arsenic story

Arsenical copper had been extensively used in the Pontic-Caspian steppe among the Early Bronze Age Yamnaya and Catacomb communities. Chernykh (1966) believed that this special alloy was sourced from the Caucasus; however, whether the copper-arsenic alloy is a natural occurrence of copper smelting or a deliberate design remains debatable. There are at least three methods to make copper objects rich in arsenic. According to Budd *et al.* (1992), the first involves the addition of native arsenic or copper arsenide to molten copper, but there is no archaeological evidence for this practice. The second approach is to smelt fahlerz ores, a grey crystalline copper-containing mineral in the forms of tetrahedrite and tennantite. The end-products normally contain both arsenic and antimony such as the copper artefacts smelted from the Ross Island mine (Bray 2009). The third method is the co-smelting of copper oxides with arsenic-bearing sulphides (e.g. enargite and arsenopyrite). The co-smelting experiment conducted by Lechtman & Klein (1999) successfully produced arsenical bronze objects with 7 to 26% As.

Even though in theory these three methods can yield copper-arsenic alloys, it is extremely difficult to distinguish which of them is most likely to have been used. Chernykh (1992) suggested that arsenic is naturally brought into the objects by smelting arsenic-rich copper ores from the Tash-Kazgan deposit, while Grigoryev (2015) argues that arsenic-rich minerals are added during the copper smelting process. As determining the exact copper-arsenic technologies is outside the scope of this thesis, I will not dwell on this technical issue. Rather, I would like to investigate how arsenic-rich copper objects are spatially distributed and their relationship with the ST bronze metallurgy.

Figure 4.9 depicts the ubiquity map of tin-bronze and arsenical bronze across the Middle Bronze Age cultures. Similar to the cut-off for tin-bronze, I use 1% arsenic for the division between unalloyed copper and arsenical bronze. Two alloying practices stand out: tin-bronze in the east and arsenical bronze in the west. Arsenical bronzes primarily focus on the northern Caucasus and the Balanbash culture in the Urals. Distribution of arsenic in objects also reveals the importance of copper-arsenic production in these two regions (Figure 4.10). Northern Caucasian and Balanbash objects contain relatively more arsenic than metals from other areas. Metals from Sintashta, Potapovka and W. ST are likely to the recycled products from the above primary centres as suggested by the decreasing arsenic pattern.

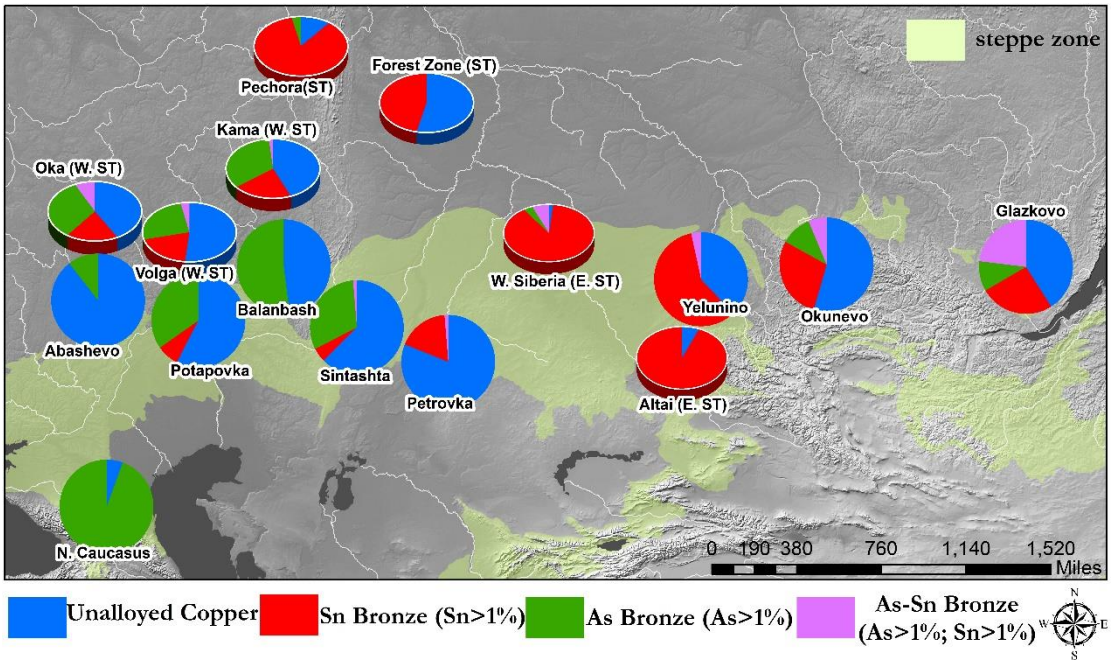


Figure 4.9 Ubiquity of tin-bronze, arsenical bronze and unalloyed copper during the Middle Bronze Age.

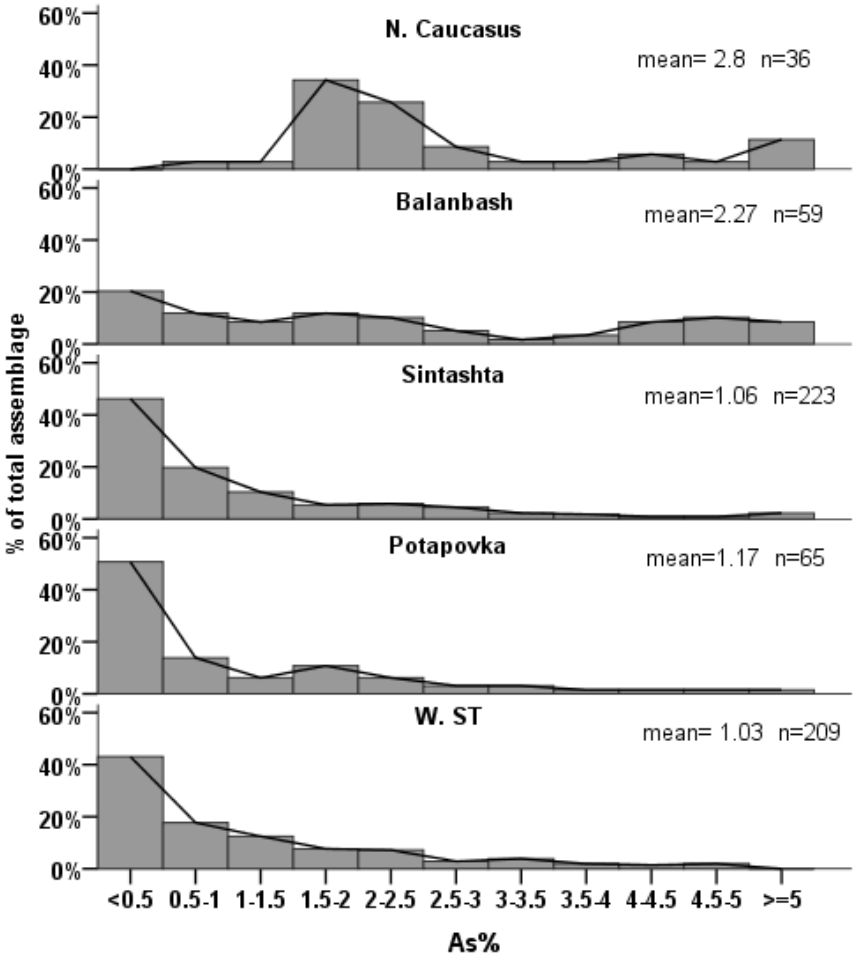


Figure 4.10 Distribution of arsenic in the MBA copper-based artefacts.

Figure 4.9 also demonstrates another important aspect that the W. ST specimens contain equal amounts of tin-bronze and arsenical copper objects. Given these two alloying

sources, one would expect a mixture between copper-tin and copper-arsenic alloys within the W. ST metalwork. Nonetheless, the data suggests not. Figure 4.11 plots all W. ST metal objects in term of their tin and corresponding arsenic concentrations. It shows that the high arsenic signal usually exists in objects with little tin (<1%). That is, tin-bronze objects are seldom being mixed with arsenical bronze. This confirms the previous viewpoint that ST tin bronzes are treated as prestigious items for direct exchange. A comparison between arsenic levels of W. ST and E. ST assemblage further pinpoints this unique characteristic of tin-bronze usage (Figure 4.12). Both W. ST and E.ST tin bronzes share the similar arsenic profile, indicating a direct movement of objects without much recycling. This argument can be further consolidated by the investigation on artefact chemistry and typology (see Section 4.6).

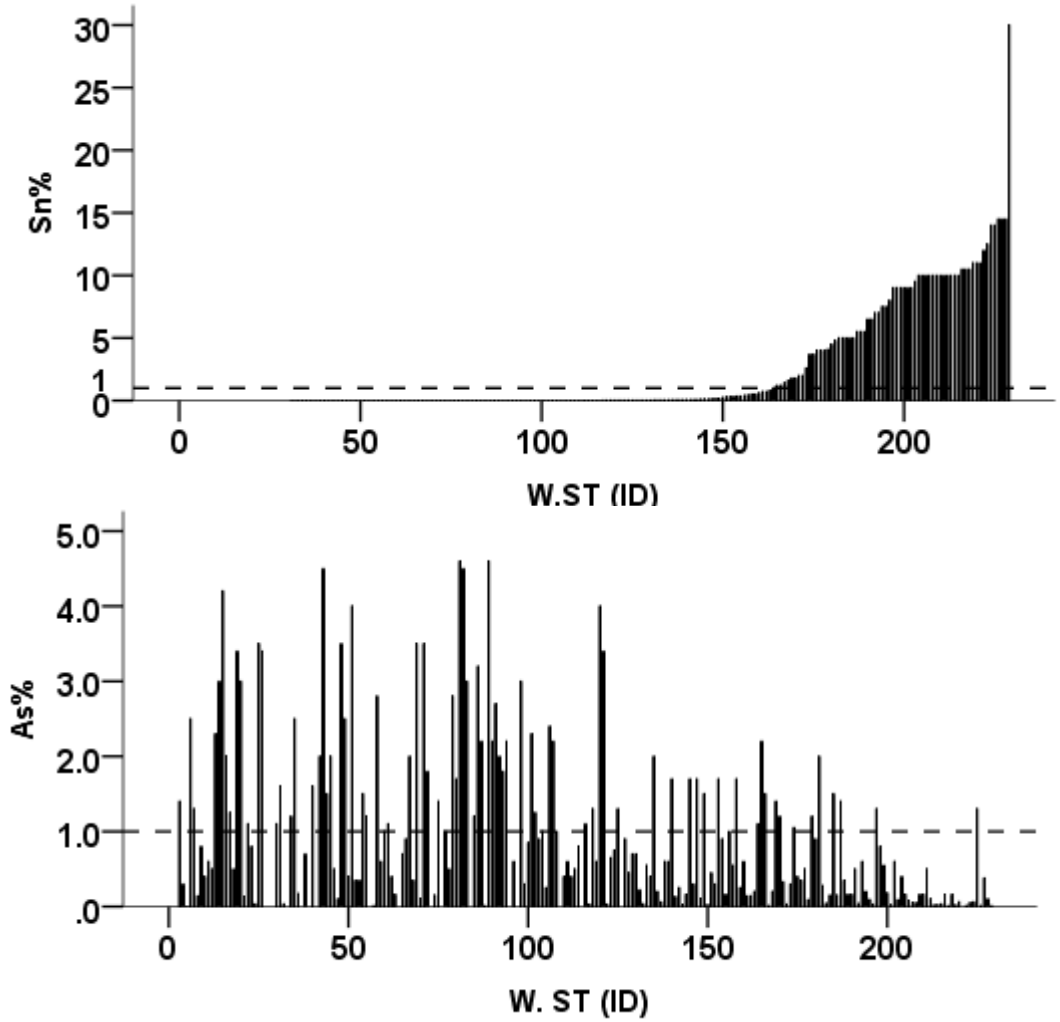


Figure 4.11 A needle plot showing tin and corresponding arsenic concentration in each W. ST object.

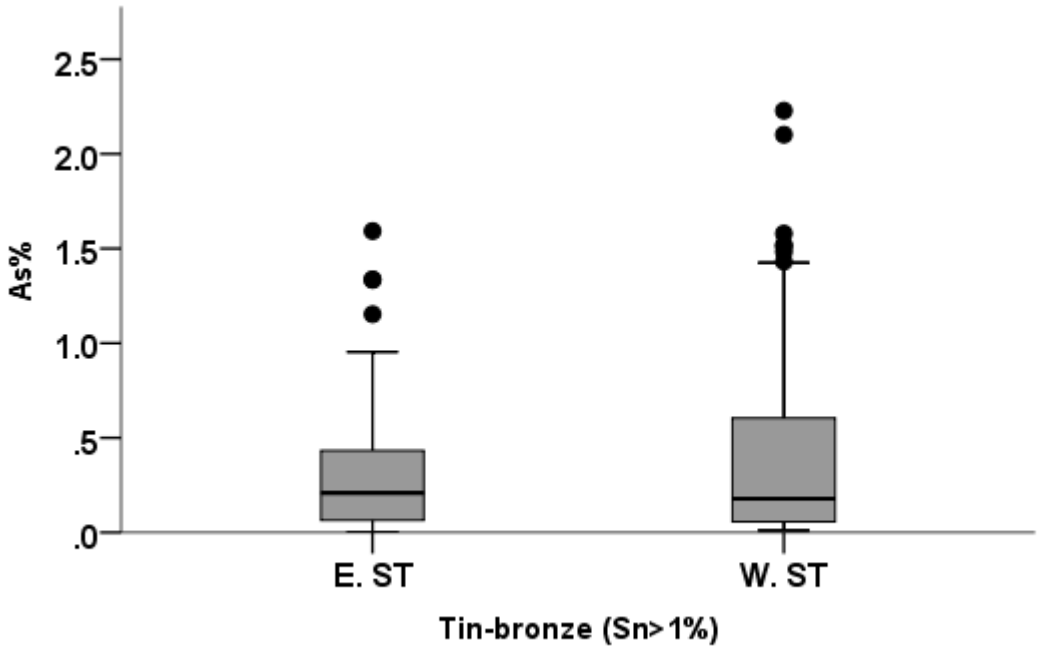


Figure 4.12 Comparison between arsenic content in the E. and W. ST tin-bronze objects

4.5 Copper chemistry

4.5.1 Copper group 1 and group 2

According to Chernykh and Kuz'minykh (1989a: 168-169), W. ST metals were sourced from the Abashevo metalwork, including pure copper, arsenical copper and arsenic-silver copper. These chemical variations can be linked to specific ore deposits in Cis- and Transurals. On the other hand, copper for E. ST artefacts chiefly stemmed from Altaian ores. This simple linear relationship between objects and raw materials overlooks the potential recycling and mixing practices. As the Eurasian steppe possesses extremely complex social and ecological environments, it is more appropriate to assume a more sophisticated exchange network involving multiple metal sources. Table 4.2 outlines the overall picture of copper used. CG1 (pure copper) and CG2 (arsenic-only copper) are most widespread copper categories being used across the Steppe. Although other copper groups play a minor role, impurities such as silver and nickel can still be useful for tracing the flow of metals.

The spatial distribution of copper groups suggests that pure copper (CG1) in the west of the Ural Mountains concentrates in the Abashevo of the Volga-Don interfluve and Garinsky-Bor in the forest zone of eastern Europe, where over 60% of objects belong to this category (Figure 4.13). It is not surprising to observe a focus of pure copper in the Garinsky-Bor sites as most of them are located in the area of well-known copper sandstone deposits that can potentially produce clean copper. Some of Abashevo

Table 4.2 Ubiquity of copper groups across the MBA metal-using cultures.

	Metal-Using Culture												
N=1175	N. Caucasus	Abashevo	Balanbash	Garinsky-Bor	Potapovka	Sintashta	Petrovka	W. ST	N. ST	E. ST	Elunino	Okunevo	Glazkovo
CG1 *pure*	2.8%(1)	**65.8%(50)**	21.9%(16)	**61.8%(21)**	15.2%(10)	7.6%(17)	**86.9%(133)**	15.9%(36)	**45.8%(11)**	**46.6%(41)**	**87.5%(21)**	**43.2%(48)**	23.1%(9)
CG2 *As*	**66.7%(24)**	23.7%(18)	**49.3%(36)**	–	19.7%(13)	**42.9%(96)**	9.2%(14)	**29.6%(67)**	**29.2%(7)**	**29.5%(26)**	12.5%(3)	26.1%(29)	12.8%(5)
CG3 *Sb*	–	–	–	–	–	0.4%(1)	1.3%(2)	0.4%(1)	8.3%(2)	–	–	3.6%(4)	–
CG4 *Ag*	–	9.2%(7)	1.4%(1)	38.2%(13)	6.1%(4)	0.4%(1)	0.7%(1)	5.3%(12)	–	1.1%(1)	–	3.6%(4)	–
CG5 *Ni*	–	–		–	3%(2)	1.3%(3)	–	–	–	–	–	–	2.6%(1)
CG6 *AsSb*	–	–		–	1.5%(1)	2.7%(6)	1.3%(2)	5.8%(13)	4.2%(1)	9.1%(8)	–	14.4%(16)	–
CG7 *SbAg*	–	–		–	–	–	–	0.4%(1)	–	–	–	–	–
CG8 AgNi	–	–		–	–	–	–	–	–	–	–	–	10.3%(4)
CG9 *AsAg*	11.1%(4)	1.3%(1)	13.7%(10)	–	6.1%(4)	6.7%(15)	0.7%(1)	**21.2%(48)**	12.5%(3)	3.4%(3)	–	0.9%(1)	–
CG11 *AsNi*	2.8%(1)	–	12.3%(9)	–	**45.5%(30)**	**29.9%(67)**	–	7.5%(17)	–	5.7%(5)	–	1.8%(2)	10.3%(4)
CG12 *AsSbAg*	5.6%(2)	–		–	–	0.4%(1)	–	1.8%(4)	–	2.3%(2)	–	1.8%(2)	–
CG14 *AsSbNi*	–	–		–	–	4%(9)	–	2.2%(5)	–	1.1%(1)	–	3.6%(4)	–
CG15 *AsAgNi*	–	–	1.4%(1)	–	2%(3)	3.1%(7)	–	5.8%(13)	–	1.1%(1)	–	–	10.3%(4)
CG16 *AsAgSbNi*	5.6%(2)	–		–	–	0.4%(1)	–	4%(9)	–	–	–	–	15.4%(6)
Total N	36	76	73	34	67	224	153	226	24	88	24	111	39

monuments fall outside the domain of this potential copper source, so it is likely to have another pure copper source from further west (e.g. the Don river basin).

The ratio of CG1 declines when moving further away from the core area to the regions of W. ST, Balanbash and Potapovka, where CG1 occupies around 15-20% of the total assemblage. CG1 production becomes insignificant in the Sintashta culture (less than 8%). This geographical distribution of CG1, with the focus on the Kama-Oka-Volga interfluve, reflects the possible use of copper sandstones in western Urals.

In the east of the Ural Mts. pure copper primarily concentrates in Petrovka and Elunino cultures (86.9% and 87.5%, respectively). E. ST metals containing an intermediate ratio of CG1 could potentially receive copper from both sources. When travelling to the east, pure copper gradually decreases from the Elunino, through the Okunevo and finally to the Glazkovo. The eastern movement of CG1 illuminates a possible link between the Ob river and the Baikal region.

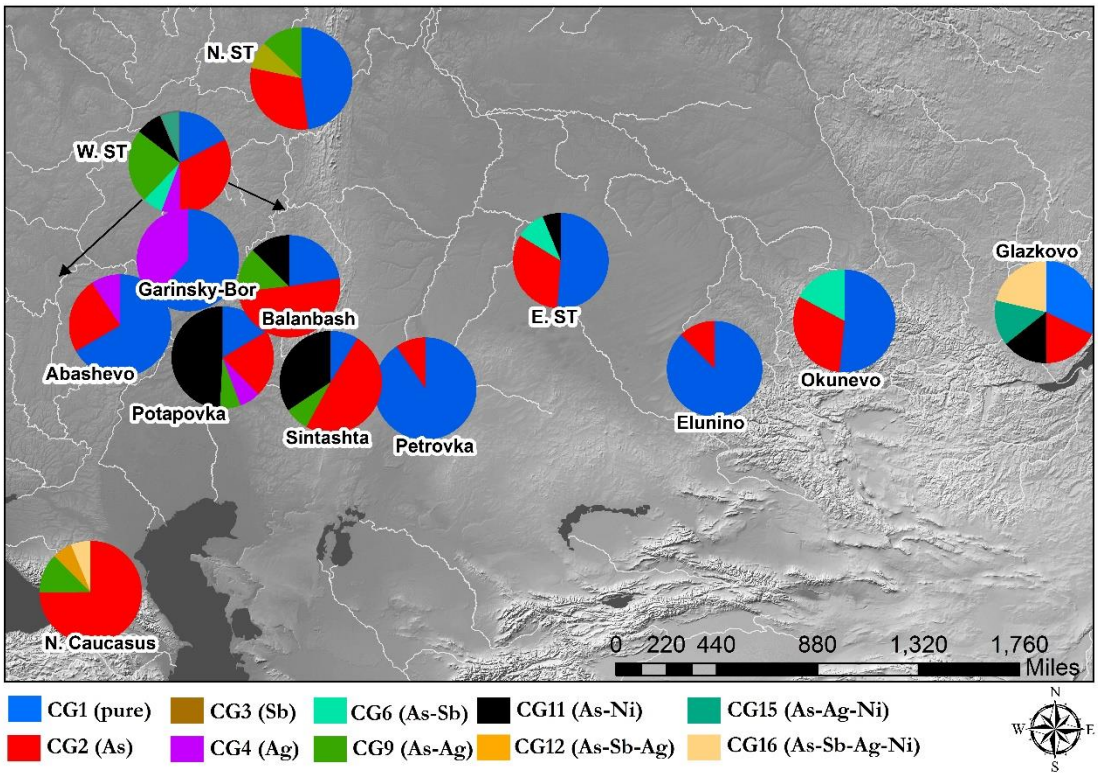


Figure 4.13 Ubiquity of copper groups across the MBA cultures in the Steppe. See Figure 4. 3 for specific ST sites.

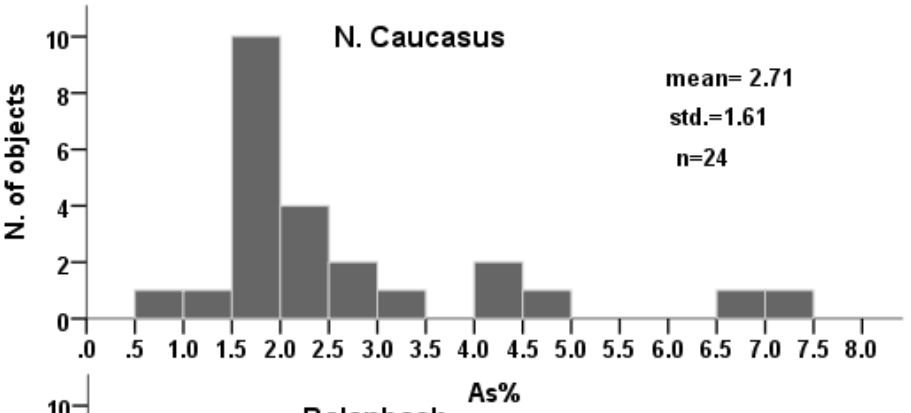
In the previous section, we treat arsenical copper as an alloying practice. However, these copper-arsenic artefacts actually bear some diagnostic trace elements (e.g. nickel and silver) that may represent different "life histories". We have to break arsenic-copper

into three categories: arsenic-only copper (CG2), arsenic-nickel copper (CG11), and arsenic-silver copper (CG9). CG2 is the most common copper chemistry throughout the Eurasian steppe. Percentages of CG2 demonstrate a rather complicated system of metal exchanges. In the west, there seem to be several CG2 production centres in N. Caucasus, Balabash and Sintashta cultures in which over 40% of artefacts are made of this copper. The Caucasus region had long been recognised as a crucial copper-arsenic production centre since the Early Bronze Age. The data seems to suggest its continuity during the Middle Bronze Age as well. Nonetheless, the Ural regions arose to become another important provider for arsenical copper, which has been emphasised many times in Chernykh's research (Chernykh 1992). Cultures between Caucasian and Uralian centres, namely the Abashevo, Potapovka and W. ST, were likely received CG2 metals from the Caucasus and Urals through the recycling.

Plotting distribution of arsenic across CG2 allows us to identify primary and non-primary production. Primary centres are represented by N. Caucasus and Balanbash, with several peaks at high amount of arsenic (average 2.7% and 2% respectively, Figure 4.14). On the contrary, other adjacent metal-using communities, such as the W. ST, Abashevo and Sintashta, feature low-arsenic production except for occasional high-arsenic objects (Figure 4.15). The most drastic recycling occurs in Potapovka and Petrovka metals in which most of them have no more than 0.5% arsenic (Figure 4.16).

There is much debate about whether arsenical copper during this period was the result of smelting copper-arsenic ores (Chernykh 1970) or of co-smelting (Grigor'yev 2015). Instead of exploring this challenging issue, we can; however, show a more meaningful exchange network of arsenic copper focusing on N. Caucasus and Balanbash, and their flow into neighbouring regions/cultures by means of metal recycling.

Unlike a clear directional movement of CG2 in the west, metal-using cultures in the east do not have a clear pattern due to a lack of chemical data in some essential areas such as Kazakhstan and the Altai. Although both E. ST and Okunevo artefacts are represented by decreasing arsenic levels, the geographical distribution of overall data is too fragmented to draw any firm conclusion of metal in circulation (Figure 4.16).



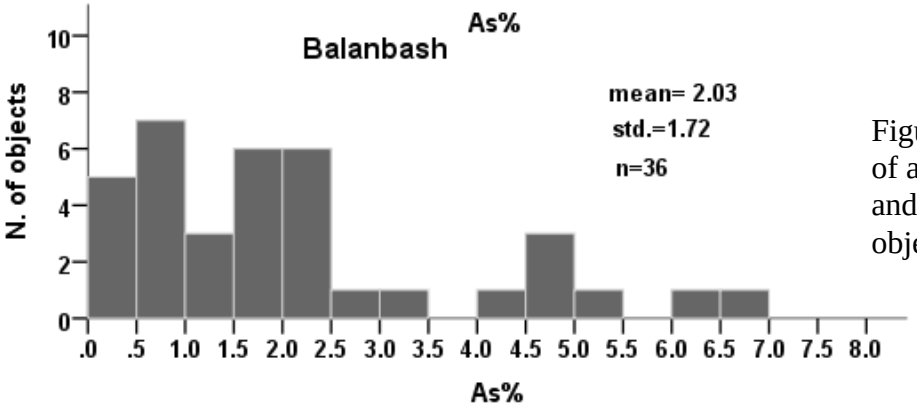
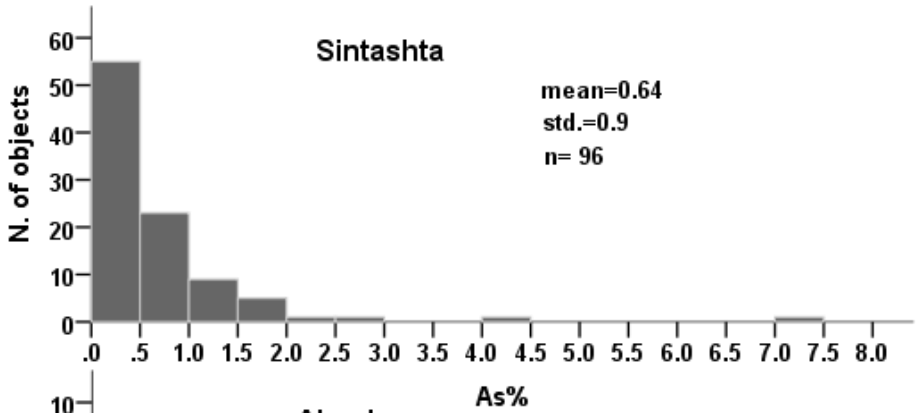
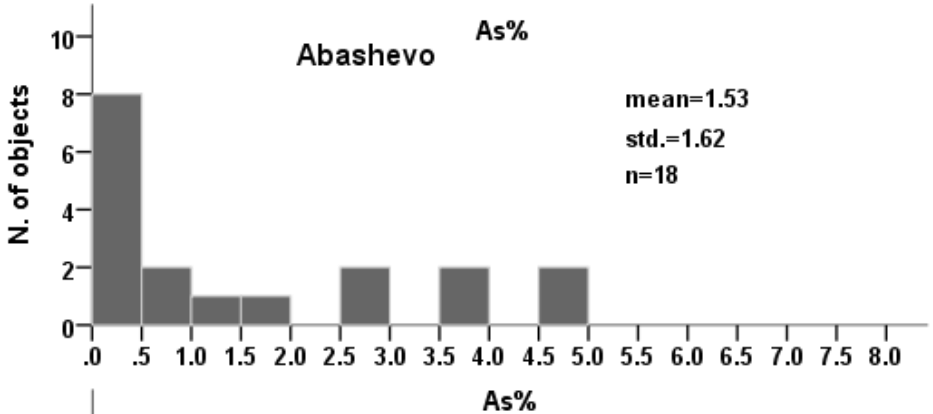


Figure 4.14 Distribution of arsenic in Caucasian and Balanbash CG2 objects.





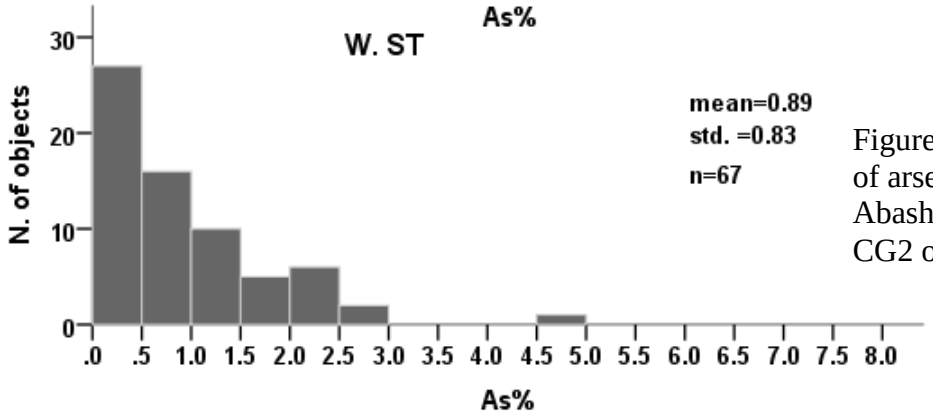


Figure 4.15 Distribution of arsenic in Sintashta, Abashevo, and W. ST CG2 objects.

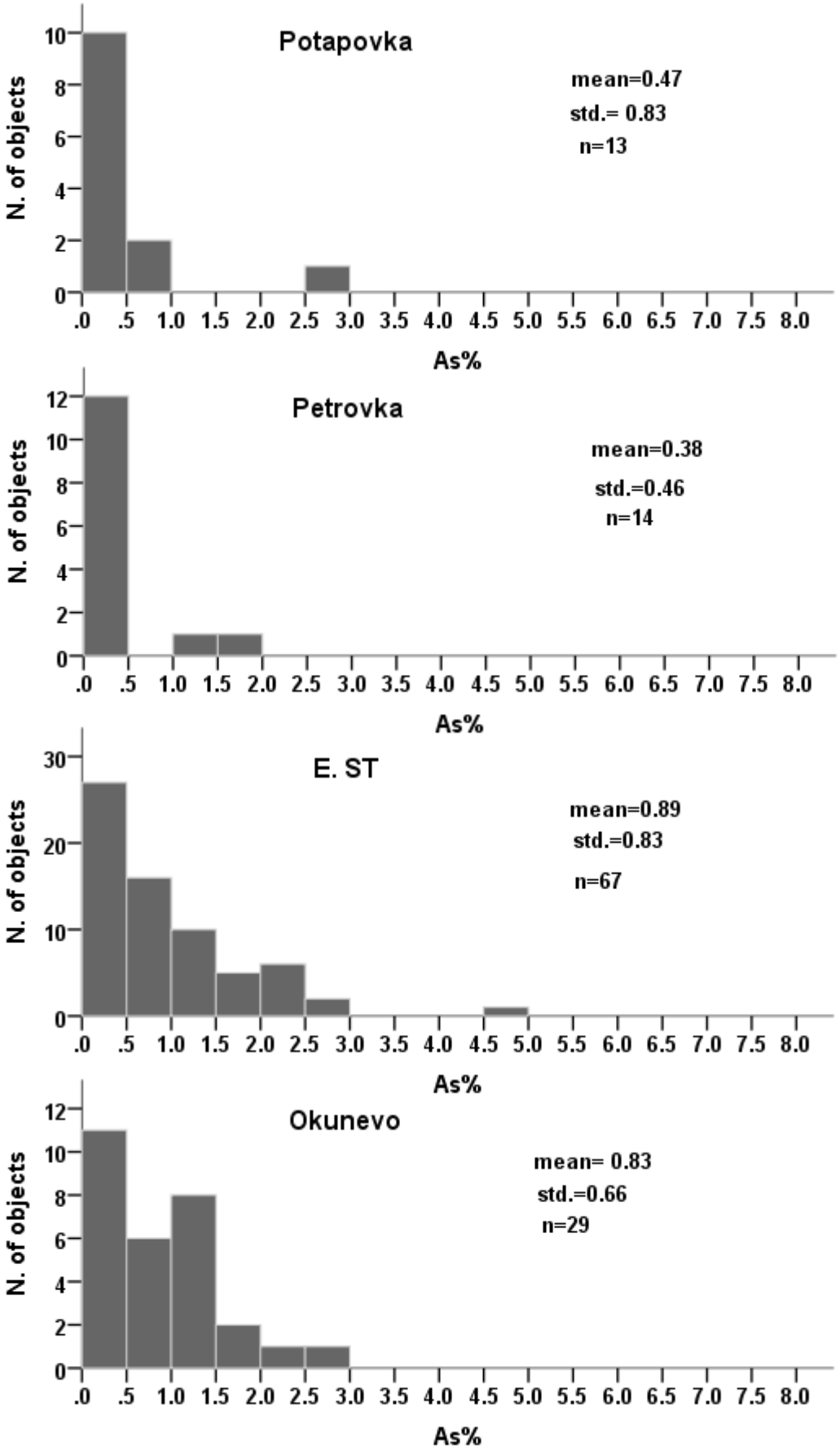


Figure 4.16 Distribution of arsenic in Potapovka, Petrovka, E. ST and Okunevo CG2 objects.

4.5.2 Other Copper groups

The chemistry of the Sintashta metallurgy is marked by the presence of copper with arsenic and nickel (CG11). This copper type occupies nearly 30% of the total Sintashta copper-based artefacts (see Figure 4.17). CG11 is also a diagnostic feature in the Potapovka sites of the middle Volga, a sister culture of the Sintashta. Interestingly, both arsenic and nickel concentrations in the Sintashta and Potapovka objects display a similar distribution pattern, indicating a possible direct exchange between the Transurals and the Volga region (Figure 4.17). As the Potapovka culture only consists of burials, it is likely that those funeral monuments in the Volga were actually constructed by Sintastha people who buried their dead with metal objects of the Transural traditions.

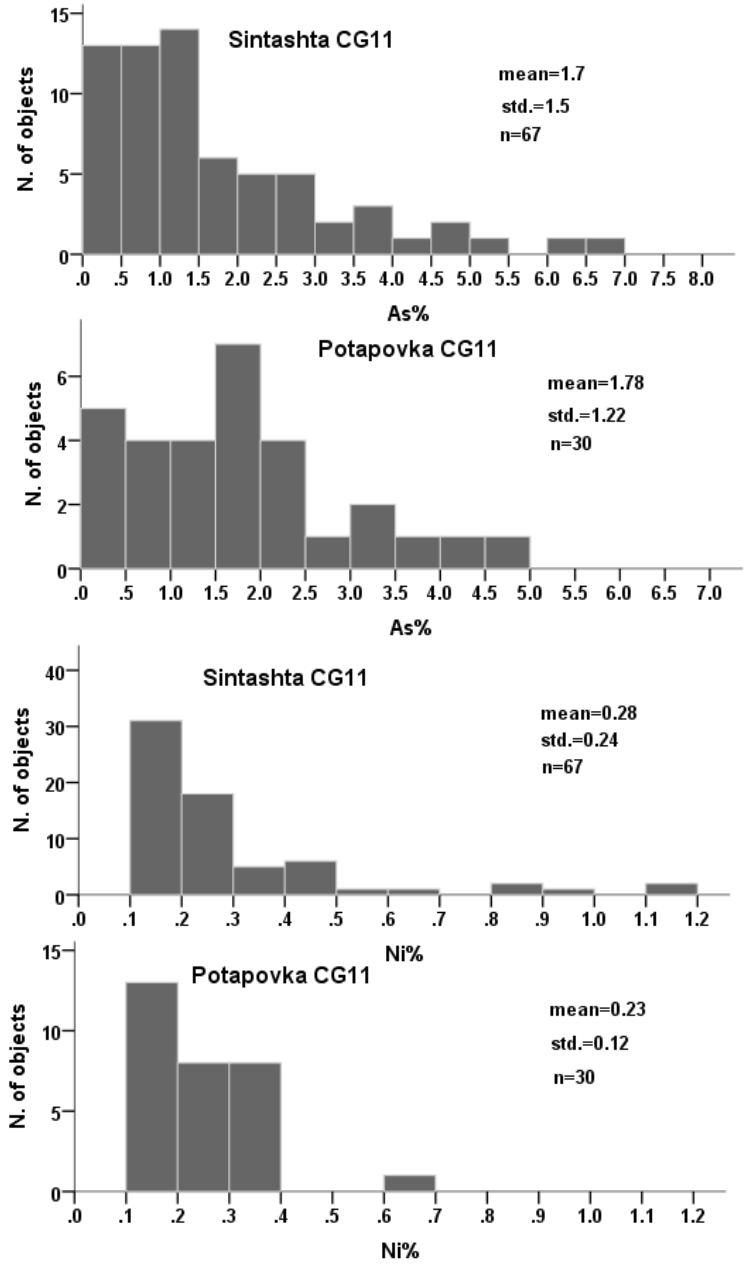


Figure 4.17 Distribution of arsenic and nickel in Sintashta and Potapovka CG11 objects.

Despite relatively small proportions, CG11 is also present in the Balanbash and W. ST assemblage. Balanbash artefacts contain significantly high arsenic levels, but currently it is uncertain about their relationship to the Sintastha metalwork due to very few analyses available (Figure 4.18, top). However, the influence of Sintastha metalwork over the W. ST is attested by the similar arsenic level of CG11 artefacts (Figure 4.18, bottom). These objects, as shown by typological studies, are direct imports from the steppe communities (see Section 4.6).

CG9 (arsenic-silver copper) chiefly comes from the W.ST assemblage. Such a composition could be obtained either from smelting of specific copper ores rich in silver or the mixture between arsenic-only copper (CG2) with silver-only copper (CG4). The latter scenario is more plausible because the W. ST sites are geographically adjacent to the Balanbash culture (rich in CG2) and Garinsky-Bor sites (rich in CG4). This finding contradicts Chernykh's argument that silver-rich artefacts are sourced from the Nikolskoye mine in the Transurals. This statement is unlikely to be true as silver-containing metals (CG4 & CG9) are rather unrepresentative in the east of the Ural Mts.

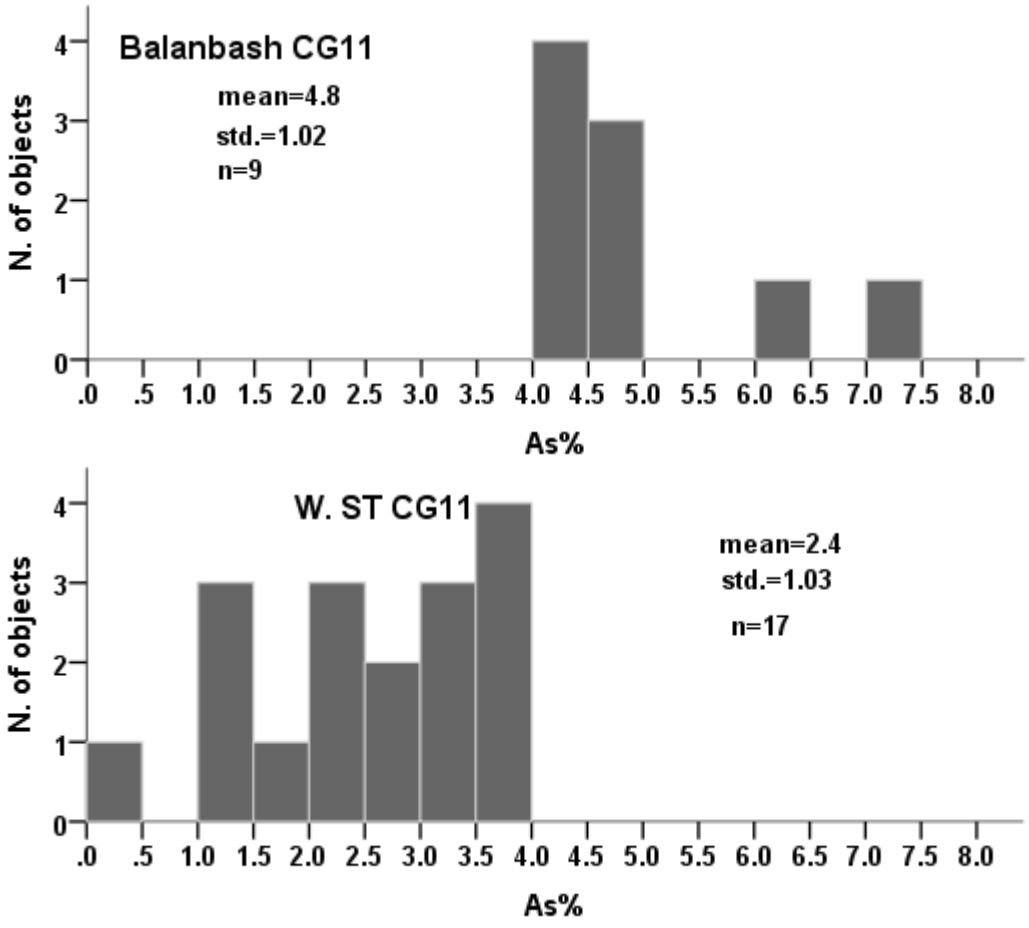


Figure 4.18 Distribution of arsenic in Balanbash and W. ST CG11 objects.

4.5.3 The Seima-Turbino bronze metallurgy

As discussed above, we have recognised the Urals as a hub to export copper resources to other regions/cultures during the Middle Bronze Age. Two of the most influential copper supplies are arsenical copper from the Balanbash and arsenic-nickel copper from the Sintastha. However, the circulation of arsenical (or arsenic-nickel) copper was limited to the local exchange network within the Ural-Volga interfluve. By contrast, the ST phenomenon is characterised by the transfer of bronze metallurgy across different cultural groups over an enormous distance. This raises a question of how ST metalwork interacts with indigenous cultures/regions along their spread to the west. Figure 4.19 illustrates the ubiquity of some major copper groups associated with the ST metals. Starting from the east, CG1 is predominant in the Altai, including both ST and Elunino artefacts. Further west in western Siberia, namely the Rostovka cemetery, we encounter a decrease in CG1 but an increase in the use of arsenic-only copper (CG2). Afterwards, the movement of the ST metals seems to adopt two routes: one passes through the Siberian Taiga zone (A), and the other crosses the Urals Mountains, reaching the Kama via the river systems (B).

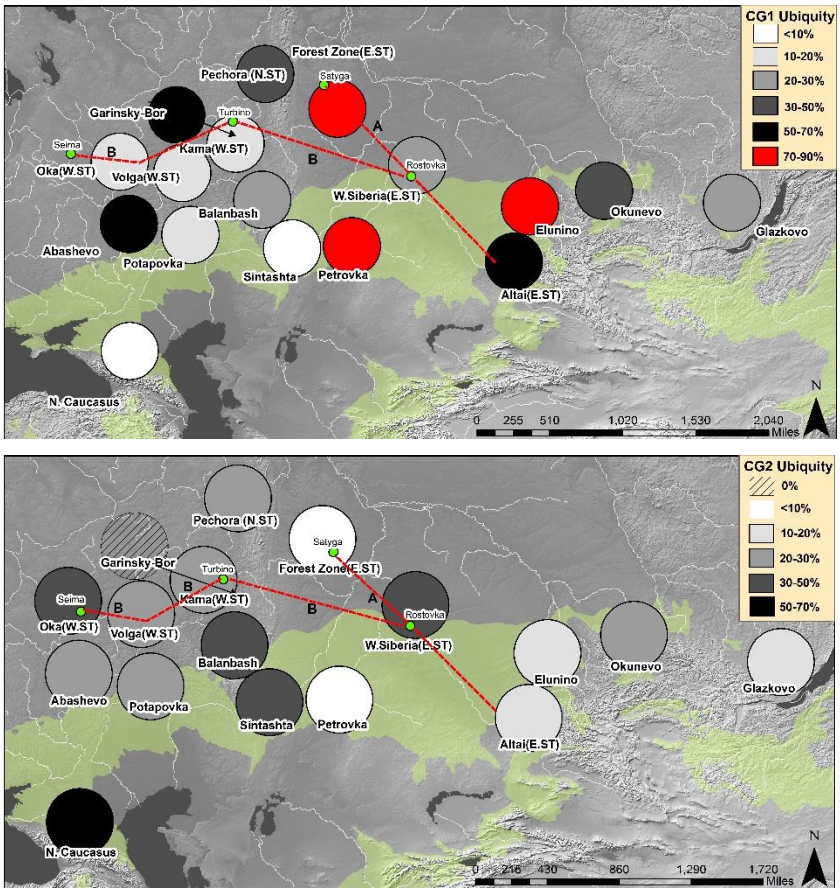


Figure 4.19 Ubiquity of CG1and CG2 across the regional ST metal objects. See Figure 4.3 for specific ST sites.

The forest pathway is attested by the discovery of the Saytga cemetery. Metal articles from this site are dominated by the simple double-bladed knives made of pure copper (CG1) and low-tin copper alloys. The use of rather clean copper and insignificant amount of tin may suggest the metal recycling in this Taiga area.

The Kama route is represented by the Turbino cemetery. A decline in both ubiquity ratios of CG1 and CG2 suggests the directional movement of metal from western Siberia to Kama. Some CG1 and CG2 objects are made of high-tin bronze as the evidence of direct exchange from the east (see below). The unique feature of some the Turbino metals is the use of arsenic-silver copper (CG9), presumably as the mixture between CG2 from the Balanbash and CG4 from the Garinsky-Bor (Figure 4.20, top & middle). Following the Turbino burials, ST metalwork is spread along river systems to the Volga, where arsenic-nickel copper (CG11) becomes important due to the influence from the Potapovka culture rich in such metal (Figure 4.20, bottom). Eventually, the westernmost ST sites, namely Seima and Reshone cemeteries, have more arsenic-only copper (CG2) than other ST metals from the Volga and Kama. This revival of CG2 may be explained by the contact with metal-using communities in the forest zone of eastern and/or northern Europe.

To briefly sum up the flow of copper between ST groups, CG1 and CG2 are common copper groups shared by ST metals. In the west of the Urals, copper supplies primarily come from their southern steppe neighbours on the basis of local, short-distance exchange, such as the presence of silver-bearing copper in Garinsky-Bor, Balanbash sites, and the Turbino cemetery, or nickel-containing copper in the Potapovka culture and the ST objects from the Volga.

Mixing and recycling occurred when the ST metalworkers obtained copper from their southern steppe neighbours in order to cast the typical ST weaponry. By contrast, tin bronzes were seldom subject to significant recycling or mixing with foreign copper due to its special role as prestigious items in the ST communities. As we associate copper groups with tin bronzes, the division between tin-bronze and tin-less copper within the ST assemblage becomes even more explicit. Figure 4.21 depicts the tin distribution in CG1, CG2 and other copper groups in the ST metals. CG1 artefacts from both western Siberia and Kama are chiefly composed of primary tin-bronze (10-13%), while the Oka region is represented by low-tin bronze (Figure 4.21, top). Furthermore, the tin profile

of CG2 objects in western Siberia shares the same peaks at 10-13% tin and 4-7% tin with the Kama and Oka assemblage respectively (Figure 4.21, middle). This suggests a direct movement of metals from east to west by means of tin bronzes with the same copper chemistry.

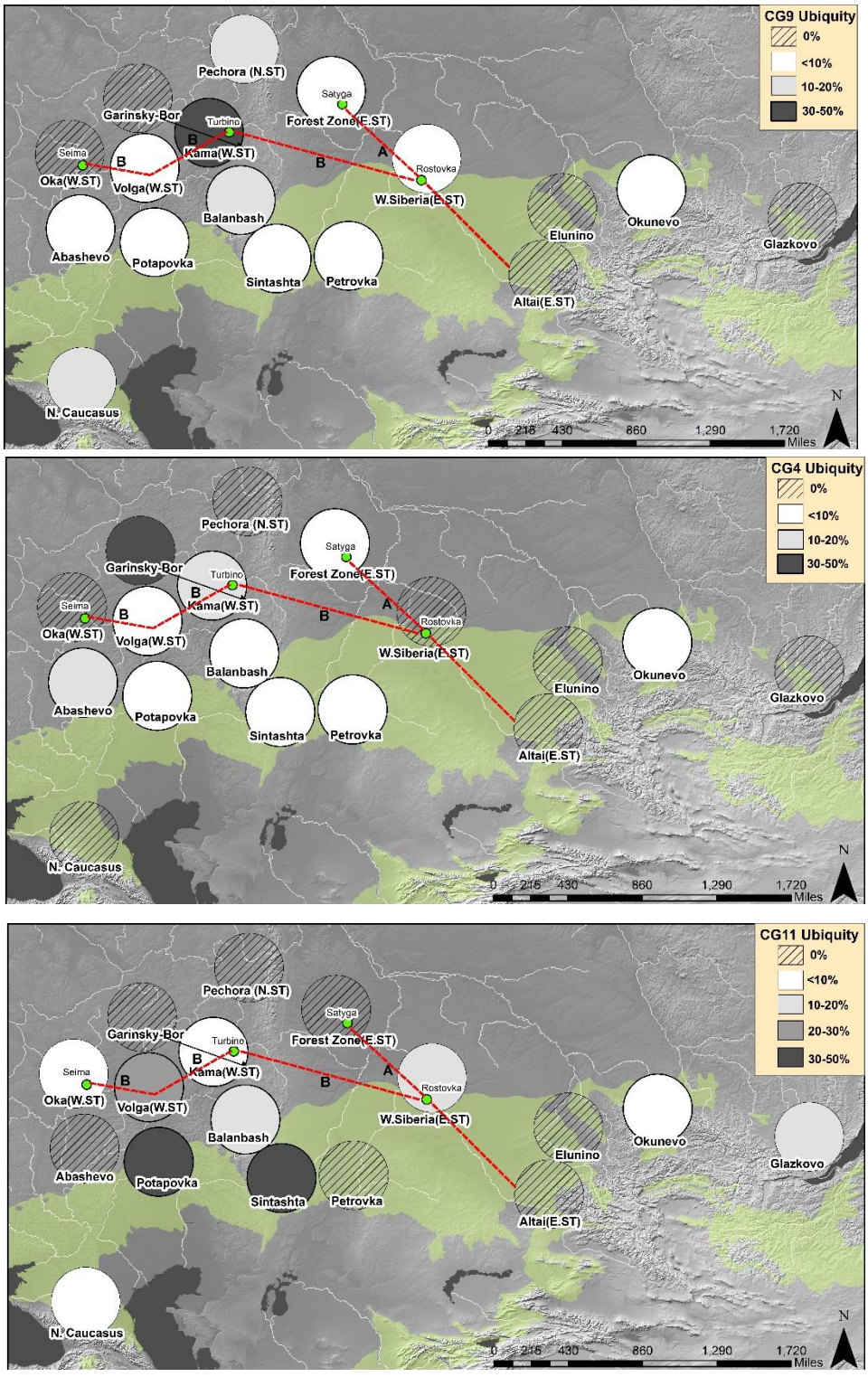


Figure 4.20 Ubiquity of CG9, CG4 and CG11 across the regional ST metal objects.

An even more intriguing pattern is reflected by tin concentrations in other copper groups. Figure 4.21 (bottom) clearly demonstrates that ST metals in western Siberia still broadly represent a primary tin-bronze production while metals from Kama and Oka are dominated by recycling practices, presumably from the re-use of Abashevo-Sintastha copper sources (e.g. CG4 and CG11).

These scenarios of metal usage echo the diversity of metal artefacts found in the ST sites. This leads to the next topic regarding the correlation between artefact typology and chemistry.

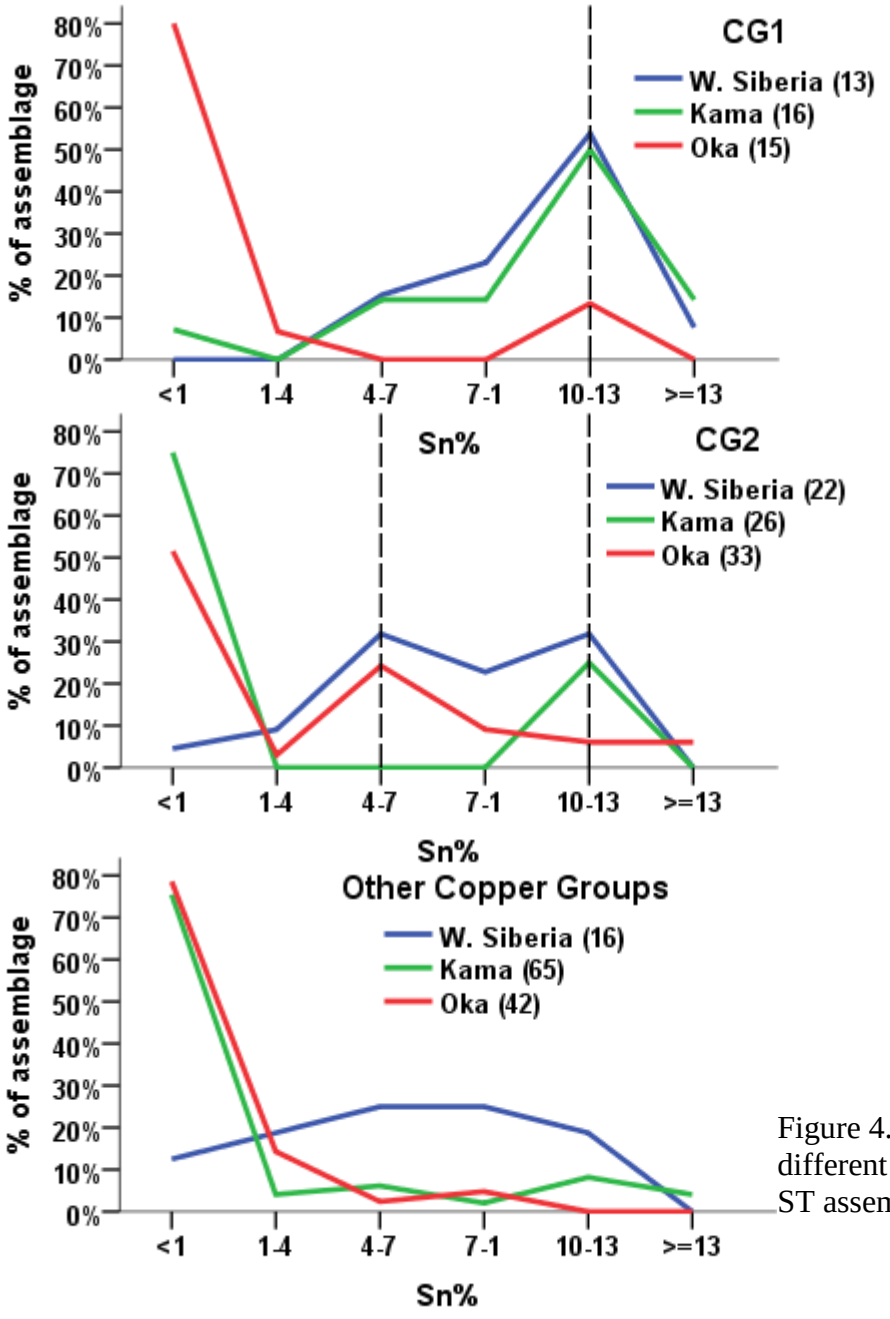


Figure 4.21 Distribution of tin in different copper groups across the ST assemblage.

4.6 Object chemistry and typology

Chemistry of the ST assemblage is highly associated with object types and styles. In E. ST specimens, socketed axes and spearheads are dominated by relatively high-tin bronze with a primary tin-alloying peak (Figure 4.22, top). This probably represents a "designed recipe" for a primary or initial tin-bronze composition. Socketed axes and spearheads are the highly decorated items amongst the ST metal assemble. They are constantly cast with geometric patterns or animal-style motifs, and probably serve as elite or prestige goods with standardised tin content. As a result, the addition of tin not only improves the mechanical properties of copper objects, the tin bronze becomes a social marker to symbolise the status of owners as tin itself is also a precious material. This statement becomes more plausible as tools and knives, which usually are plain in design, contain less tin.

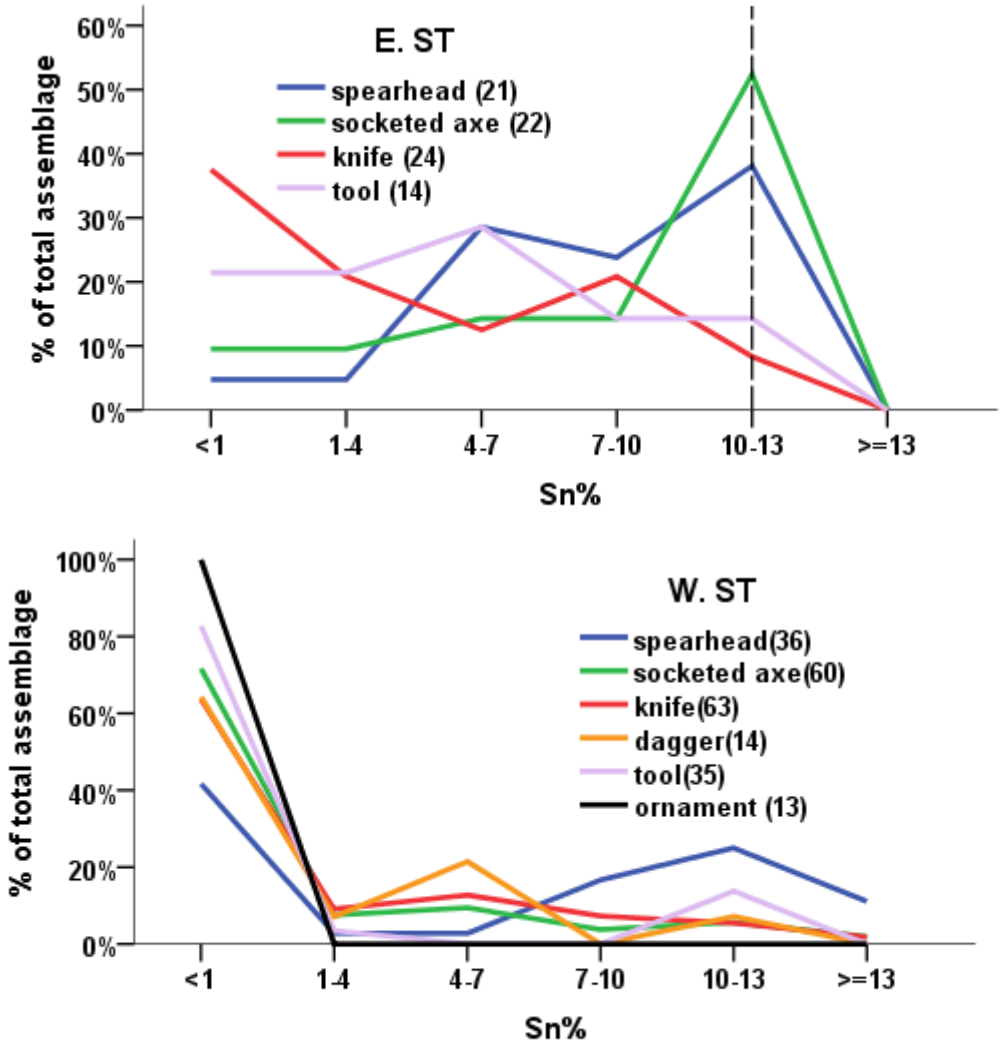


Figure 4.22 Distribution of tin by artefact typology in the ST assemblage.

As ST metalworkers in the west no longer had access to tin, more and more ST items are made of the imported Abashevo-Sintashta copper without tin (Figure 4.22, bottom). Therefore, some typical spearheads or socketed axes are now made of arsenical copper. It is particularly true for personal adornments as they all contain less than 1% tin (these decorative items are actually imports from the southern steppe, see below). Nevertheless, certain artefacts, spearheads in particular, were valued by the W. ST people, and they rarely mixed these tin bronzes with copper. It is evidenced by the presence of the primary tin peak at 10-13%, identical to the alloying tradition in E. ST metalwork. These high-tin bronzes may be considered as direct imports.

As Chernykh and Kuz'minykh (1989a) already recognised different "styles" of the ST metals as eastern, western, common and Eurasian groups, it is worthwhile to examine their classification in terms of object chemistry to see how it fits into the framework of the ST phenomenon. Table 4.4 demonstrates the percentages of alloy types and copper groups in terms of different styles. As can be seen, there is a decreasing tin-bronze ratio from eastern, common, western and Eurasian groups, echoing the westward movement of the ST metals (Figure 4.23). The eastern type is marked by a primary tin-bronze production at around 10-13% tin. Along the transfer of ST metalwork to the west, the proportion of this primary signal gradually decreases as ST metalworkers began to produce pure copper or arsenical copper made from Abashevo-Sintastha tin-free metals. This is reflected by a huge amount of unalloyed copper (<1% tin) within the western type.

Another essential point is the nature of Eurasian-style artefacts found in the ST sites. The majority of them are tin-less copper with only few articles (15.1%) made of tin-bronze. These metal objects are probably direct imports from the Eurasian Metallurgical Province due to their relatively higher arsenic concentrations (Figure 4.24). Some objects are cast with arsenic-nickel copper (CG11), a typical copper group among Sintashta metals (Table 4.4).

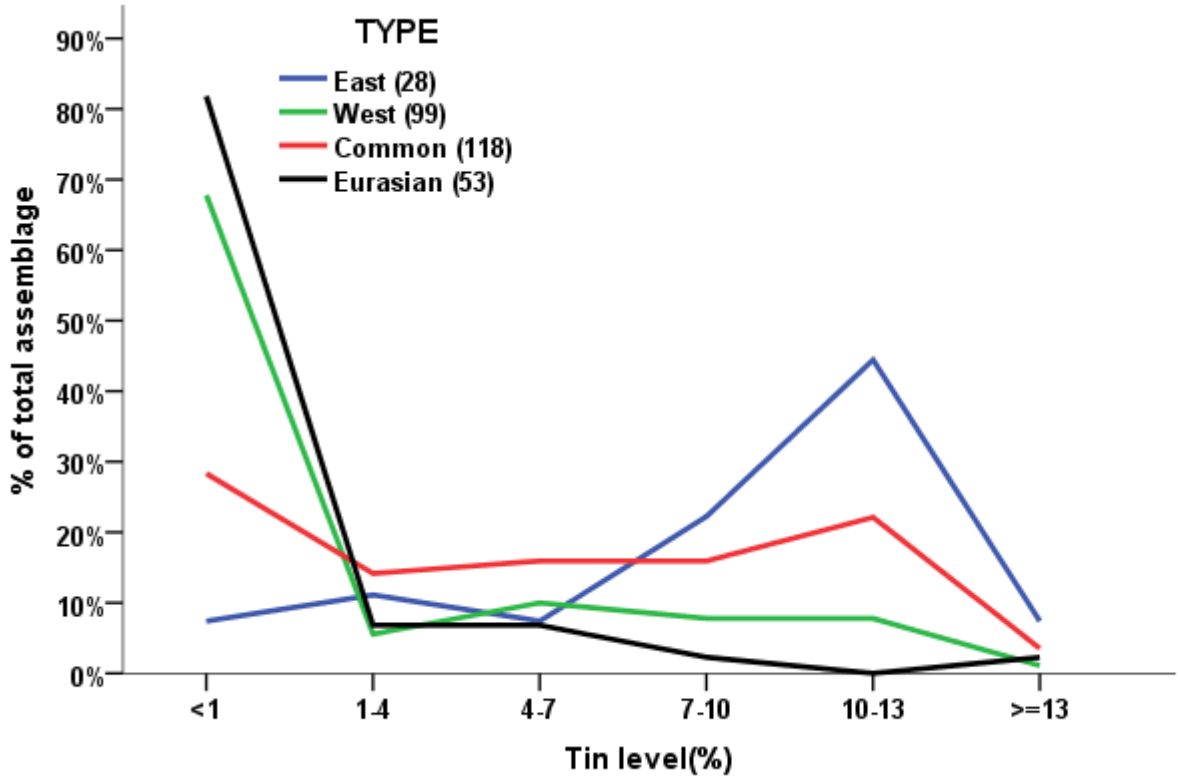


Figure 4.23 Distribution of tin by artefact style.

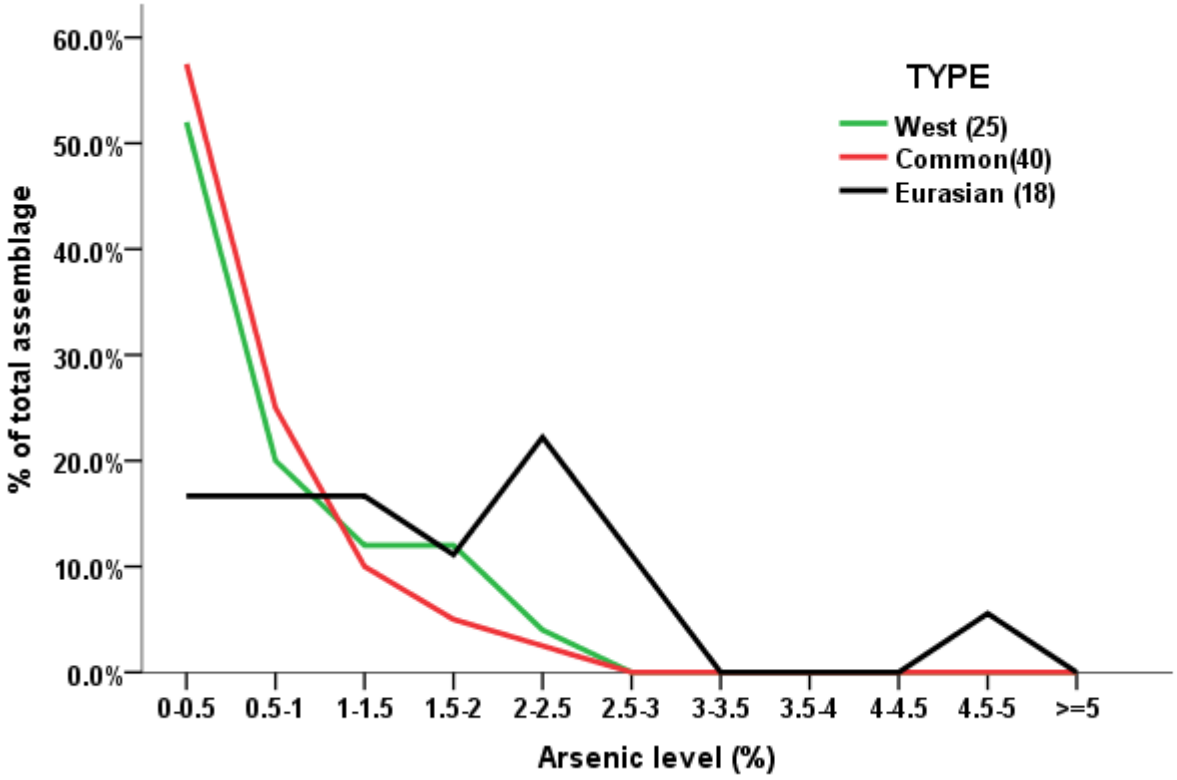


Figure 4.24 Distribution of CG2 arsenic by artefact style.

Table 4.4 Ubiquity of copper groups and alloy types by the ST artefact style

Seima-Tubino Alloy Type				
	East	Common	West	Eurasian
Cu	10.7%	31.4%	70.7%	**84.9%**
Cu-Sn	**78.6%**	**65.3%**	29.3%	15.1%
Cu-Sn-Pb	10.7%	3.4%	—	—
Total N	28	99	118	53
Seima-Tubino Copper Group				
	East	Common	West	Eurasian
CG1 *pure*	50.0%	**25.4%**	16.2%	13.2%
CG2 *As*	**28.6%**	**33.9%**	**25.3%**	**34.0%**
CG3 *Sb*		0.8%	1.0%	1.9%
CG4 *Ag*		4.2%	2.0%	5.7%
CG6 *AsSb*	14.3%	7.6%	4.0%	7.5%
CG7 *SbAg*	3.6%			
CG9 *AsAg*		12.7%	**31.3%**	7.5%
CG11 *AsNi*		4.2%	5.1%	18.9%
CG12 *AsSbAg*	3.6%	2.5%	2.0%	
CG14 *AsSbNi*		2.5%	2.0%	
CG15 *AsAgNi*		3.4%	6.1%	7.5%
CG16 *AsAgSbNi*		2.5%	5.1%	1.9%
Total N	28	118	99	53

4.7 Chronologies of the Seima-Turbino phenomenon

When the Seima-Turbino phenomenon had formed is another unsettled debate among Eurasian prehistory. According to Chernykh (2008), the formation of ST metalwork coexisted with the Abashevo-Sintahsta-Petrovka cultures, dated around 2150 to 1690

cal. BC (Chernykh 2008; Hank *et al.* 2007). Unfortunately, we know little about the absolute chronology of the ST sites as there are only four radiocarbon dates available: one from the Satyga XVI cemetery in the forest zone (Hanks *et al.* 2007) and another three from the Yurino burial in the Upper Volga (Solov'yev 2005). The subsequent discussion attempts to provide some new thoughts on the ST chronology, based on radiocarbon dates from other relevant archaeological communities (Table 4.5).

It is extremely difficult to precisely date E. ST sites as there is only one date from the Satyga cemetery that gives a time interval between 2140 and 1940 cal. BC. We have to rely on chronologies of other archaeological cultures related to the ST metalwork. ST bronze artefacts are found in the graves of Elunino I in the Altai and Preobrazhenka 6 in western Siberia. They are dated to 1960-1870 cal. BC and 2204-2050 cal. BC respectively (Solov'yev 2005; Marchenko *et al.* 2015). Dates from Satyga and Preobrazhenka 6 overlap between 2140 and 2050 cal. BC, which can be considered as the early phase of the E. ST phenomenon (Figure 4.). Another indirect evidence to determine the dates of E. ST comes from the low-tin bronzes in the Petrovka culture. This initial use of tin-bronze may suggest a possible influence from the ST metalwork. The Petrovka sites are dated to 1930-1690 cal. BC. If we combine absolute dates of the Elunino, Preobrazhenka, Satyga, and Petrovka sites, we are able to roughly derive a chronology for the E. ST between 2140 and 1690 cal. BC.

In the W. ST sites, burials are constantly accompanied by the Abashevo ceramics, and some metal artefacts (classified as the Eurasian type) are either sourced from the

Table 4.5 Radiocarbon dates of ST sites and related archaeological cultures.

Culture or Site	**N**	**Upper date**	**Lower date**	**Probability**	**Reference**
Abashevo (Volga & Cisurals)	22	2150	1750	68.2	Chernykh 2008
Sintashta (Transurals)	14	2020	1750	68.2	Hank *et al.* 2007
Petrovka (Transurals)	5	1940	1690	68.2	Hank *et al.* 2007
Elunino (Upper Ob)	1	1960	1870	68.2	Solov'yev 2005
Okunevo (Minusinsk)	20	2461	1901	95.4	Svyatko *et al.* 2009
Seima-Turbino (forest zone)	1	2140	1940	95.4	Hank *et al.* 2007
Seima-Turbino (Volga)	3	1950	1620	68.2	Solov'yev 2005
Preobrazhenka 6 (W. Siberia)	11	2204	2050	95.4	Marchenko *et al.* 2015
Potapovka (M. Volga)	8	2340	1680	95.4	Anthony 2007
Srubnaya (Volga)	119	1950	1500	68.2	Chernykh 2008
Glazkovo (Cisbaikal)		2500	1900	95.4	Schulting personal communication

Abashevo or Srubnaya communities (Chernykh and Kuz'minykh 1989a:219-221). Radiocarbon dates of these two cultures overlap between 1900 and 1770 cal. BC, which gives a rough estimation when the ST metallurgy travelled to eastern Europe (the phase of transmission). Interesting, a typical W. ST burial (Yurino) shows a very long occupation from 1900 to 1620 cal. BC. It suggests that the transfer of ST metallurgy is not a one-time, large-scale movement. Instead, it is more probably that there were different waves of movements in different times. A late phase of the ST phenomenon is roughly synchronous to the developed Srubnaya culture after 1700 BC (Figure 4.25).

The statement above is merely a tentative proposal for the chronology of the Seima-Turbino phenomenon. Currently, we still do not have enough dates taken directly from the ST sties. Furthermore, Chernykh (2008) did not publish the raw data for the Bronze Age communities in the Eurasian steppe, making it impossible to compare the chronologies of all cultures under the same probability (95.4%). It is hoped to obtain those uncalibrated dates and re-model them in the OxCal for a more robust age determination.

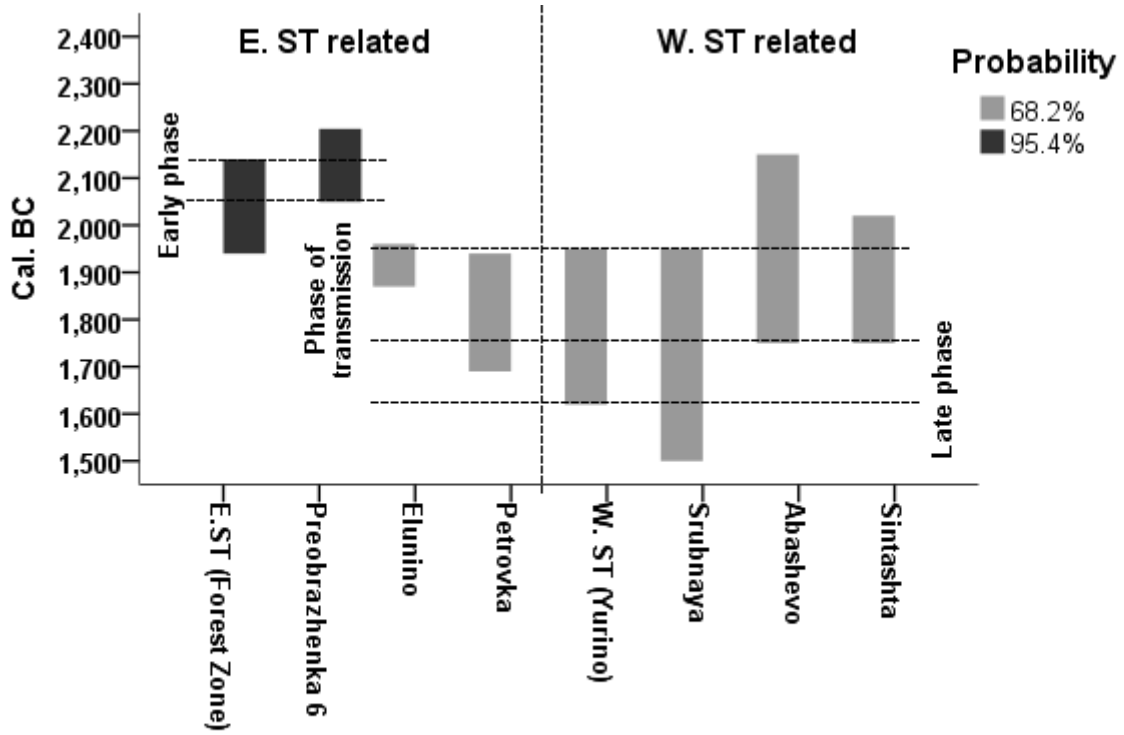


Figure 4.25 Absolute chronologies of the ST sites and associated archaeological communities. See Table 4.5 for references.

Metal composition can serve as another reference to estimate the chronology of the W. ST metallurgy. Figure 4.26 demonstrates the comparison of tin distribution in Srubnaya and W. ST copper-tin alloys. Surprisingly, they share two identical peaks at 4-7% and

10-13% tin, indicating the co-existence of W. ST and Srubnaya bronze metallurgy with a similar alloying practice.

Overall, given the dates for E. ST and W. ST (2140-1690 cal. BC and 1900-1620 cal. BC, respectively), ST bronze metallurgy may have first taken place in the regions of western Siberia and Altai around the 22nd century BC. ST tin bronzes started to penetrate into the west from 2000/1900 BC onwards. As W. ST and E. ST metal artefacts coexisted over 200 years, the movement of the ST metalwork did not seem to be a large-scale migration to the west. Instead, the transmission of bronze technologies is probably driven by small bands of skilful craftsmen who seek for new lands or patrons in the west. Of course, as very few dates associated with ST sites are currently available, this chronological scenario remains a suggestion rather than a conclusion.

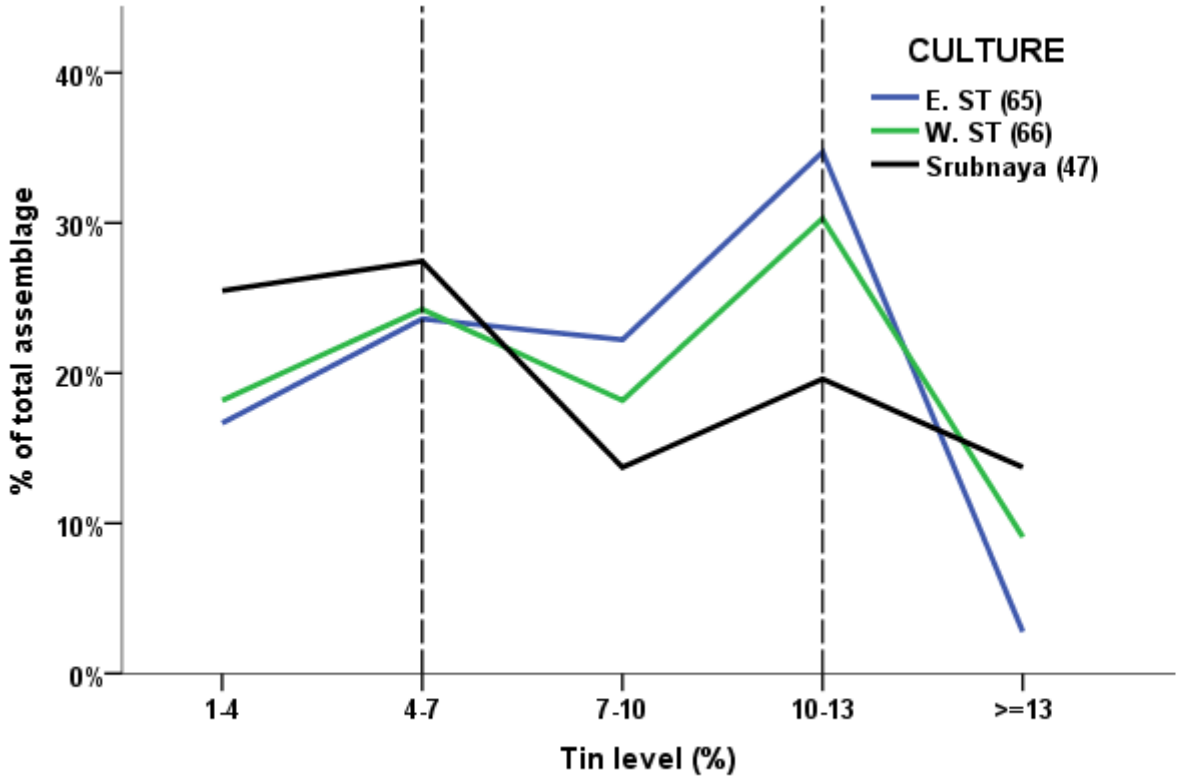


Figure 4.26 Distribution of tin in ST and Srubnaya tin-bronze items.
The spread of tin levels are similar between ST and Srubnaya cultures.

4.8 The implications of the Seima-Turbino metallurgy

Before the late 3rd millennium BC, the focus of copper-based metallurgy remained in the western steppe (the Pontic-Caspian steppe). Metalwork was organised in the framework of the Circumpontic Metallurgical Province to produce arsenical copper/bronze production for personal adornments or tools. These metallurgical

traditions (both artefact typology and alloying preferences) were succeeded by the subsequent Abashevo-Sintastha-Petrovka cultures extending as far as northern Kazakhstan. By contrast, new technological innovations emerged in the eastern part of the Eurasian steppe among the Seima-Turbino communities. According to the patterns of compositional analysis, the Seima-Turbino trans-cultural phenomenon likely originated from the East (western Siberia and the Altai), in agreement with Chernykh's perspective. Although we do not know where and when exactly this specific culture had formed, the rise of the ST metalwork had shaped the trajectories of Eurasian steppe prehistory in many ways. First of all, the advent of ST bronze metallurgy introduced a completely new package of artefact types and tin-alloying technologies to the steppe communities during the transition from the Middle Bronze Age to Late Bronze Age (c. 1700 BC). Prior to the LBA, the Eurasian steppe was still marked by the use of arsenical copper among the Abashevo-Sintashta societies, with occasional low-tin objects in the Petrovka culture. This production mode was completely shifted to the predominant use of tin-bronze among the LBA Srubnaya and Andronovo communities, successors of the Abashevo-Sintashta cultures. Production of tin-bronze had experienced the huge increase in quality and quantity across the Steppe. To achieve such intensity of bronze production, it is not enough to simply re-melt ST tin-bronze objects, but requires the knowledge of locating and smelting casiterite ores for the making of copper-tin alloys. This expertise might have passed down to the steppe inhabitants in the beginning of the Late Bronze Age through the movement of skilful ST bronze smiths.

The other breakthrough of the ST metalwork lies in the creation of the new styles of metal artefacts serving as the prototypes of the Late Bronze Age copper-alloy objects in the Eurasian steppe. Daggers, single-bladed knives, socketed axes and spearheads, which rarely occur among Abashevo-Sintastha communities, become the key elements of the Srubnaya and Andronovo metal portfolios. Similar forms of ST artefacts are witnessed in eastern Europe and western China. The Borodino hoard in Moldavia, typologically dated around 1600 BC, yields a silver forked-shank spearhead of the Seima-Turbino type (Vladár 1973:341-4). Shenna, a site of the Qija culture (c. 2100-1700 BC) in western China, also contains a large spearhead with a side hook similar to typical E.ST specimens from the Altai (Mei 2003, 2009a, 2009b).

Interestingly, while ST metal objects in the East are primarily made of tin-bronze, ST metals in the West actually adopt the tradition of arsenic copper from their southern

steppe neighbours. This trend clearly sets out two fundamental alloying practices in the Steppe from 2000 BC onwards: arsenical copper/bronze in the West and tin-bronze in the East. Most importantly, the emergence of the Seima-Turbino bronze metallurgy overturns the conventional belief that inventions of metal technologies followed a linear trajectory from the use of native copper, arsenical copper, to tin-bronze or the diffusion model that technologies always flew from the "advanced" to less-developed societies. For millennia the western Eurasian steppe played a dominant role in metal production, shifting from the use of pure copper at the fifth millennium BC to arsenical copper at the third millennium BC. Prestigious shaft-hole axes and exquisite personal adornments constituted the central piece of manufacture. On the contrary, the eastern steppe during this time produced a limited amount of small copper ornaments and implements within Afanasevo and Okunevo societies of the Altai-Sayan Mountains. Given such different scale of production between the West and East, one would expect the copper-tin alloying and complicate multi-mould casting in the Seima-Turbino context, if there were any, should have first appeared in the Pontic-Caspian steppe, where the knowledge of metallurgy had been deeply rooted. However, according to chemical analysis, tin-bronze technology apparently initiated in the East. One of the reasons is no doubt the presence of rich tin deposits in the Altai, which provides a prerequisite for the formation of the ST tin-bronze. What is equally important was the social change during the Middle Bronze Age of the Eurasian steppe. In the southern Urals, there was an increasing number of conflicts among both Abashevo and Sintashta communities (Anthony 2009). At the Abashevo site of Pepkino, a single pit was found containing 28 young male individuals, 18 of them decapitated, and many with axe wounds (Chernykh 1992:200-204). Increased warfare is even more visible in the Sintastha culture, manifested by the construction of fortified settlements, deposits of bone and bronze weapons in burials, and horse-driven chariots for battle (Anthony 2009:54). This dramatic social change may encourage the need to secure the tribal alliances through gift exchange. Metal objects as high-value and portable items may serve as a type of social currency to either pay for the establishment of diplomatic relations between tribes or to attract more followers. This high demand for metals during this troubled time may lead to the increase in metal production. Thus, I argue that the intense use of metals, driven by the social change in the western steppe, connect individual steppe communities under the unified exchange network. Under this wave, the ST people in the east began to procure more metal resources. Recent studies have suggested an

increasing mining and smelting activities in the eastern Eurasian steppe at the turn of the third and second millennium BC, which may link to the rise of the ST metalwork. One is the Odinovo-Krovtovo culture in western Siberia and the other is the Elunino culture in the Altai (Molodin *et al.* 2012; Molodin & Durakov 2013; Molodin 2014; Marchenko *et al.* 2015). Both cultures contain settlements with metallurgical activities (casting moulds, slags and crucibles). The appearance of these metalworking settlements may shed some light on the formation of the ST phenomenon.

The inception of ST tin bronzes is not the only case to demonstrate a sudden advance in metal technology. If we zoom out to examine the development of bronze metallurgy outside the Steppe, some metal-producing cultures witness a similar transition towards a developed tin-bronze production. Bactria in central Asia had experienced a boost of tin-bronze production during the first half of the second millennium BC (Kaniuth 2006). Some western scholars have argued the possibility of the flow of "steppe tin" into central Asia and the Middle East (Parzinger *et al.* 2003; Gorelik et al .2013). In the East, tin-bronze first made its appearance in the Qijia and Erlitou sites (c. 1700 BC). The Erlitou bronze metallurgy (later being modified by the addition of lead) along with the piece-mould casting had become a standardised technological package for ancient Chinese bronzes (Fitzgerald-Huber 1995).

It is not purely by chance to observe the increase in tin-bronze production in the Steppe, Bactria and ancient China during the transition from the MBA to LBA. The spread of the Seima-Turbino bronze metallurgy certainly stimulated this process of adoption, but it was the following Andronovo culture that amplified the effect of tin-bronze transmission to steppe regions and beyond.

5. The Increasing Complexity of Bronze Metallurgy in the Steppe

5.1 Background

The Eurasian steppe during the Late Bronze Age (c. 1700-1400 BC) was marked by a significant increase in metal production within the domain of the so-called Andronovo-Srubnaya communities from the Altai Mountains to the Dnieper River (Figure 5.1). According to Chernykh (2008:48-49), this unified archaeological horizon formed a specific metallurgical practice, known as the Eurasian Metallurgical Province (EAMP) characterised by the widespread use of tin bronzes, new metalworking techniques and the typological standardisation of metal artefacts across the steppe and forest landscapes. The influence of the EAMP metalwork was also extended into southern Central Asia, Minusinsk, Xinjiang, Hexi Corridor and the Northern Zone of China.

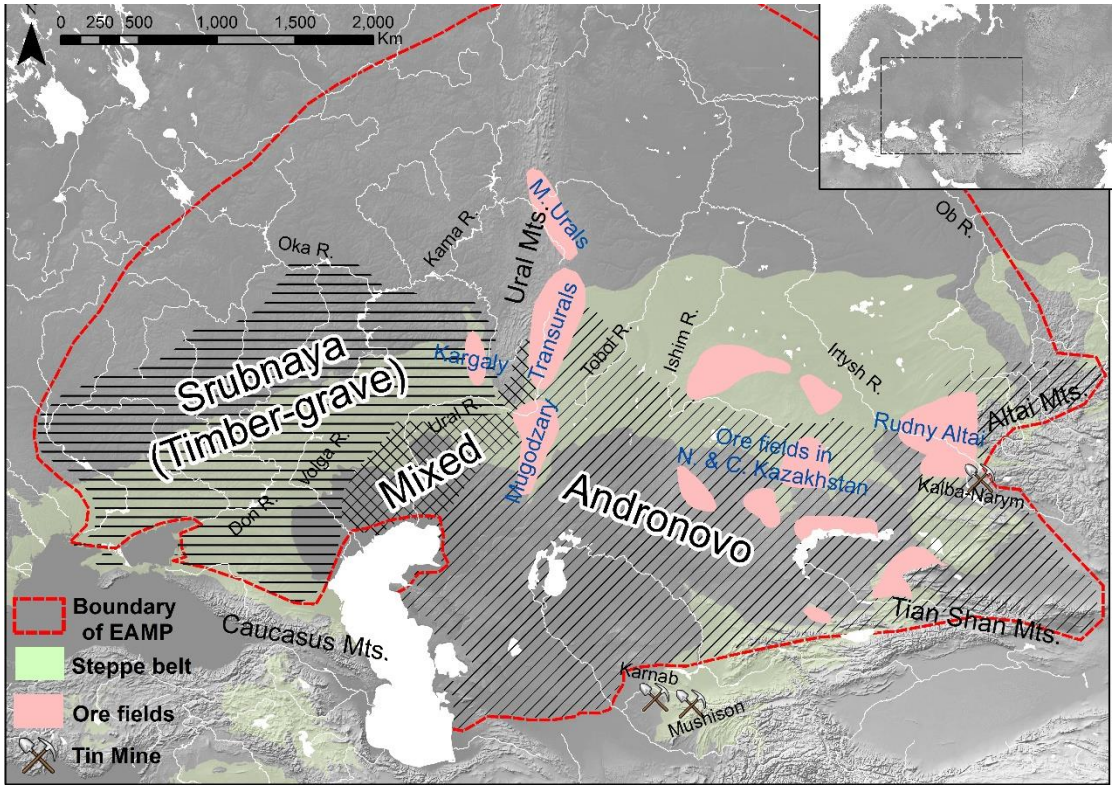


Figure 5.1 Distribution of the LBA cultures and ore deposits in the Eurasian steppe Data from Chernykh (2008); Stöllner *et al.* (2011); Gorelik *et al.* (2013); Garner (2015).

This overarching Eurasian network corresponds to the increasing exploitation of a number of copper, gold and cassiterrite deposits mined by Andronovo herders (Figure 5.1, also see Kuz'mina 2007, Ch. 3). Amongst the most important ore fields are the Ural Mountains and the present extent of Kazakhstan. The Urals contains four major mining districts: deposits of cupriferous sandstone in the Kargaly, copper carbonates in

the Middle Urals, copper deposits in the Transural and the Mugodzhary (Yuminov *et al.* 2013: 87). On the other hand, Kazakhstan features the use of copper-oxide bearing minerals in central Kazakhstan, copper polymetallic deposits in the Rudny Altai, and gold deposits in Stepnaya of northern Kazakhstan (Koryakova & Epimakhov 2007:42). Most importantly, the emergence of the highly specialised mining and metalworking settlements (e.g. Gorny nearby the Kargaly mine and Atasu in central Kazakhstan) witnesses division of the labour in the formation of complex metal-producing societies (Chernykh 2004; Kuznetsova & Teplovodskaya 1994).

The prevalence of tin-bronze within the Andronovo culture was also one of the most vital components in the development of the steppe metallurgy. Prior to the Late Bronze Age, the Seima-Turbino metal assemblage was the only group featuring developed tin-bronze technology with primary tin alloying (10-13% tin). Other contemporary copper-tin alloys, such as tin-bronze objects from the Petrovka culture, was represented by low tin concentrations (<4%), which may be the consequence of metal recycling/mixing. Further west in the Abashevo-Sintashta communities, tin was practically absent in metal artefacts. However, such monopoly of tin-bronze production had completely vanished as the LBA Andronovo pastoralists applied copper-tin alloys to the manufacture of the typical EAMP artefacts across their inhabitation from the Urals to the Altai-Sayan Mountains. This large-scale tin-bronze production was fuelled by the opening of several cassiterrite deposits. The most important mines are situated in the Kalba and Narym mountain ranges of eastern Kazakhstan (Gorelik *et al.* 2013). Many scholars have emphasised their role in providing tin for the Bronze Age metalwork in the Steppe and beyond. Another tin deposit is the Karnab mine in the west of Samarkand of central Asia, which was in use during the Andronovo period (Parzinger *et al.* 2003). The Atasu tin deposit in central Kazakhstan was also reported to be the source for the Atasu tin bronzes (Kuznetsova 1987: 44).

In addition to the increasing use of tin alloying, copper smelting had experienced a fundamental change during the Andronovo period. Both copper oxide and sulphide ores from quartz rocks were regularly smelted (or co-smelted), which was different from the oxide ores of ultramafic origin used by the preceding Sintashta period (see Chapter 3). Smelting copper sulphides also requires more complicated multi-step processes (roasting and matte forming) compared with copper from weathered oxide ores. Furthermore, unlike Sintashta-type sites, where primary smelting was conducted

on a small scale with low output, copper smelting during the Andronovo period became a specialised profession within certain settlements close to the accessible raw material, such as Elenovka in the Transurals, Atasu in central Kazakhstan and Kayrak-Kum in Tajikistan. As a result, several independent local metallurgical centres flourished across the territory of the Andronovo community (Kuzmina 2007:94). Likewise, in the west of the Ural Mountains, the contemporary Srubnaya culture also embarked on a regional metal-producing industry in the Gorny settlement near the Kargaly mining complex (see later discussion). This potential copper deposit has been identified by Chernykh as the candidate for the chemical group MP (Chernykh 2007:92-95). Except for the Kargaly, some similar copper sedimentary deposits occur in the Don river basin but have not yet been fully studied. The lack of raw material in the Pontic-Caspian steppe is reflected by the fact that most of Srubnaya sites only yield remains of metal-casting workshops or founder's burials. It is the reason why Chernykh would argue that metal supplies for the Srubnaya societies were primarily based on the Kargaly mines (Chernykh 2007).

5.2 Copper and tin resources in the Late Bronze Age of the Steppe

5.2.1 Kargaly: a huge mining complex in the Urals

Kargaly is one of the largest copper mining district in the Bronze Age of Eurasia, situated in the southern Urals right on the border between the European and Asian continents. According to Chernykh (2004b), the extraction of copper ores in this region initiated at the turn of the third millennium BC, reached its peak by the first half of the second millennium BC, and was continually in use during the industrial development of the Russian Empire in the late 18th century AD.

Kargaly ore deposits are characterised by malachite and azurite in sedimentary grey-coloured sandstones and slates. Because ore-bearing deposits in Kargaly are randomly scattered and unevenly distributed, ancient metalworkers dug an enormous amount of testing pits on the surface in order to search for useable copper ores (Chernykh 2007, Ch. 1). Prospecting methods range from simple shafts or sinkings to more elaborate horizontal galleries or drifts. The amount of copper smelted from the Kargaly mine is estimated at between 55 and 120 thousand tons in terms of the number of potential orebodies. As smelting these ores can obtain relatively pure copper, Kargaly was recognised as one source of chemical group (MP) defined by Chernykh (2007, Ch. 6).

Copper objects recovered from Kargaly also confirm such clean copper production (34 out of 38 specimens are pure copper according to Chernykh's classification).

One of the largest smelting and metal-casting sites near the Kargaly ore field is the settlement of Gorny in the southern Urals. This site has been well dated to between 17th and 14th centuries cal. BC, operated by the Srubnaya community (Chernykh 2002-2007). According to Chernykh (2004b:233-236), it is a large-scale specialised production centre manifested by the discoveries of numerous traces of smelting and manufacture remains, including over 4000 slags, 3000 metal articles, and 172 casting moulds. Another remarkable aspect of Gorny lies in the enormous numbers of recovered animal bones: roughly 2.3 million bones and bone fragments mainly composed of domesticated cattle (98%, see Antipina 2004a). It is believed that this huge amount of livestock was used to exchange for the copper ores and products from Kargaly (Chernykh 2004b: 235)

5.2.2 Tin mines in eastern Kazakhstan

As has been mentioned in Chapter 4, eastern Kazakhstan is one of the most probable tin sources in the prehistoric Eurasian steppe. Tin deposits concentrate in the Kalba-Narym ranges as sandstones and calcareous rocks intrusively embedded with pegmatites, granites and granodiorites (Scherba *et al.* 1984; Malchenko & Ermolov 2006). Ore deposits primarily feature pegmatitic vein-mineralizations that were formed during the Middle Devonian to Lower Carboniferous Ages (Stöllner *et al.* 2011: 235). Since the 1930s, Chernikov (1949) had documented several ancient tin mining districts in the Kalba-Narym ore field and noticed the importance of their exploitation during the Bronze Age (Figure 5.2). However, the concrete evidence for the extraction of tin mines began with the Andronovo period. This was confirmed by a series of geo-archaeological surveys undertaken by the Beringen Mining Museum during 2003 to 2008 (Gorelik *et al.* 2013). They have investigated the mining districts reported by Chernikov. At the Askaraly (Delgebetej) ore field they found several clusters of open pit mining depressions with scattered hammer stones in the tailings. Particularly, the mine of Askaraly II yields Andronovo ceramics in the upper layers of refill and radiocarbon dates of charcoal fall in the first half of the second millennium cal. BC. In addition, the Beringen team also excavated several burials and a settlement near the tin-mining sites. They turned out to be associated with the Andronovo herders based on unearthed pottery and metal typology and radiocarbon dates. The settlement contains

stone tools for ore processing and most importantly there are crucible fragments used for cassiterite smelting.

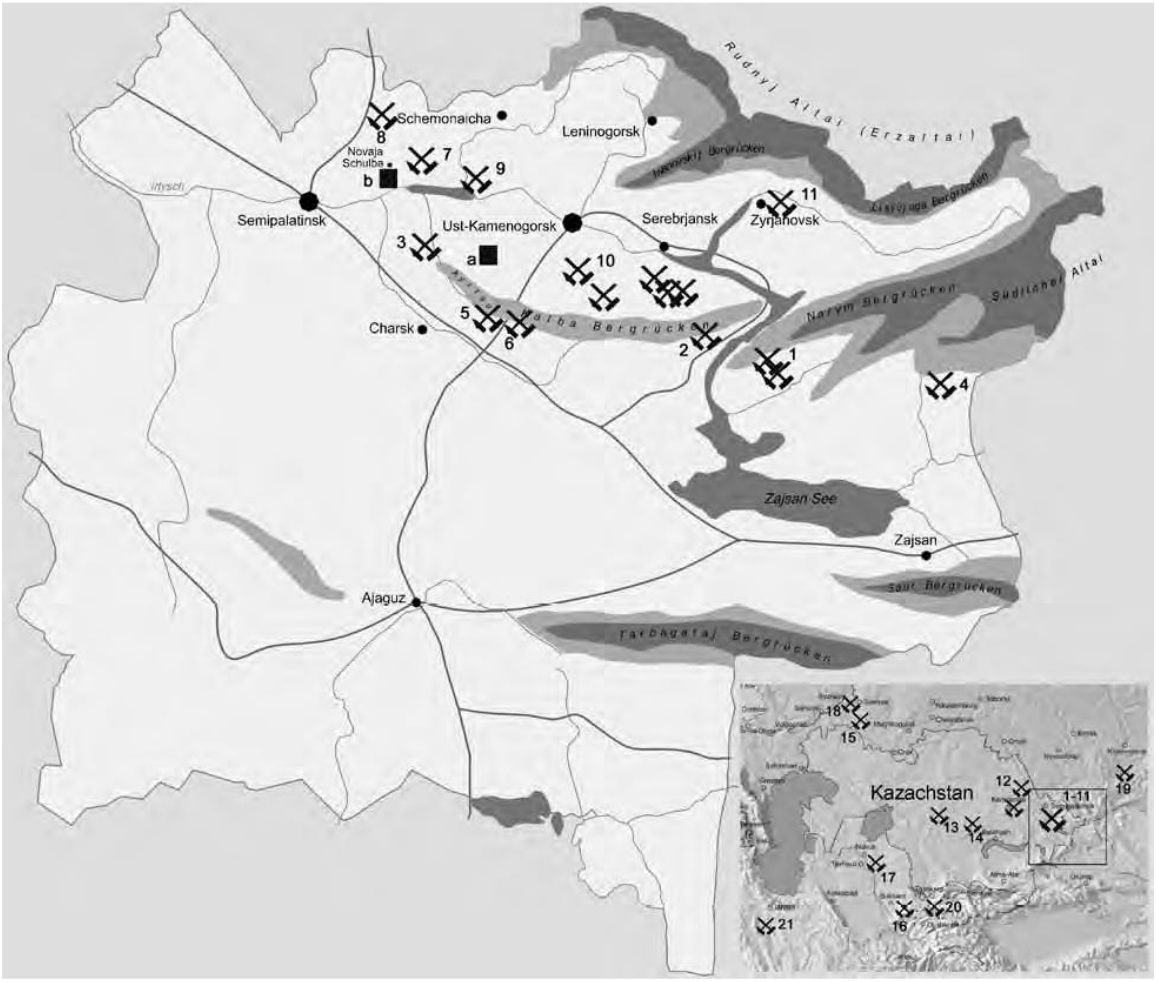


Figure 5.2 Mining sites in E. Kazakhstan. Copper: 4, 7, 8, 11, 12, 13, 14, 15, 17, 18, 19 and 21. Tin: 1, 2, 3, 6, 9, 10, 16 and 20. Gold: 5. From Stöllner *et al.* (2011: 243, fig. 2).

5.2.3 Tin mines in central Asia

The Zerafshan valley in central Asia was another crucial tin mining zone during the Bronze Age (Alimov *et al.* 1998; Parzinger *et al.* 2003). It is situated in the Soghd region of Tajikistan. The ore mineralisation is composed of cassiterite bearing quartz veins with massive granite intrusions, dated to the Cretaceous age (Garner 2015: 138). A multi-national project has started recently to uncover several mining districts in the valley. Among them, tin mines at Karnab and Mushiston are the most intensely studied (Figure 5.3, also see Garner 2015). At Karnab ancient extraction takes the form of open cast trench mines. There are traces of fire setting for cracking rocks by heat to enable the extraction of ores. Many stone hammers are found for the ore crushing.

Accompanying pottery sherds in mines indicate the use of tin deposits by the Andronovo-Tazabagjab communities (a branch of the Andronovo culture in central Asia). Radiocarbon dates fall between 1600 and 900 cal. BC.

Unlike the Karnab site in the steppe area of the Zeravshan valley, the Mushiston tin mining complex is located at 3000 m above sea level in the western part of the Pamir Altai Mountains. Here the main feature consists of many galleries and chambers to form a huge underground infrastructure. Copper ores and tin ores are related and form a special copper-tin mineral – mushistonite $(Cu,Zn,Fe)Sn(OH)_6$. Smelting this type of ore could potentially obtain natural-occurring tin bronzes. The dating of the Mushiston mines suggests two phases of development: one lies between 2400 and 1900 BC and the other from the middle to the end of the second millennium BC.

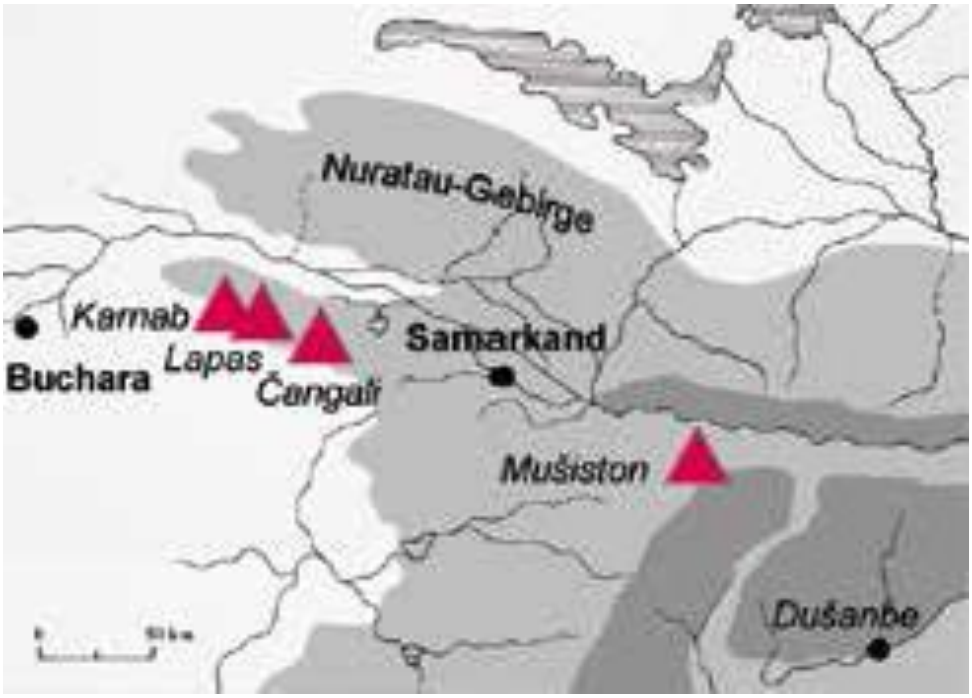


Figure 5.3 Tin mining sites in central Asia. From Garner (2015: 136, fig. 1).

5.3 Previous compositional research on the LBA metallurgy

5.3.1 Andronovo metalwork

The first comprehensive examination of the Andronovo metals from the Transurals was conducted by Chernykh (Chernykh 1970). Chemical results show that tin-bronze makes up most of Andronovo specimens (over 60%) and the rest of them are clean copper and very few arsenic-antimony alloys. Copper chemistry is mostly very pure (EU group), and the secondary largest group is ВУ with elevated arsenic and antimony. In examining copper and copper alloys from the forest-steppe of the Tobol basin (Alakul

type), Kuz'minykh & Chernykh (1985) derived the similar result that 52.4% of analysed objects are tin-bronze and remaining specimens are clean copper. Alloy types are highly associated with artefact typology. The majority of tin-bronze objects are personal adornments as opposed to tools and weapons made of pure copper or copper with arsenic. Tin content in tin-bronze artefacts ranges from 0.01 to 10% and some intermediate tin levels might be the result of mixing. Also, leaded tin-bronze makes its appearance during this time. Although in general metals from the Tobol are mostly EU (64.4%) followed by BУ (14.4%), copper chemistry is relatively more heterogeneous than Andronovo objects from the Transurals. There might be some other copper sources from Kazakhstan contributing to the Andronovo metalwork in the Tobol (Kuz'minykh & Chernykh 1985: 366).

In recent years, a number of chemical studies on the Andronovo (Alakul) metals have been undertaken by another technique (ICP-AES) other than the OES method used by Chernykh's laboratory (Kostomarova & Flek 2008; Flek 2008, 2010 & 2011; Degtyareva & Kostomarova 2011 Tigeyeva 2013). Their research generates similar results that tin-bronze production plays a major role in the Andronovo metallurgy and copper chemistry is relatively free from impurities.

5.3.2 Srubnaya metalwork

Chernykh (1970 & 2007) has thoroughly analysed copper-based objects from the Srubnaya communities. In the early monograph (1970), he concluded that 28.7% of objects are made of tin-bronze, 35.6% of arsenic-antimony alloy and the remaining of pure copper. In terms of copper chemistry, the largest group is BK, followed by EU, BУ and MP groups (as defined in Chapter 1). Therefore, Chernykh (1992) argued that Srubnaya metalwork principally relied on imported metals from copper deposits in the Transurals. The use of local sandstones in the western Ural region was considered as a secondary source (10-15% of the analysed samples). Tin-bronze was also a foreign product from the extreme east of the EAMP, presumably tin deposits in Rudny Altai of eastern Kazakhstan (Chernykh 1992: 206). However, after investigating the Kargaly site, Chernykh (2002-2007) turned to consider the Kargaly mining district as the most important copper supply for the entire Srubnaya community in eastern Europe. He has built a larger chemical database of 857 Srubnaya metals and divided them into different alloy types (Table 5.1, unfortunately raw data has not been published). Of the most important metal production is pure copper (including clean copper and copper with

trace amount of impurities) and tin-bronze. He notices that chemical groups are highly mixed and it is difficult to define territorial differences between them. He admits that although metal objects near the Kargaly mining field are slightly biased towards clean copper, mixing copper from difference sources was commonplace among the Srubnaya metallurgy.

Contact between Srubnaya and Andronovo metallurgy is visible in the Cisurals. One of the best examples is the Novye Yabalakly cemetery in which over 100 personal adornments were uncovered. Although this site is identified as the Srubnaya culture, decorative items are clearly of the Andronovo style. Chemical composition of these ornaments indicates the predominant use of tin-bronze with low impurities. This chemical pattern is very common among the Andronovo copper-tin ornaments featuring clean copper from Elenovka and Ush-Katta deposits in the Transurals. Kuz'minykh (1983) argued that this jewellery collection was imported from the Andronovo communities in the form of finished products.

Table 5.1 Distribution of alloy types among Srubnaya copper-based objects. Classifying criteria for each alloy type is not reported. After Chernykh (2007: 93, tab. 6.3)

Alloy Type								
pure Cu	pure Cu with impurities	Cu+Sn	Cu+Sn+As	Cu+As	Cu+As+Sb	Cu+Sb	unidentified	Total
165	226	357	27	62	8	6	6	857
19.3%	26.4%	41.7%	3.2%	7.2%	0.9%	0.7%	0.7%	100%

5.4 The Main questions regarding the LBA metallurgy

Given a wealth of metallurgical evidence, there is little doubt that the Andronovo communities played a vital role in shaping the history of metallurgy in the Late Bronze Age of the Eurasian steppe. Chernykh's works have laid the foundation in defining the structures of the LBA metalwork. However, there are still several questions requiring further consideration. First of all, the chemical groups Chernykh identified are designed to be tied with copper deposits. Such a static classification oversimplifies the dynamic nature of metal exchanges through recycling and mixing. In the 2007 publication, he started to pay attention to certain pure copper group with elevated impurities as opposed to genuine clean copper. He attributed its occurrence to the result of mixing with other copper sources with higher impurities. This finding directly touches upon the key point of this thesis on the study of metal flow, yet he did not elaborate further on how this

copper mixture took place and how it was spread. This leads to the question of in what routes metals were being transferred from one area to another. Traditionally, metal composition of the LBA objects is compared based on cultural groups (either Andronovo or Srubnaya cultures). This approach may suffer from a serious confusion as archaeological cultures during this period are of mixed character and it is difficult to securely assign one metal object to its actual cultural identity. For instance, the Andronovo-style metal artefacts are not only found in the steppe zone, but also other communities in forest and desert landscapes. Should we regard Andronovo objects in foreign lands as real Andronovo manufacture or local production? If we stick with the classification by cultural groups, it may not reflect how metal objects were actually moved in this interactive Late Bronze Age network. One way to circumvent this issue is to use the geographical features as proxies to discuss the movement of goods. It has been noted that the majority of the LBA settlements were usually situated on the banks of small rivers. The better strategy is to look into the river transport for the circulation of metals and see whether chemical pattern of objects can reveal the most likely pathways.

Another question lies in the resolution of chemical grouping done by Chernykh. The compositional classification shown in Table 5.1 neglects the actual "quality" of alloying or minor elements in copper-based objects. For instance, we have no idea how much tin in copper-tin alloys and how tin is distributed over the metal assemblage. These are key information to reveal the primary and non-primary tin-bronze production. Furthermore, Table 5.1 does not document other important trace elements such as nickel and silver, which can potentially serve as diagnostic indicators for regional/cultural features (such as nickel-bearing copper in the Sintashta culture). These variables must be taken into account in order to reconstruct the flow of the LBA metals.

Last but not the least, although previous studies pointed out the correlation between object typology and chemistry, they tend to focus on a rather regional scale. I will focus on this important issue by spatially demonstrating how the artefact chemistry can be used as a marker to reflect the long-distance contact.

5.5 Characterising copper production

5.5.1 Copper chemistry by cultural groups

The LBA database chiefly derives from chemical results published by Chernykh and his colleagues (Chernykh 1970; Kuz'minykh & Chernykh 1985; Lun'kov *et al.* 2009, 2011, 2013). The cultural identity of the analysed objects mainly belongs to the Andronovo (mainly Alakul type) and Srubnaya communities, plus a cemetery site from the N. Caucasus. There are also some chance finds distributed along the Kama-Upper Volga-Oka interfluve (Figure 5.4). This distribution map highlights a considerable overlap between analysed Adornovo and Srubnaya objects particularly in the Urals (marked as the mixed area). I will first show how copper chemistry varies among different cultural groups, and then turn to a more appropriate grouping by the geographical features.

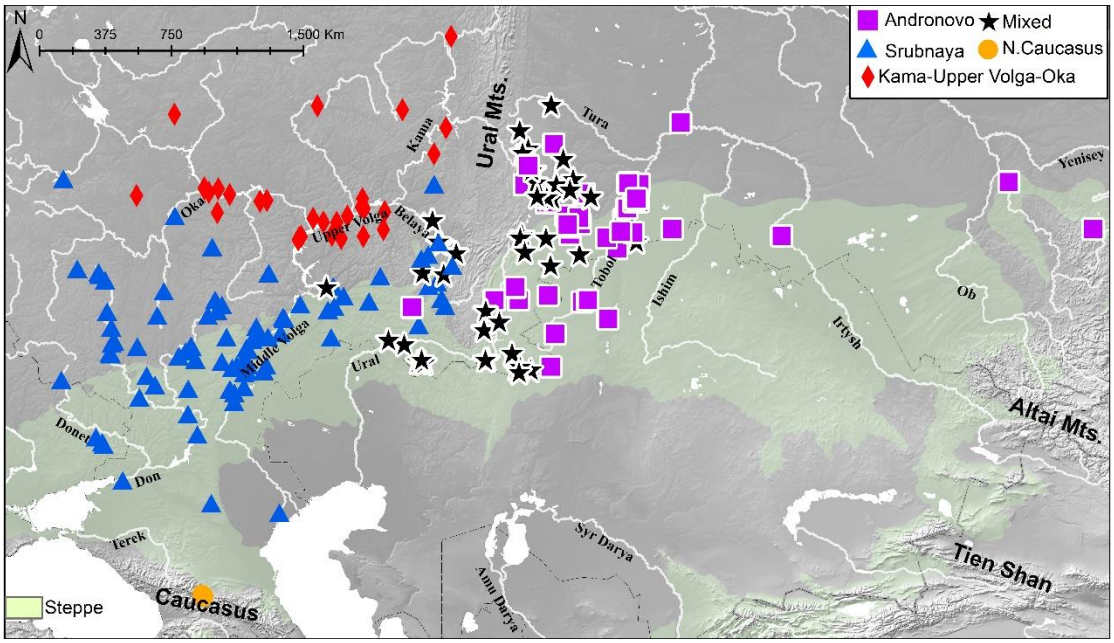


Figure 5.4 Distribution of analysed objects during the Late Bronze Age.

By applying the proposed methodology to the LBA data, we can derive several copper categories that are commonly present in individual cultures (Table 5.2). CG1, or pure copper, is the most ubiquitous group among all assemblages except for specimens from northern Caucasus. It primarily focuses on the Andronovo culture and mixed zone in the Urals. Next, CG2 arsenic-only copper dominates the Caucasian metals while it plays a minor role in the rest of cultures. There are also some regional features such as nickel-bearing metals (CG5 and CG11) in the Srubnaya culture, silver-containing copper (CG4 and CG9) in the Kama-Oka, and CG16 (copper with all four trace elements) in northern Caucasus. In general, CG1 and CG2 occupy over 50% of overall analysed objects in

which specimens from Andronovo and mixed zone share a similar profile of copper chemistry.

Table 5.2 Distribution of copper groups in the LBA cultures of the Steppe.

c 1700-1500/1400 BC	*The Late Bronze Age Culture/Region in the Eurasian Steppe*				
	Srubnaya	**Mixed**	**Andronovo**	**Forest Cultures**	**N. Caucasus**
CG1 pure	**54.0%**	**71.4%**	**70.0%**	**31.3%**	4.0%
CG2 As	**9.7%**	11.2%	**12.0%**	**21.7%**	**48.0%**
CG3 Sb	2.4%	1.9%	8.1%	1.2%	
CG4 Ag	2.7%	6.8%	3.6%	**19.6%**	
CG5 Ni	**9.0%**		1.1%		
CG6 AsSb	4.6%	3.7%	2.9%	7.2%	4.0%
CG9 AsAg	1.0%	1.2%	1.1%	**12.0%**	
CG11 AsNi	**8.5%**	1.9%	0.3%	2.4%	4.0%
CG14 AsSbNi	4.4%	0.6%	0.3%		4.0%
G16 AsSbAgNi	2.7%				**32.0%**
n	411	161	700	83	25
					Total N=1380

Although this rough classification may reveal some useful information, it may not reflect the actual metallurgical network. As material culture of the LBA communities is so mixed up, it is difficult to define cultural boundaries and effectively allocate metal objects to specific cultural identities. Not even to mention that many metal artefacts are noted as chance finds without archaeological context. Therefore, instead of using cultural groups to categorise the data, I propose to utilise inland waterways as proxies to reflect the transportation in prehistory. The river networks were the main ways of communication between the European Russia and Siberia before the 1730s. The Volga system with its tributaries like the Kama, the Oka and the Belaya is the most important carrier of waterborne traffic in Russia. Rivers within the Volga drainage basin are seasonally navigable and some cut through the Ural Mountains to form accessible corridors for east-west movement. To obtain the drainage basins of major waterways, I use the hydrological analysis provided by the ArcGIS to delineate primary watersheds in the extent of the data points (Figure 5.5). This creates several river basins that can be served as basic units for the discussion of metal in circulation (Figure 5.6).

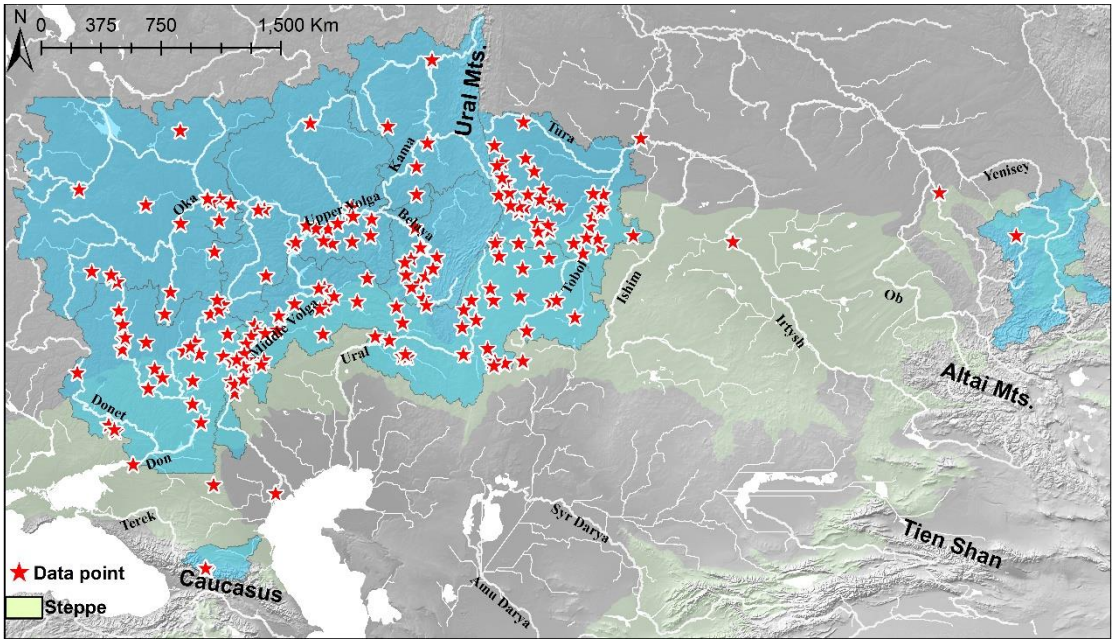


Figure 5.5 Major watersheds defined by the ArcGIS hydrological analysis.

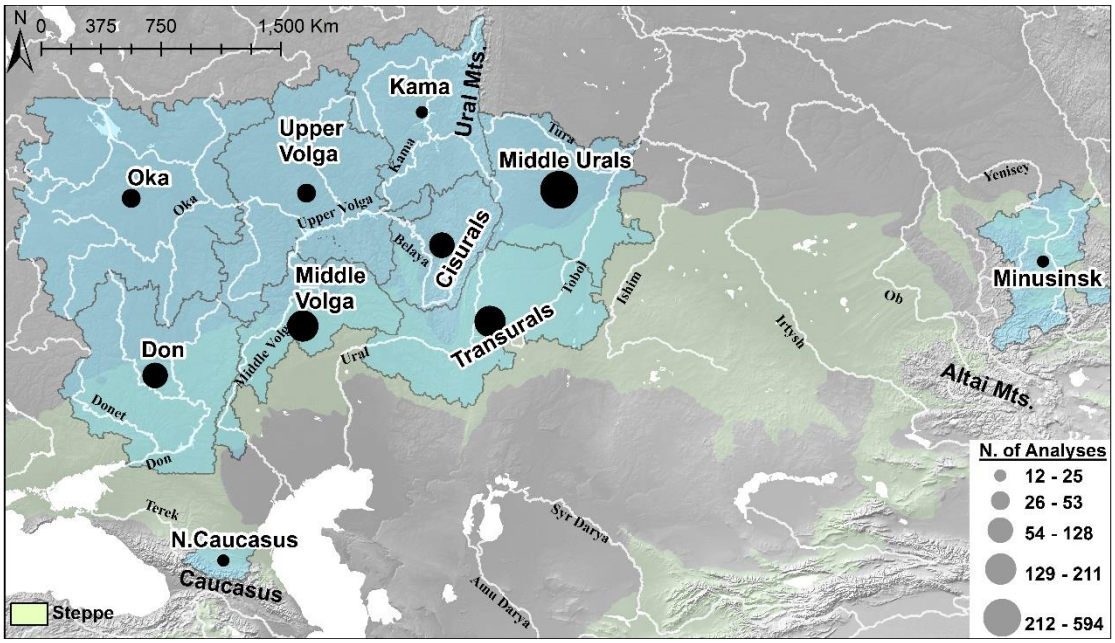


Figure 5.6 River basins under the area of interest.

5.6 Copper chemistry based on river systems

5.6.1 Fresh metal supplies

Drawing from watershed units, we are able to remodify our datasets into the ubiquity of copper groups in a given river system (Table 5.3). Distribution of copper groups shows that pure copper (CG1) dominates in the regions along the Ural Mountains, namely Cisurals, Transurals and Middle Urals (Figure 5.7). Among them, the Cisurals along the Belaya River stands out as a hot spot, not far away from the famous Kargaly

Table 5.3 Distribution of copper groups in the analysed objects by watershed.

c 1700-1500/1400 BC	*River Basin*									
	Minusinsk	**M_Urals (Middle Tobol)**	**Transurals (Ural-Lower Tobol)**	**Cisurals (Belaya)**	**M_Volga**	**Kama**	**U_Volga**	**Oka**	**Don**	**N.Caucasus (Terek)**
CG1 pure	**54.5%**	**69.9%**	**73.9%**	**89.1%**	**30.2%**	**50.0%**	**22.6%**	**59.3%**	**52.4%**	4.0%
CG2 As	**18.2%**	**11.1%**	**12.3%**	3.9%	8.8%	**25.0%**	**20.8%**	**18.5%**	**16.7%**	**48.0%**
CG3 Sb		**9.4%**	1.4%	0.8%	2.9%			3.7%		
CG4 Ag	**13.6%**	3.7%	4.3%	2.3%	1.8%	8.3%	**24.5%**	1.4%		
CG5 Ni		1.3%			**21.1%**					
CG6 AsSb	4.5%	2.2%	4.7%	1.6%	4.1%		7.5%	1.4%	7.9%	4.0%
CG9 AsAg		1.3%	0.5%	2.3%			**17.0%**	3.7%	1.6%	
CG11 AsNi		0.2%	1.4%		**18.1%**	8.3%	1.9%		3.2%	4.0%
CG14 AsSbNi		0.2%	0.9%		7.6%				4.0%	4.0%
G16 AsSbAgNi					4.1%					**32.0%**
N	22	594	211	128	171	12	53	27	126	25
										Total N=1372

mining complex. Chernykh (1970) had argued that copper deposits in the Urals were the most important source for "clean copper" production in Andronovo-Srubnaya communities. Chemical signatures were represented by MP and EU groups, corresponding to Cisural copper sandstone deposits and Elenovka-Ushkatta mines in the Transurals, respectively. The investigation of the Kargaly complex and its associated Gorny settlement has shown a fresh supply to sustain approximately 100,000 tons of copper. Copper ores were mined and transported to other settlements for further smelting and casting. Both ore/slag chemistry and smelting experiments suggest that relative clean copper can be obtained from smelting copper sandstone ores from Kargaly (Rovira 1999, 2004). Chemical data of metal objects indeed suggests that pure copper production concentrates in the Belaya basin of Cisurals and from there the proportion of this copper group gradually diminishes. While Kargaly is no doubt an important source for clean copper, we cannot rule out other deposits in the west of the Ural Mountains, which geochemically resemble the Kargly mines. (Grigor'yev 2015: 416).

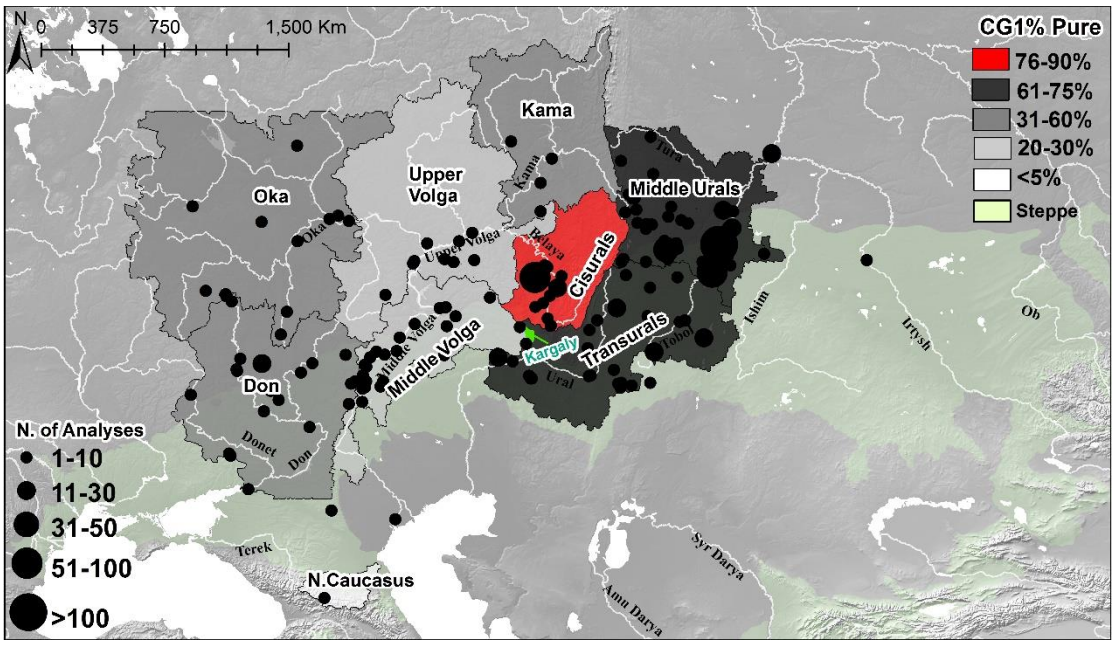


Figure 5.7 Map showing the ubiquity of CG1 objects in a given river system.

Further west of the Cisurals, the proportion of CG1 drops to less than around 30% in the Middle and Upper Volga, but rises up again in the Oka and Don river basins. The Volga regions are actually characterised by the use of recycling/mixing copper groups (see Section 5.6.2). Instead, the Don and Oka areas would probably exploit local copper sandstones or receive fresh clean metals from further west in the Carpathian Basin

or/and Baltic coast. Unfortunately, it is outside the scope of this thesis to investigate European copper sources.

5.6.2 Recycling/mixing of metals

The main question I would like to address here is that whether or not recycling or mixing occurred during the Late Bronze Age and how to identify such possibility. As stressed above, Chernykh has recognised that mixing indeed takes place within some Srubnaya copper objects with relative high amounts of impurities. According to the spatial distribution of copper groups, we can comment on this phenomenon in more detail.

There are at least two main scenarios of metal recycling/mixing during the Late Bronze Age. One is the nickel-bearing copper of CG11 (As-Ni) and CG5 (Ni-only). Both groups primarily centre in the Middle Volga, where nearly 40% of artefacts are made of such chemistry (Figure 5.8). Arsenic is relatively vulnerable to oxidative loss during high-temperature melt, which can potentially transform arsenic-nickel copper into nickel-only metal. The loss of arsenic can also lead to illusion of nickel enrichment in our data so that nickel content in CG5 is slightly higher than that in CG11 (Figure 5.9). Furthermore, further depletion of arsenic in the Middle Volga assemblage is possible through the mixture with pure copper from the Urals. The coexistence of CG11 and CG5 explains likely regional recycling/mixing practices in the Middle Volga as opposed to fresh metal production in the neighbouring Urals.

Recycling/mixing of copper-based artefacts sometimes takes a long-lasting process for centuries and thus we have to take the time dimension into account. In this regard, I include the Middle Bronze Age data from the same copper groups to compare with the LBA assemblage. They are the Sintashta culture in the Transurals and the Potapovka culture in the Middle Volga. As can been seen in Figure 5.10, in these two cultures arsenic concentrations are relatively higher and more scattered (median: 1.2% for Sintashta and 1.6% for Potapovka) than those of the LBA metal with confined ranges (<0.5%). This suggests a possible re-use of old metal stocks from the Sintashta and Potapovka communities. In addition, nickel content in the Sintashta can reach up to 1.2% and as noted before, nickel is extremely resistant to removal unless caused by dilution with nickel-poor copper. Pure copper sources from the Ural Mountains provide the

opportunity for the mixture of metal, leading to the drop in nickel concentrations in the LBA metals.

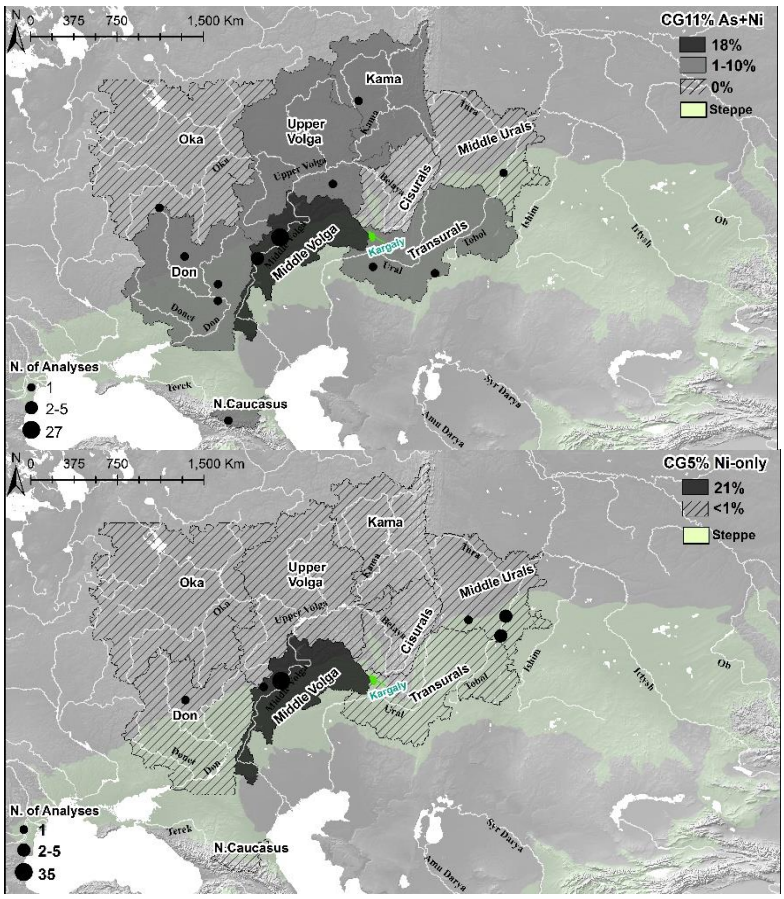


Figure 5.8 Map showing the ubiquity of CG11 (top) and CG5 (bottom) objects in a given river system.

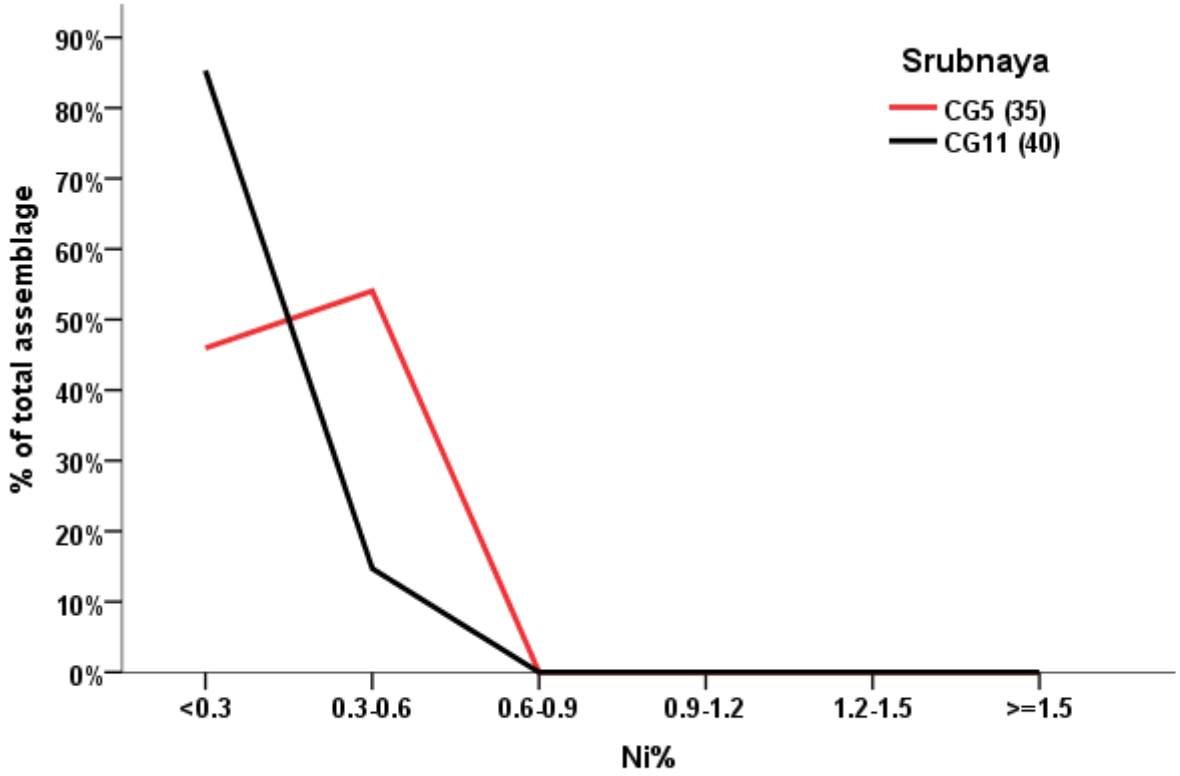


Figure 5.9 Comparison of nickel content between CG11 and CG5 objects

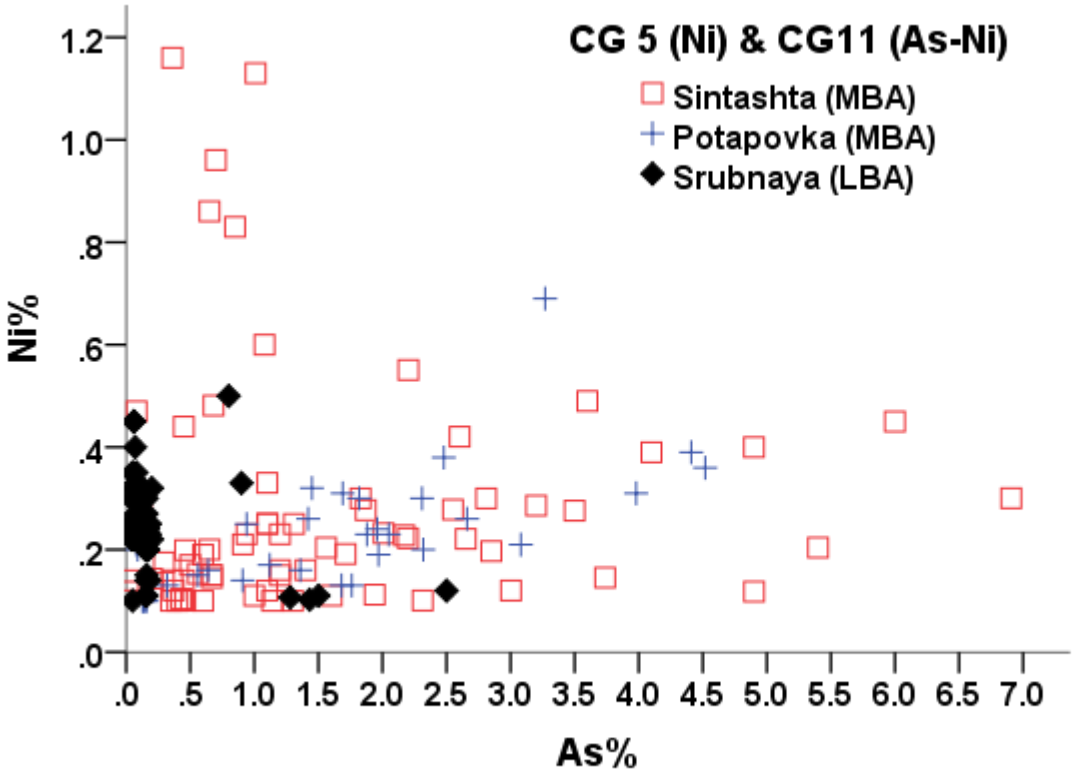


Figure 5.10 Comparison of As-Ni plots between the MBA and LBA nickel-bearing objects.

In short, there is a regional recycling/mixing of nickel-bearing copper by means of the re-use of previous MBA metals to mix up with the Uralian pure copper supplies.

The other possibility of metal recycling/mixing is marked by the silver-containing CG9 (As-Ag) and CG4 (Ag-only). They are both chiefly distributed in the Upper Volga (Figure 5.11). Parallel to the example of CG11 and CG5, the depletion of arsenic in CG9 leads to the emergence of CG4 (silver-only). Interestingly, these trace element patterns are also diagnostic to copper chemistry in the Abashevo and Seima-Turbino objects during the Middle Bronze Age. Drawing from analyses of silver-containing metals, we can identify that the MBA cultures contain relatively higher and more dispersed arsenic levels than those of the LBA specimens from the Upper Volga (Figure 5.12). Silver concentrations in the Seima-Turbino bronzes can reach as high as 2%. Silver, as an element reluctant to form oxides, is difficult to be removed unless being diluted by silver-poor material. Again, mixing with pure copper sources from the Urals could potentially cause the apparent loss of silver. Like the case of the Middle Volga copper-nickel metals, the reduction in silver in the Upper Volga specimens might be the consequences of the mixture between old silver-rich metals and clean copper supplies from the Urals.

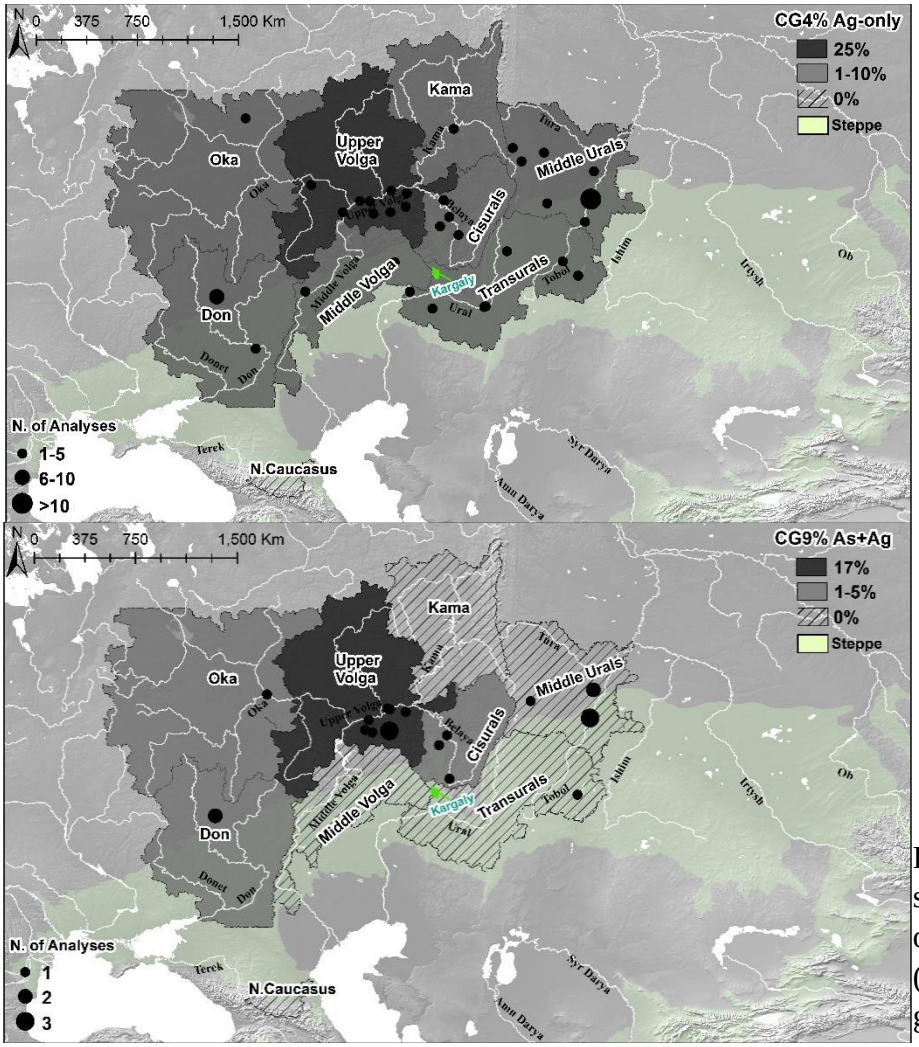


Figure 5.11 Map showing the ubiquity of CG4 (top) and CG9 (bottom) objects in a given river system

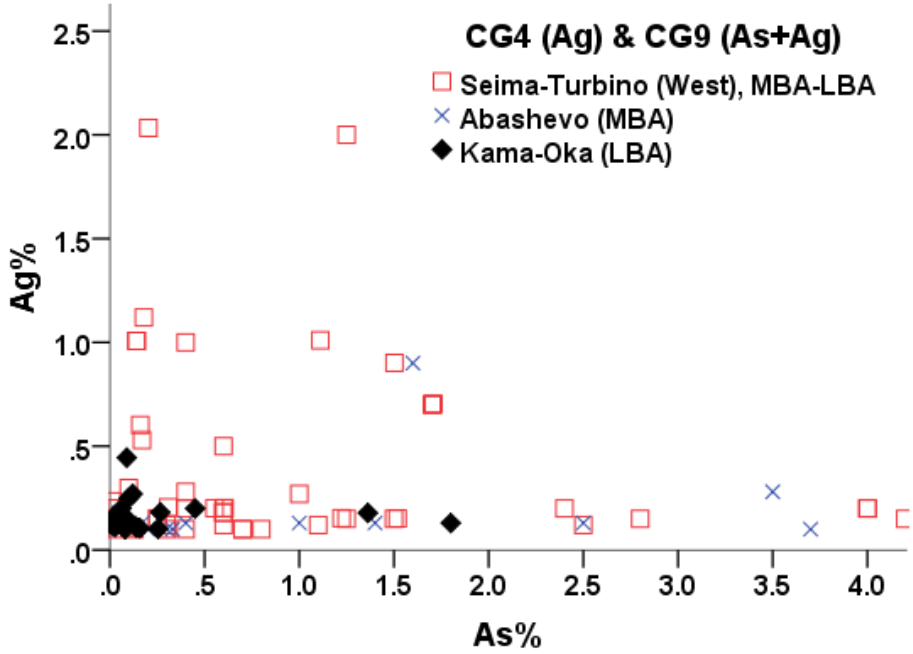


Figure 5.12 Comparison of As-Ag plots between the MBA and LBA silver-bearing objects.

5.6.3 Other copper groups

CG2 arsenic-only metals, as one of the most essential components in the Abashevo-Sintashta metallurgy, greatly decrease in proportion during the Late Bronze Age (Figure 5.13). Most areas contain less than 30% CG2 in the total assemblage except for the Terek river basin in North Caucasus, where arsenical copper had been an alloying tradition since the fourth millennium BC (Chernykh 1966). Even though we can perceive that CG2 is slightly biased towards the west (Volga, Kama, and Don), its difference with the east is not so great. N. Caucasus seems to remain a principal arsenical copper production, which may provide arsenic-only metals to the Pontic-Caspian steppe.

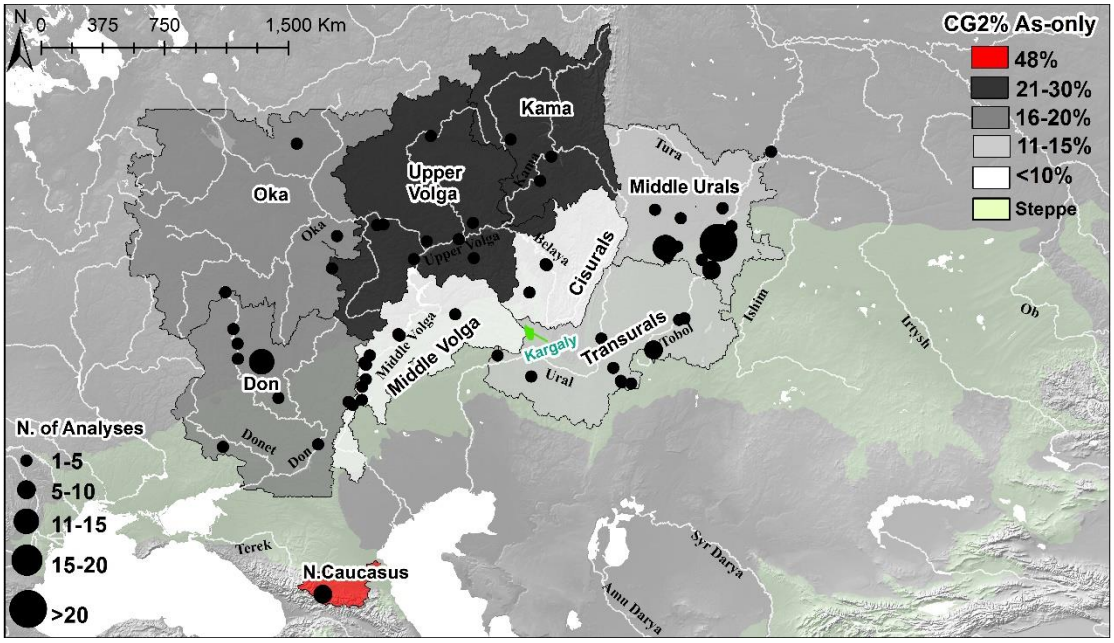


Figure 5.13 Map showing the ubiquity of CG2 objects in a given river system.

Distribution of arsenic concentrations in metal objects also attests a low "quality" of CG2 production in most regions of the Steppe (Figure 5.14). While it is beyond doubt that N. Caucasus, with the enormously high arsenic content, serves as clear evidence of primary CG2 production, other steppe areas contain relatively low arsenic concentrations (mostly <1%). This reduction in arsenic may indicate multiple life histories of arsenic-only copper objects. They can be either the products from the recycling of Caucasian or simply the re-use of previous MBA metals rich in arsenic. Of course, it is also possible to create such low-arsenic copper by mixing with fresh clean copper sources (such as Kargaly deposits).

Although it is difficult to identify any recognisable flow of CG2 metals apart from its likely source from N. Caucasus, Figure 5.14 seems to suggest a movement across the steppe zone rather than forest zone. It is noted that the Don, Middle Volga and Transurals, situated along the grasslands, tend to have higher arsenic than those in the forest zone (Upper Volga and Middle Urals).

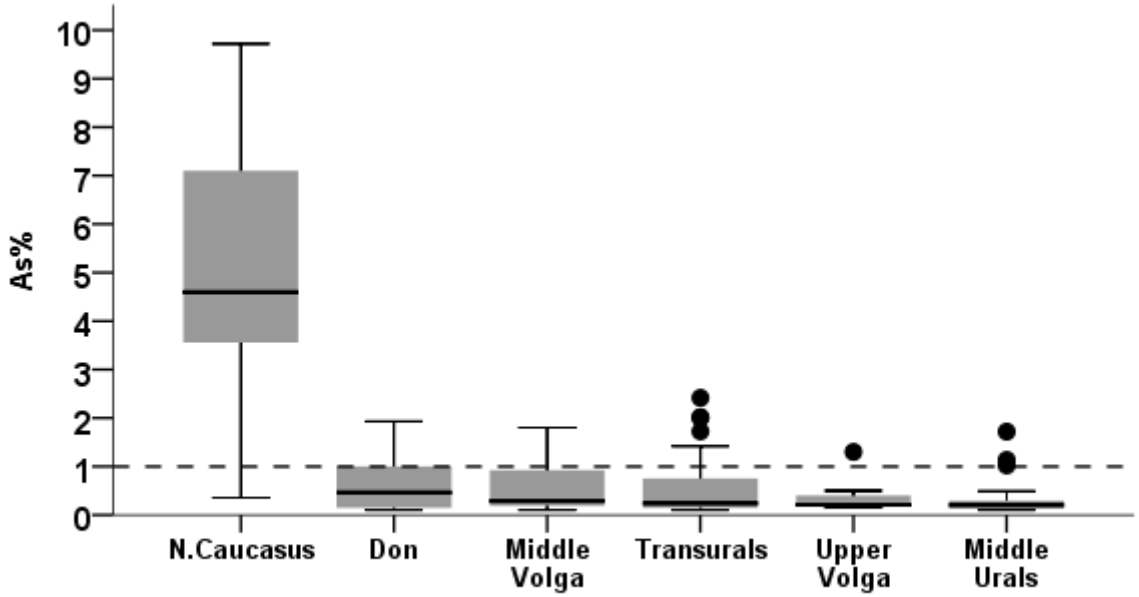


Figure 5.14 Distribution of CG2 arsenic in a given river system.

5.7 Circulation of tin-bronze

Prior to the Late Bronze Age, the Eurasian steppe was characterised by the use of arsenical copper/bronze for over 2000 years. Interestingly, this long-lasting alloying preference gradually died out during the Andronovo-Srubnaya period. As shown by Figure 5.15, distribution of arsenical copper (As>1%) is primarily limited to N. Caucasus and becomes relatively insignificant in the rest of the Steppe. Grigor'yev (2015) links this reduction in copper-arsenic alloys to the initial use of copper sulphides in the Steppe as the roasting process required by smelting such ores would potentially drive out arsenic under an oxidising condition. While it sounds reasonable, he neglects the possibility of recycling/mixing that may achieve the same outcome. As CG1 (clean copper) production served as the most important copper source during the Late Bronze Age, the mixture between old (arsenic-rich copper) and new (pure copper) metal units was highly probable.

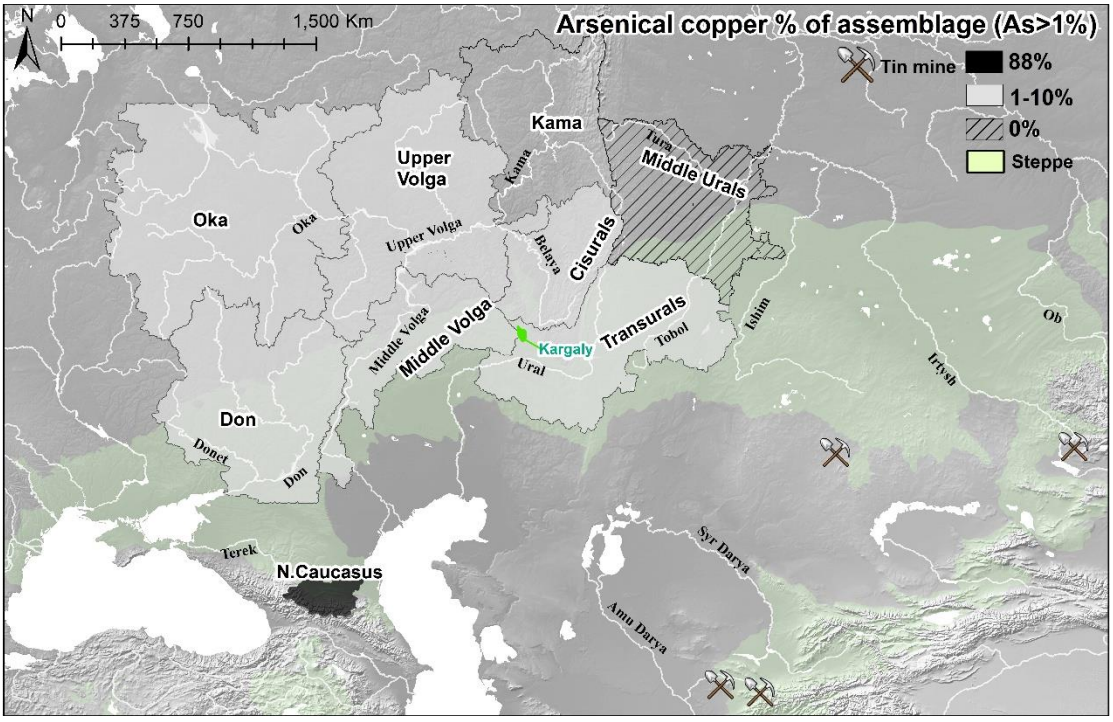


Figure 5.15 Map showing the ubiquity of arsenical copper (As>1%) in each river system.

The main character of the LBA copper alloying had shifted to the use of tin-bronze. Before, copper-tin alloys were primarily restricted to the Seima-Turbino cultural horizon and they were extremely rare in the vast territory of the central and western Eurasian steppes. The advent of the Andronovo culture had made the tin-bronze production more available across the Steppe, which is supported by chemical results. As can be seen in Table 5.4, tin-bronze occupies over 50% of the total Andronovo specimens and there seems to be a rapid spread of tin-bronze across the mixed zone, the Srubnaya culture and the Kama-Oka forest communities with a similar ubiquity (30-35%). Alternatively, we can also demonstrate the distribution of tin-bronze in terms of the river networks (Figure 5.16). The distribution map highlights a hot spot in the regions of the Transurals, Cisurals and Middle Ural, where nearly 50% of artefacts are made of tin-bronze (>1%). As we know that contemporary tin mines are mostly located in the East (central and eastern Kazakhstan) and Southeast (central Asia), it is not surprising to identify the Urals as the forefront of tin-bronze production in term of closeness to potential deposits.

Further west tin-bronze seems to be transported along the Upper Volga River to Oka and Don river basins but bypass the Kama and Middle Volga regions. This is probably because the ease access from the Middle Urals to Cisurals as the mountain ranges are

the lowest. Historically, it was the location where the Huns entered Europe around 370AD (Érdy 1995). This pathway could be potentially taken by steppe people during the Late Bronze Age.

Table 5.4 Distribution of alloy types in each LBA culture.

c 1700-1500/ 1400BC	Cu	Cu-Sn	Cu-Sn-Pb	Cu-Pb	Total N
Andronovo	**39.4%**	**52.2%**	8.3%		701
Mixed	**60.5%**	**34.0%**	3.7%	1.2%	162
Srubnaya	**66.5%**	**31.6%**	1.0%	0.2%	415
Forest cultures	**63.9%**	**36.1%**			83
N. Caucasus	**88.0%**	**12.0%**			25
		Sn>1%	Sn & Pb>1%	Pb>1%	**1386**

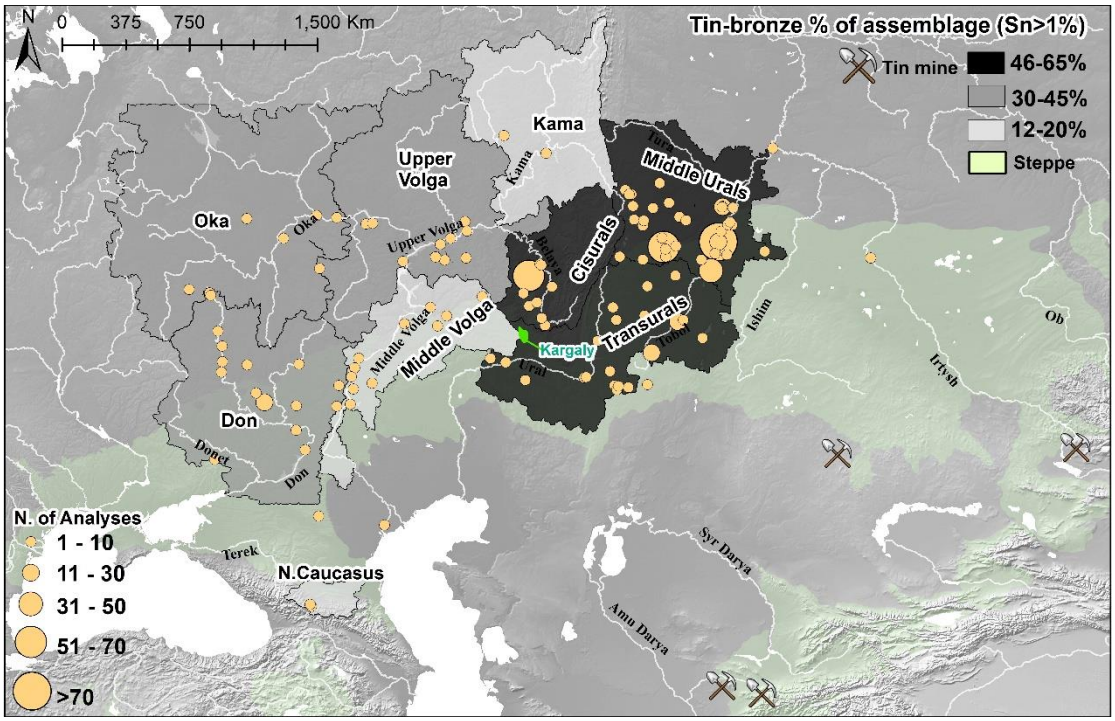


Figure 5.16 Map showing the ubiquity of tin-bronze (Sn>1%) in a given watershed.

By increasing the threshold of tin content, we can observe several interesting patterns. Figure 5.17 demonstrates two possible tin-bronze usages: one in the Urals and the other in the Oka-Don regions. While the former is likely based on tin from the Altai or central Asia, the latter should come from European sources. One possible candidate belongs to the contemporary archaeological cultures in northern Europe (Scandinavia and Baltic Coast), where some metal artefacts show the contact with the Seima-Turbino metalwork (Yushkova 2012). A recent project has shown a potential primary tin-bronze

production with standardised tin concentrations in the Scandinavian Early Metal Ages (Figure 5.18, also see Ling *et al.* 2014). These high-tin bronzes could be transported to the forest-steppe zone of eastern Europe and be recycled as low-tin bronzes in Oka and Don areas.

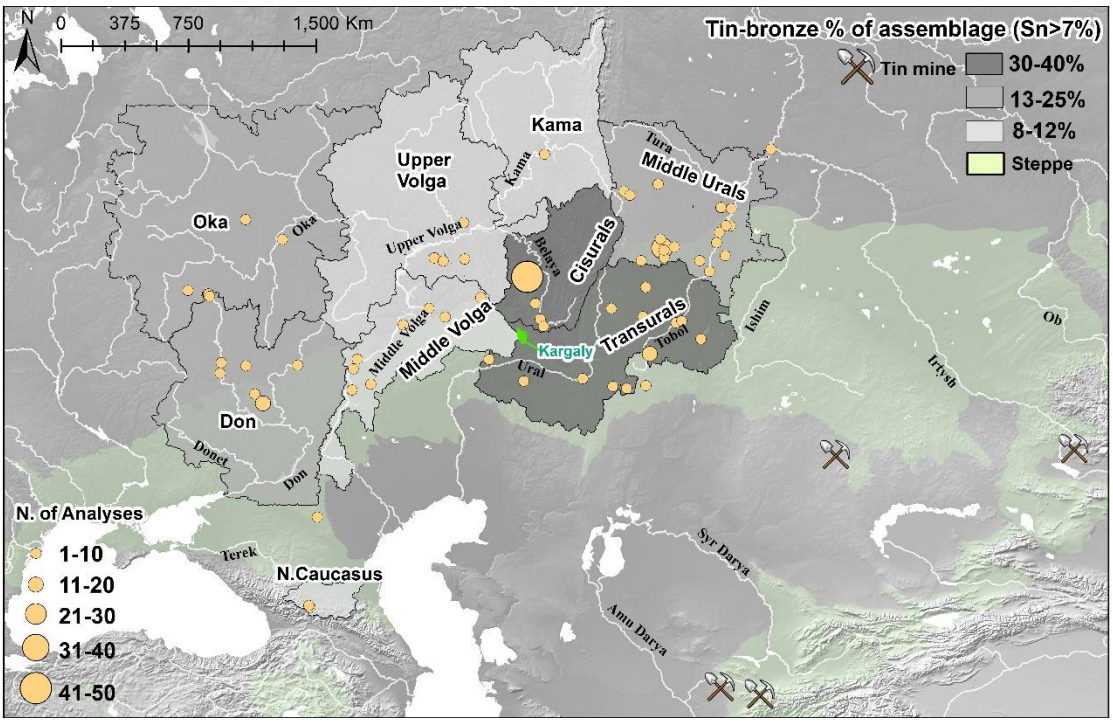


Figure 5.17 Map showing the ubiquity of copper-tin alloys (Sn>7%) in each river system.

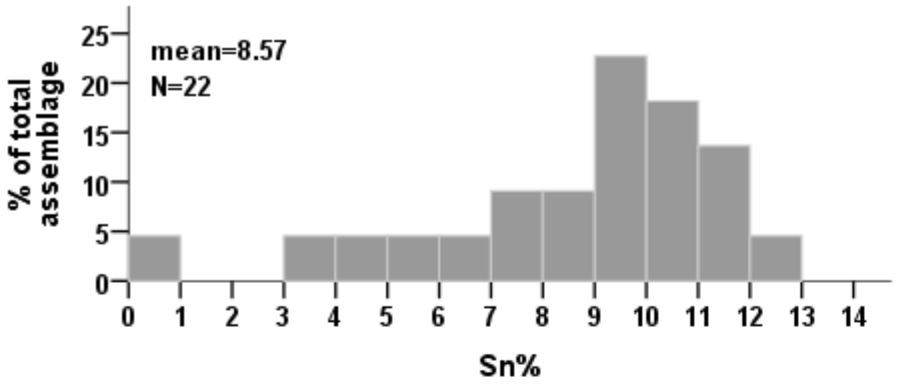


Figure 5.18 Distribution of tin in Scandinavian bronze artefacts dated to 1700-1300 BC. Data from Ling *et al.* (2014).

If we allow for a further increase in the tin cut-off up to 10%, Transurals becomes the sole place producing high quality copper-tin alloys (Figure 5.19). The distance to the nearest tin deposit in central Kazakhstan exceeds over 1000 km and this distance is even greater when considering the sources from the Altai and central Asia. Researchers have found very little evidence of tin smelting or copper-tin alloys near the tin deposits, suggesting that tin as either tin ores or ingots, was transported to distant settlements for

further smelting and bronze casting. Although the distance between mining and production sites looks formidable, many studies have indicated that Andronovo herders undertook seasonal migrations (both horizontal and vertical) over a long distance (e.g. Anthony 2007; Frachetti 2008). Pastoralists from the Transurals may not engage in extracting tin, but they can certainly travel to a middle place to trade with those who have access to tin resources.

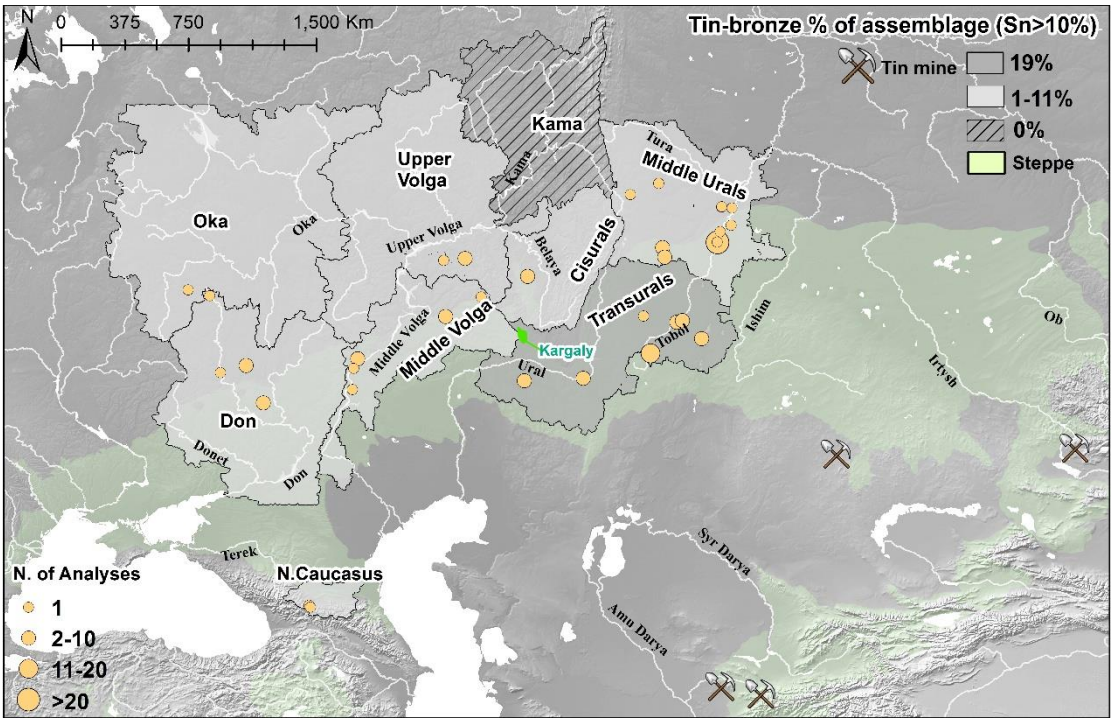


Figure 5.19 Map showing the ubiquity of copper-tin alloys (tin >10%) in each river system.

Finally, tin concentrations in different copper groups may also illuminate different life histories of copper-tin alloys. As can been seen in Figure 5.20, CG1 Srubnaya artefacts feature a diagnostic peak at 7-10% tin, which may belong to direct imports from the Andronovo communities (they are mostly personal adornments see below). Instead, the diminishing pattern of CG5 and CG11 objects signifies a dilution through the mixture between foreign pure copper (CG1) tin-bronze and local nickel-bearing copper.

5.8 Typology and chemistry

5.8.1 Copper chemistry of sickles

So far we explore the flow of the LBA metals by taking all artefacts into account. It would be much more meaningful to link chemical composition with artefact types to

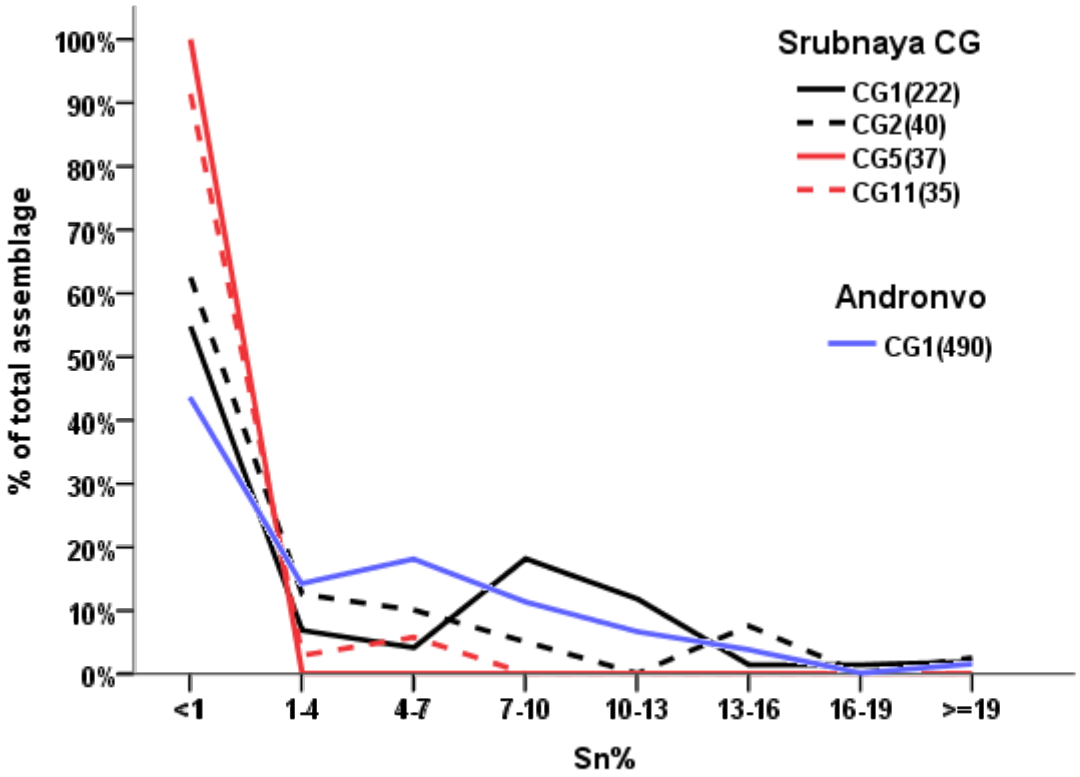


Figure 5.20 Distribution of tin between different Srubnaya copper groups.

reconstruct the object biography. The Late Bronze Age artefacts mainly consist of weapons (daggers, spearheads, shaft-hole axes and arrowheads), personal adornments, sickles, tools and ingots (Figure 5.21). Both Andronvo and Srubnaya metal specimens are dominated by tools and ornaments, while the Kama-Oka forest cultures tend to have more weapons and socketed axes. Sickles are also one of the most characteristic metal artefacts in the LBA of eastern Europe (Dergachev & Bochkarev 2002).

Copper chemistry of sickles demonstrates a rather striking feature of metal recycling and mixing. The majority of nickel-bearing objects we have mentioned above actually come from this artefact type in the Middle Volga (Figure 5.22). In addition, more than half of the sickles from the Upper Volga are composed of silver-containing copper (CG4 and CG9), another important category of recycled/mixed metals. By contrast, sickles from the Cisurals are represented by CG1 as a fresh clean copper supply from the Ural Mountains. These three sets of sickles (Middle Volga, Upper Volga and Cisurals), with different chemical composition characteristic to their regions, indicate the locality of sickle production.

Moreover, the archaeological context associated with sickles is also important. Most nickel-bearing sickles come from a single hoard (Sosnovaya Maza) in the Middle Volga. The metal hoarding has been argued for its special purpose as storage of raw material

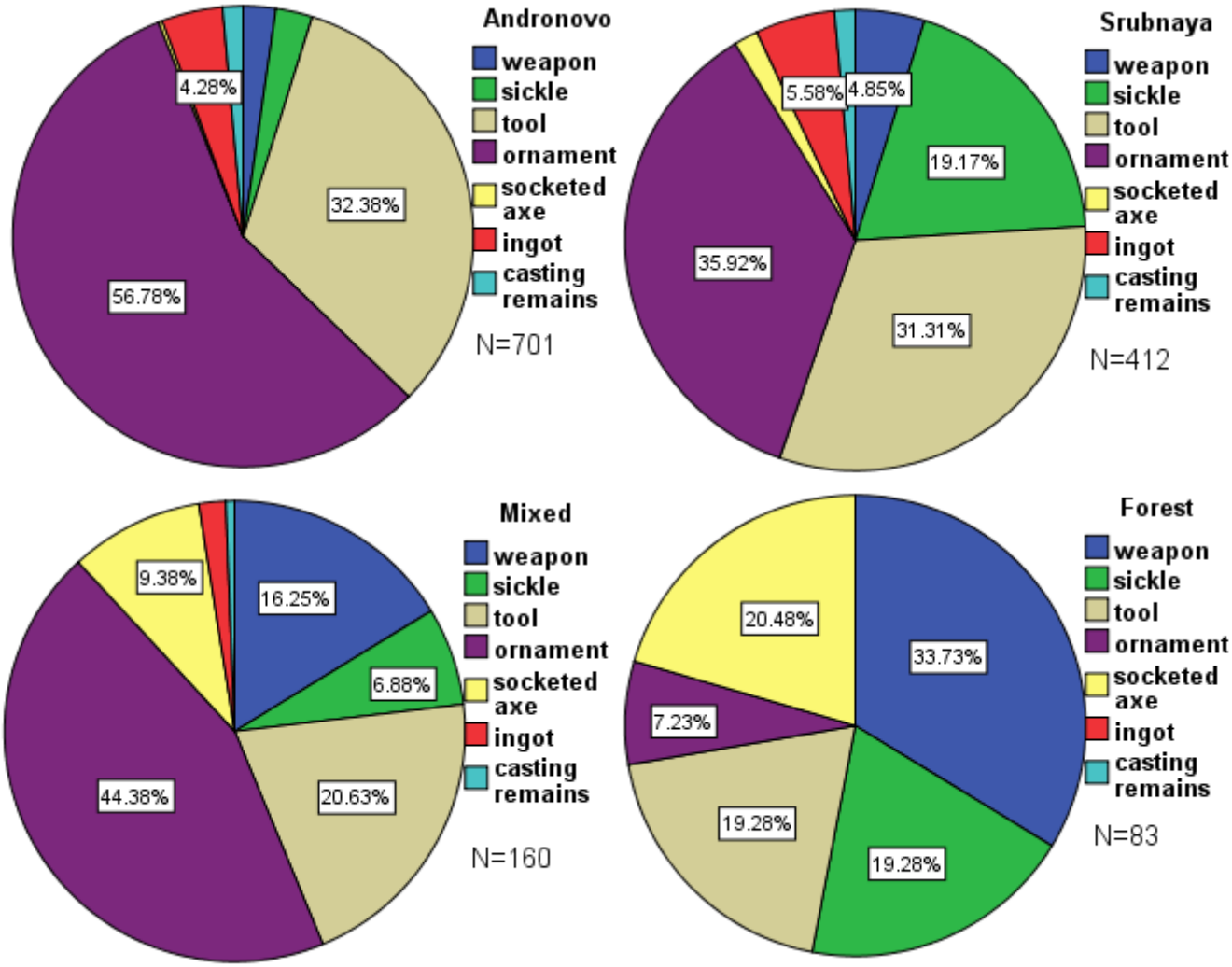


Figure 5.21 Distribution of artefact types among the LBA cultures/regions.

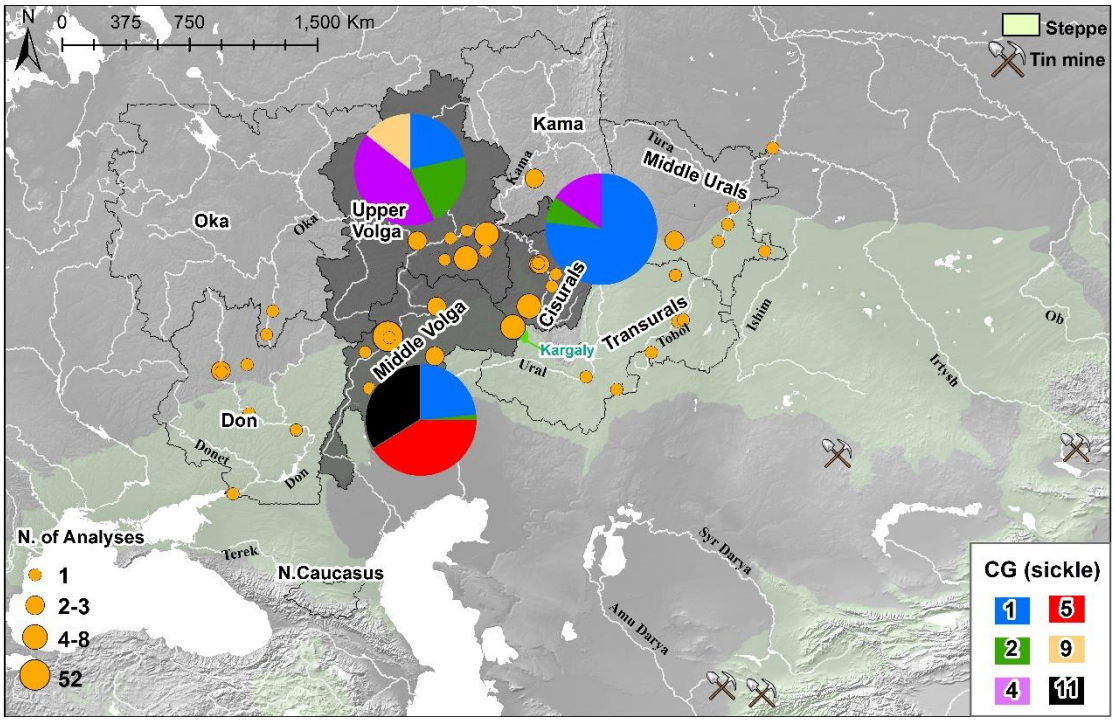


Figure 5.22 Distribution of copper types among the LBA sickles.

(ingots or finished objects for further processing) or ritual offering (Bradley 2013). The intentional re-use of copper sickles by the Srubnaya communities in the Middle Volga seems to bear some social meaning. Apart from metal sickles, other object types do not show a huge difference in terms of copper chemistry.

5.8.2 Alloying choices for different artefact types

Personal adornments are highly affiliated with copper-tin alloying as both Andronovo and Srubnaya ornaments are marked by pronounced high-tin peaks (Figure 5.23). Plotting the spatial distribution of ornaments reveals an even more striking pattern that bronze decorative items are ubiquitous from the Urals to the Don river basin, basically following the steppe belt (Figure 5.24). Small clothing appliques have been recognised as the essential element among the Bronze Age steppe cultures (Kupriyanova 2008). These small ornaments are highly transferable goods across pastoralist societies, presumably as the reciprocal exchange. Especially when these items are constantly made of tin-bronze, they become valuable raw material as the sources of tin. Therefore, tin-bronze ornaments enclose both social and economic implications among the Andronovo-Srubnaya communities. As Pigott has pointed out (Pigott 2011: 273), tin-bronze production in antiquity may represent social and ritual significance among the prehistoric societies. Copper-tin alloys were initially made for decorative items in prehistoric metallurgy (e.g. ancient Mesopotamia). This tendency is also reflected by the Srubnaya metals as shown by the primary tin-bronze production for ornaments (Figure 5.25, top). However, the same argument does not hold true for the Andronovo metalwork as both decorative items and weapons are made of high-tin content (Figure 5.25, bottom).

5.9 Conclusions

To sum up, the Andronovo (Alakul) and Srubnaya communities broadly share similar copper chemistry. It is marked by the production of "clean copper" in the central Eurasian steppe, especially in the Cisurals. Chernykh (2007) argues that this copper source is highly associated with the Kargaly mining complex. According to him, as regions around the Kargaly are mostly treeless grasslands, ancient people might have transported the copper ores to the forest-steppe Cisurals for primary smelting and casting, parallel to what Russian industrialists did during the18th to 19th centuries (Chernykh 2002a: 49). Nonetheless, as the core of this thesis emphasises the

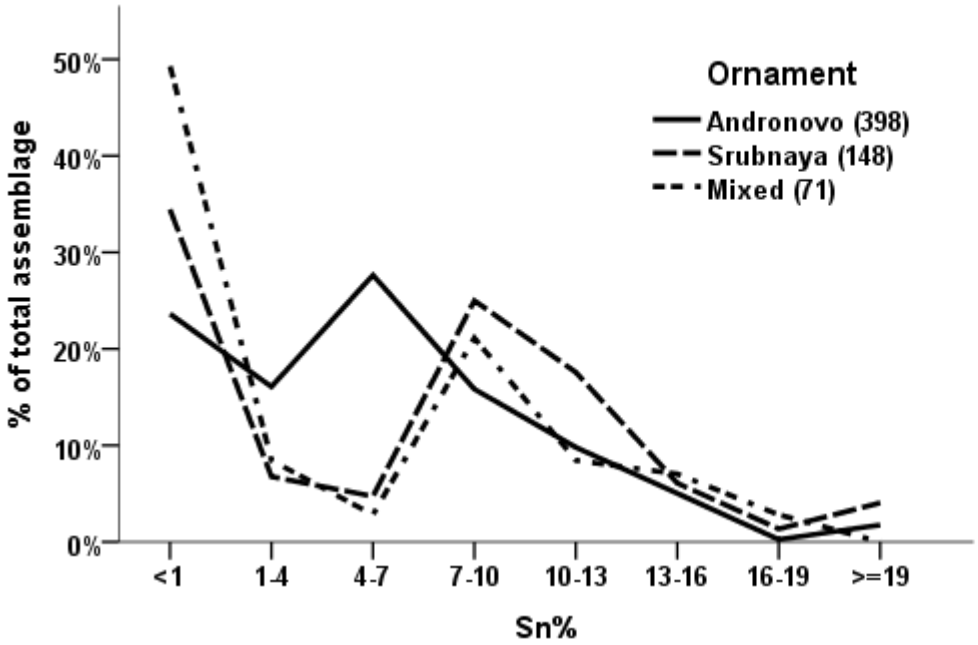


Figure 5.23 Distribution of artefact types among the LBA cultures/regions.

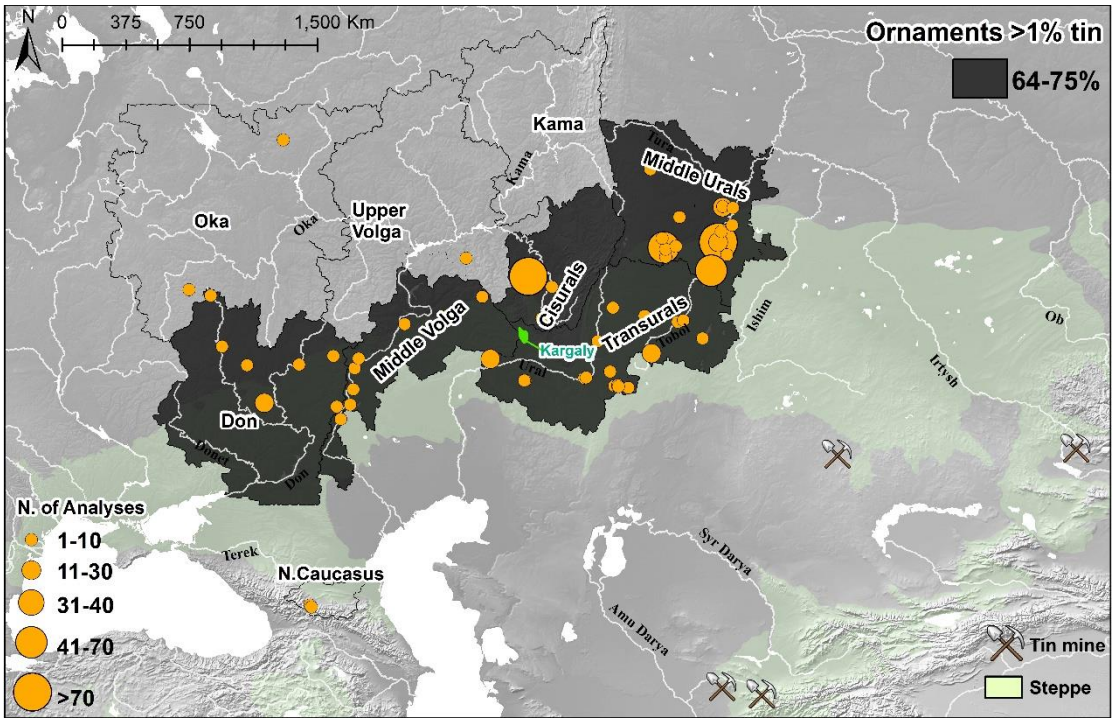


Figure 5.24 Ubiquity of tin-bronze (Sn>1%) among the LBA ornaments.

the importance of human engagement with metal production, we must take the recycling, mixing and re-alloying into consideration. Andronovo herders certainly exploited a number of indigenous copper mines in the Transurals and Kazakhstan that could potentially generate clean copper signal. Since pure copper lacks any impurities for tracing possible recycling/mixing patterns, our only hope is to turn to lead isotope analyses to differentiate between copper ore deposits (although this method could be invalid due to overlapping isotopic compositions).

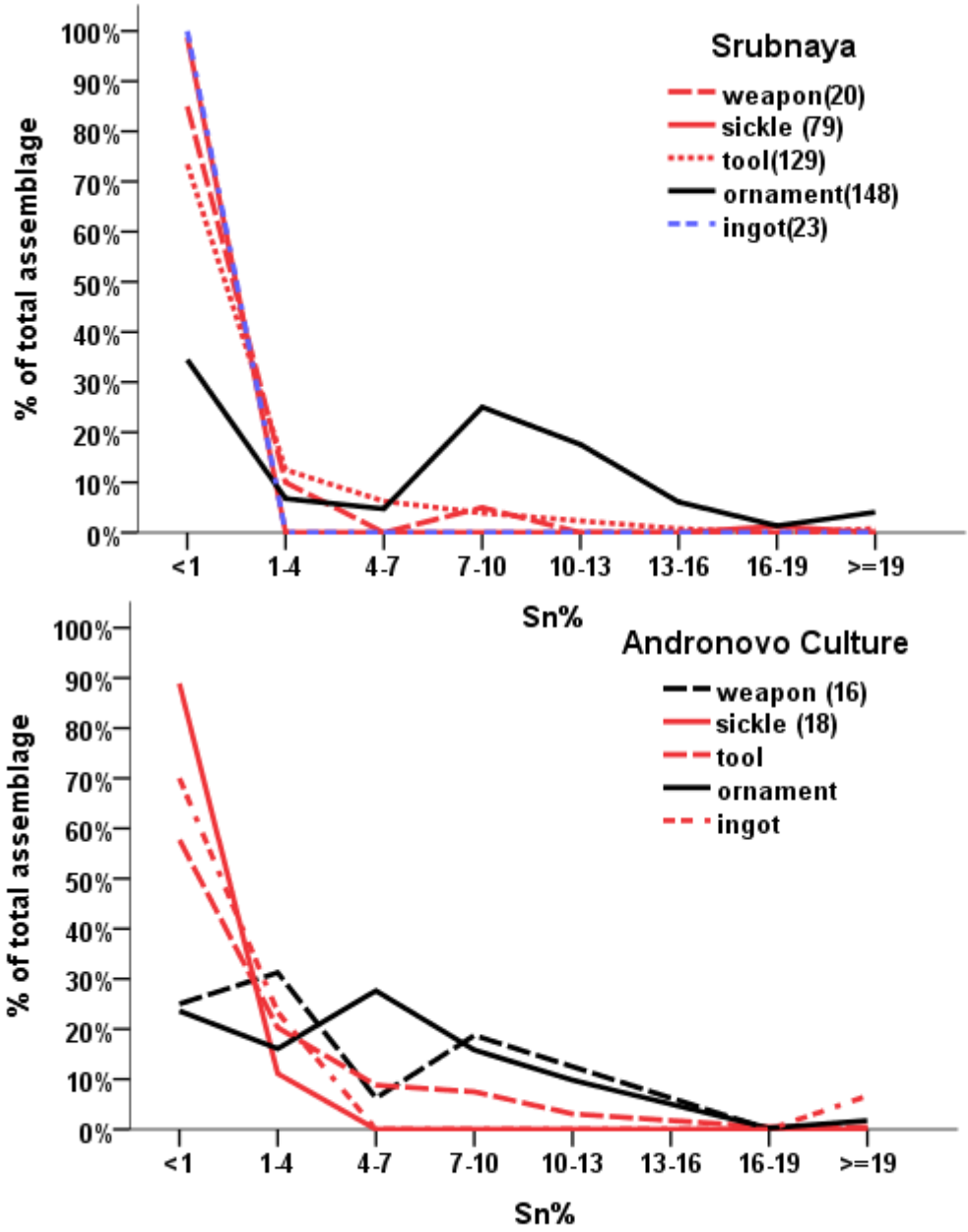


Figure 5.25 Distribution of tin by artefact type in Srubnaya (top) and Andronovo (bottom) cultures.

Apart from pure copper production, copper objects contain more significant amounts of impurities in the Middle and Upper Volga. This has not been addressed by previous research. Copper with nickel and silver is relatively more abundant in the western part of the Urals than the east. This is not purely by chance but is drawn from previous Abashevo-Sintashta and Seima-Turbino metallurgy, including As-Ni copper in the Sintashta culture and As-Ag copper in the Abashevo and Seima-Turbino communities. These two types of metal stocks were re-used by the subsequent Srubnaya people as attested by decreasing arsenic content in both nickel- and silver-containing metals. As the core region of the Srubnaya communities lacks mineral resources, re-melting old metals becomes commonplace.

By scrutinising the tin distribution of individual artefact types, one may recognise that the early use of tin-bronze may not result from its mechanical superiority over arsenical copper. As shown earlier, Andronovo-style copper-tin ornaments are prevalent in the steppe zone from the Urals to the Don basin. Their high-tin concentrations suggest a direct movement of objects from the East to West without much recycling. This explains that a tin-bronze personal adornment, as either a social marker (symbol of status) or a commodity (raw material), integrates the Andronovo and Srubnaya cultures into a coherent social and economic network. Instead, utilitarian items, such as weapons and tools, are more or less subject to certain degree of recycling and mixing.

The most important facet of the Late Bronze Age metalwork is marked by the spread of tin-bronze. The rise of the ST bronze metallurgy in the East turned out to have detrimental and far-reaching consequences in the Late Bronze Age (c.1700-1400 BC). The knowledge of tin alloying and mining of tin were adopted and amplified by the Andronovo communities in the Ural-Kazakh steppe, which led to the widespread use of tin-bronze across the Eurasian steppe and central Asia, and operation of tin mines in eastern Kazakhstan and the Zeravshan valley. This steppe tin now draws archaeologists' attention to the possible tin source for the ancient Near East during the second millennium BC (Pigott 2011). New copper supplies from the Ural Mountains and Kazakhstan also enrich the dynamics of metallurgy within the territory of the Andronovo-Srubnaya communities.

With these abundant metallic resources, the eastern steppe for the first time became a more important production centre than its western counterpart. As a result, Srubnaya people inhabiting in the west tended to rely heavily on recycled or mixed metals from the eastern steppe.

The rapid spread of the Andronovo metallurgy is primarily driven by an increasing mobility of economy based on animal husbandry. As Özyarkent pointed out (2013:11), Andronovo miners were also well-equipped herders, who performed seasonal migrations to sustain the fodder of their livestock. There are several instances that metallurgical activities occurred side by side with the specific subsistence strategies of the Andronovo populations. In the Altai near the Askaraly tin deposit, a temporary settlement Mastau Bai and miner's graves were discovered (Stöllner *et al.* 2011). A large half-pit house built with a stone foundation yields many animal bones as well as

metallurgical-related items such as hammer stones, a casting spoon and fragments of crucibles. Andronovo herders may perform a vertical movement to pursue summer alpine pastures in the mountainous areas. Another example of mining with seasonal expeditions is the exploitation of tin deposits at Karnab of central Asia (Boroffka *et al.* 2002; Parzinger *et al.* 2003). A settlement with pit houses and a number of fireplaces were found. Pit-house 2 contains fragments of arsenical copper, an ingot and droplets of tin-bronze. The analysis of some fire installations shows traces of tin. There are also many stone tools associated with grinding and crushing tin ores. The assemblage of animal bones indicates a mixed economy. Hunted game played a vital role in diet, then followed by sheep and cattle. The discovery of horse and camel bones was indicative of a long-distance network. Based on the examples of the Askaraly and Karnab, I argue that seasonal movements required by Andronovo stockbreeding economy led to the discovery of copper and tin mines in mountain ranges. These new resources in turn boosted the metal production among the Andronovo communities.

In addition to economic factors, the social network within the Andronovo culture also stimulated the spread of tin-bronze metallurgy. According to Kuz'mina (2007), the Andronovo people occupied the territory across different ecological zones: forest-steppes of the Middle Urals and western Siberia, steppes of the Ural-Kazakhstan region, and semi-desert zones of central Asia. Diverse ecological environments cultivated different cultural groups and the interaction between them was channelled by the exchange of gift. As Peterson *et al.* suggested (2015:8), metals could be used as a social payment to consolidate the tribal relationships in pastoralist societies. This type of payment in the Steppe would probably be the Andronovo bronze ornaments. Decorative items with high tin levels are found in both western and eastern steppes over a great distance. They may serve as the social tie between the Andronovo and the Srubnaya communities. The most remarkable example is the cemetery at Novye Yabalakly of the Cisurals. Even though burial practices and pottery typology follow the Srubnaya tradition, bronze ornaments such as beads, bracelets, and pedants are typical Andronovo manufacture (Kuz'minykh 1983).

6. Inner Asian Mountain Corridors and Steppe-China Connections during the Final Bronze Age

6.1 Background

The Final Bronze Age of the Eurasian steppe (c. 1400-900 BC) was a crucial transitional stage towards the rise of the subsequent Early Iron Age horse-riding communities that devastated the settled civilisations in ancient China, Greece and the Middle East (Gérard 2004). The FBA, according to Chernykh (1983a & 1984), was marked by the formation of the Valikovaya pottery tradition emerging among many metal-using cultures from the Altai to the Carpatho-Balkan region. Its cultural identity features a single cordon (*valik* in Russian) applied to the shoulder or neck of pots. Despite the widespread distribution of this ornamental design across the Steppe, individual archaeological societies still depict a quite complicated picture of material culture (Figure 6.1).

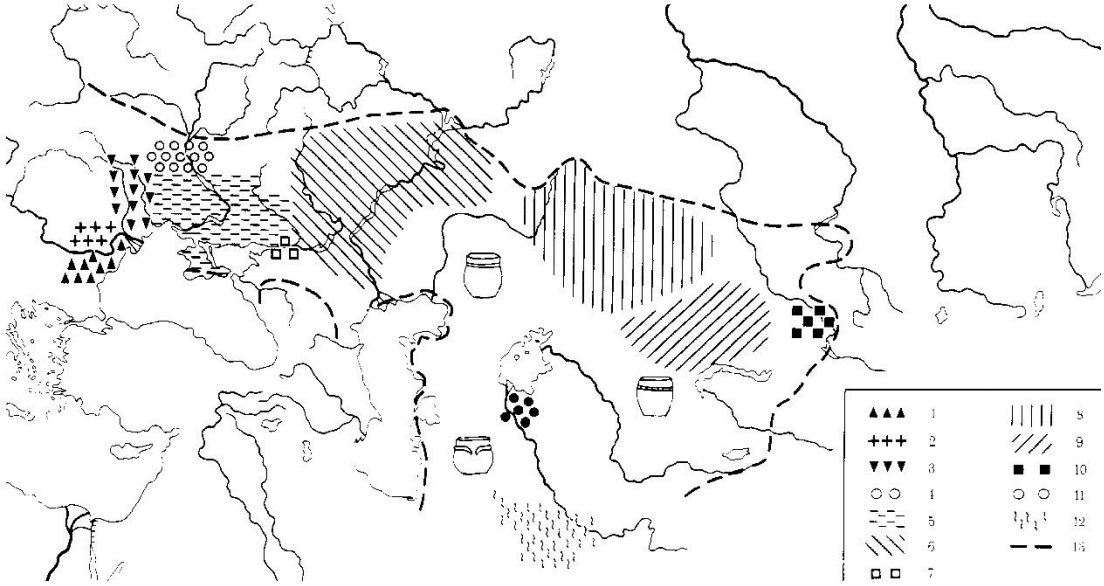


Figure 6.1 Distribution of the Valikovaya pottery tradition during the Final Bronze Age: (1) Pshenichevo-Babadag; (2) Coslogeni; (3) Noua and Moldavian "Thracian Hallstatt"; (4) Belogrudovka and Chernoles; (5) Sabatinvovka and Belozerka; (6) Srubnaya-Khavlynsk; (7) Kobyakovo; (8) Sargary culture; (9) Beghzay-Dandybai culture; (10) sites of the Trushnikovo type; (11) Amirabad culture (12) Yaz I-Tillyatepe-type sites; (13) borders of the Valikovaya Pottery community. After Chernykh (1992: 236, Fig. 79).

As the final phase of the Eurasian Metallurgical Province, this era manifested a disintegration of the metallurgical system (Chernykh 2008: 49). One can observe the decrease in both numbers of settlements and burials, probably associated with a gradual

transition towards a more mobile lifestyle (Ibid. 50). Mining and metal production also diminished at the end of the FBA, especially on the eastern steppe (Molodin *et al.* 2009:208).

Current archaeometallurgical research on the FBA metals is biased to the western Eurasian steppe in which Chernykh (1976) had conducted a grand-scale chemical investigation into metal composition and attempted to link the steppe metallurgy with European traditions (Chernykh 1992: 252-263). The western influence from the northern Balkans, the Carpathians and the Danube is visible on both composition and morphology of metal objects uncovered from the Dnieper, western Ukraine, Moldavia, and the Volga. By contrast, metallurgy in the eastern part of the Eurasian steppe is still poorly defined and only limited to a regional scale. Despite a strong metallurgical focus in Kazakhstan on the basis of its rich ore deposits and production sites, compositional data from the eastern steppe remains very fragmented and scattered in a variety of literature, making it difficult to evaluate how metals were moved across different regions or cultural groups. Therefore, this chapter attempts to synthesise published analytical results to untangle the complexity of metal flow in the eastern Eurasian steppe. To achieve this, I will chiefly target three major production areas: Minusinsk Basin, Kazakhstan and southern central Asia, plus some small-scale metal-using communities in the Upper Ob, Mongolia, Xinjiang and Fergana (Figure 6.2).

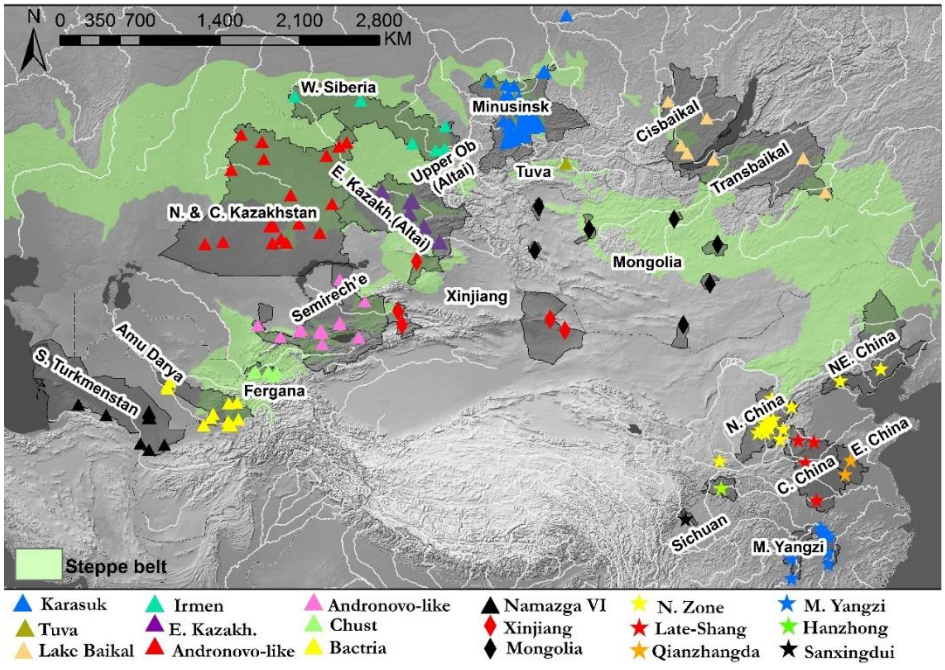


Figure 6.2 Map showing spatial distribution of the analysed LBA objects

6.2 Previous archaeometallurgical studies

6.2.1 The Minusinsk Basin: Karasuk metallurgy

The first large-scale investigation into the Karasuk copper-based artefacts was undertaken by Bogdanov-Berezovaya (1963). She analysed chemical composition of approximately 80 copper-based artefacts, including single-bladed knives, socketed axes, mirrors and personal ornaments. The results showed that Karausk metallurgy is dominated by arsenical copper, ranging roughly between 1 and 3% As, with some copper-tin-arsenic ternary alloys (tin content from 1 to 7%). The composition of impurities in all metal objects is quite homogeneous except for the presence of high nickel concentrations (up to 1%) in some artefacts.

After Bogdanov-Berezovaya's work, another important chemical analysis on Karasuk objects was conducted by Sergeeva (1981). She examined over 250 copper and copper alloys (mostly ornaments) from the burial sites and managed to divide the metals into nine alloy types (Table 6.1). The majority of them belong to copper-arsenic binary alloys, followed by copper-arsenic-nickel and copper-arsenic-tin ternary alloys. According to Sergeeva (1981:64), the coexistence of different types of alloys is probably due to several factors: (1) the use of various smelting technologies, (2) the use of diverse ore fields, and (3) the accessibility of imported metals.

Table 6.4 Alloy types in the Karasuk metals, classified by Sergeeva (1981:43)

Alloy type	Code	N. of Objects	% of the total assemblage
Cu+As	I	147	56.98%
Cu+As+Sn	II	26	10.08%
Cu+As+Ni	III	34	13.18%
Cu+As+Sb	IV	16	6.20%
Cu+Zn	V	6	2.33%
CU+Zn+As+Sn	VI	1	0.39%
Cu+Zn+As+Sb	VII	10	3.88%
CU+As+Zn+Sb+Ni	VIII	2	0.78%
Cu	IX	16	6.20%
Total		258	100.00%

Khavrin (2001) had studied metal artefacts from both Karasuk and early Tagar periods in the Minusinsk basin (c. 1400-700 BC). He argued that Minusinsk metals demonstrate increasing amounts of arsenic, antimony and nickel but a reduction in lead concentrations over time. According to him, these variations may be due to the usage

of different ore deposits. Meanwhile, alloying elements also underwent a change from Karasuk to Tagar times. Tin-bronze is generally in favour for Karasuk ornaments in contrast with early-Tagar low-tin counterparts. This chronological variation is best demonstrated by copper-based decorative items from a Karasuk cemetery (Kyurgenner I). Khavrin (2010) considered that the older burials from Kyurgenner I are dominated by tin-bronze and the younger ones are represented by copper and copper-arsenic alloys.

Instead of focusing solely on Karasuk metallurgy, Bobrov *et al.* (1997) took a further step to emphasise the complexity of internal metal production within the Karasuk communities and their external contact with neighbouring areas. They considered that the Karasuk culture consisted of two subgroups: classical Karasuk and Kamenniy Log on the basis of funerary types (however, recent radiocarbon dates suggest that these two burial types are contemporary, see Svyatko 2009). Metal artefacts uncovered from the Kamenniy Log type are mainly made of clean copper or arsenical copper (between 1 and 2% As) and usually bear high amounts of antimony and nickel (Bobrov *et al.*1997:45-54) . Instead, metals from the classical Karasuk cemeteries contain more copper-tin and copper-tin-arsenic alloys. Meanwhile, the presence of lead and silver is more common in artefacts from classical-type than those from log-type sites.

The inter-regional connection between the Minusinsk Basin and its western neighbour (western Siberia and the Upper Ob) was evidenced by the spread of Karasuk-style metal artefacts. Bobrov *et al.* (1997: 69-70) pointed out that the Irmen culture situated in the Upper Ob basin constitutes both arsenical copper and arsenic-antimony alloys. This combination is similar to Karasuk metal portfolios (especially for log-type monuments). They argued that the collapse of metallurgical network within the Valikovaya communities led to a decline in copper and tin production in Kazakhstan. This shortage of metal supplies provided an opportunity for Karasuk metals to penetrate into the Upper Ob and western Siberia.

6.2.2 Kazakhstan and Kyrgyzstan

In the second half of the second millennium BC, this region was occupied by the Andronovo cultural groups, including both Alakul and Fedorovo types and a number of regional variations (Kuz'mina 2007). A series of archaeometallurgical studies have been conducted in this area, suggesting a powerful and independent metallurgical centre in Kazakhstan, especially its tin-bronze production (Chernikov 1951; Kuz'mina 1966;

Ryndina *et al.* 1980; Vinogradov & Zharnikova 1983; Alekseyev & Kuznetsova 1983; Kuznetsova & Teplovodskaya 1994). One of the most informative summaries is given by Agapov *et al.* (2012) on the basis of over 500 analysed metal objects. According to them, metal production by this time features two mining and metallurgical centres in N. & C. Kazakhstan and E. Kazakhstan, and one metalworking centre in Semirech'e (Figure 6.3). Northern and central Kazakhstan contain huge copper deposits (e.g. Pavlodar and Uspensko-Spasskiy) exploited by the Bronze Age miners (Bearden, 1998; Bearden *et al.*, 2004:157). Metal objects, mainly uncovered from settlements, are made of pure copper, tin-bronze and arsenical tin-bronze.

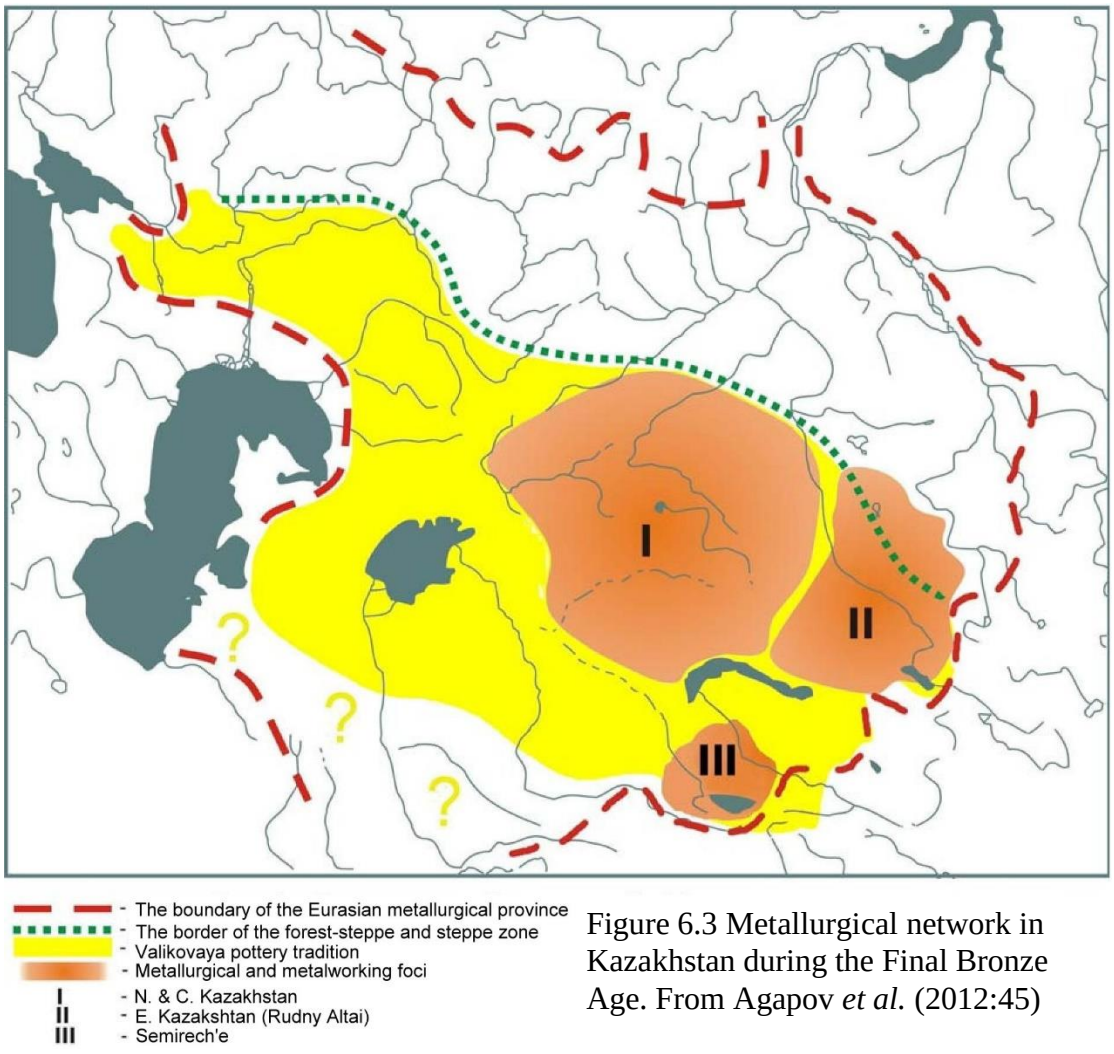


Figure 6.3 Metallurgical network in Kazakhstan during the Final Bronze Age. From Agapov *et al.* (2012:45)

Eastern Kazakhstan is exceptionally rich in mineral resources, such as the polymetallic copper deposits in Rudny Altai and cassiterite ores in the Kalba-Narym ranges (see Chapter 3 and 5). As suggested by Agapov *et al.* (2012:56), the majority of metal

artefacts come from chance finds and their object typology has a close affinity with the Karasuk culture and even the Middle Bronze Age Seima-Turbino metalwork. Artefacts are overwhelmingly high-quality tin-bronze (75% of the total analysed objects, with 12-26% tin).

Semirech'e, located in the territory of southeastern Kazakhstan and northern Kyrgyzstan, mainly relied on imported raw material from the other two metallurgical centres (Degtyareva 1985). Metal artefacts are primarily uncovered from metal hoards containing a number of bronze tools and weapons (over 100 items). Objects are dominated by low-tin copper alloys (88.8% of the total, with 1-12% tin).

6.2.3 Metalwork in southern Central Asia

This area includes present-day Turkmenistan and countries along the River Amu Darya (Uzbekistan, Tajikistan and northern Afghanistan). Based on chemical analysis of objects from the Sumbar cemetery in southern Turkmenistan, Galibin (1983) argued that half of metals are made of copper-tin alloy with tin concentrations over 5%. The rest are either pure or low-tin copper. Interestingly, he noticed that while most of decorative items are alloyed with tin, tools and weapons are generally made of pure copper or copper with a little amount of tin. He believed that metalworkers purposely added more tin to the manufacture of adornments in order to obtain a goldish colour.

Ruzanov (2013) conducted a comprehensive archaeometallurigcal project in southern central Asia. He had collected and analysed 1383 copper and copper-alloy specimens from southern regions of Turkmenistan, Uzbekistan and Tajikistan, dated to between 3200 and 1100 BC. Having adopted Chernykh's methodology (Chernykh 1966 & 1970), Ruzanov classified these analysed objects into several metallurgical and chemical groups in terms of frequency histograms and correlations between concentrations of impurities (Table 6.2). The following discussion is entirely derived from his research outcomes.

Ruzanov (2013) identified three metallurgical regions in southern Central Asia, namely southern Turkmenistan, southern Uzbekistan, and southwestern Tajikistan. Southern Turkmenistan, as the oldest metalworking centre in this area, is closely affiliated with Iranian metalwork in terms of artefact typology and chemistry. Since the Chalcolithic period (c. 4000-3000 BC), Turkmen metal objects had been utilising Iranian copper sources. In the following Early Bronze Age (c.2900-2300 BC), Iranian supplies were

Table 6.2 Metallurgical and chemical groups in southern central Asian metals. After Ruzanov (2013)

Metallurgical Group		
Type		*Criteria*
1	Cu	
2	Cu+Sn	Sn>0.8%
3	Cu+Pb	Pb>3%
4	Cu+As	As>2%
5	Cu+Sn+Pb	Sn>0.8%; Pb>3%
6	Cu+Pb+As	Pb+As>10%
7	Cu+Sn+As+Sb	Sn>10%; As>1%; Sb>1%
8	Cu+Ag	
Chemical Group		
Type	*Sub-Type*	*Ore Source*
ЮТ		Iran
ЮС	Ia	Afghanistan
	IIa	Afghanistan
	IIIa	Afghanistan
	Iva	Afghanistan
	IB	Afghanistan
	Ib-BY	Kazakhstan or Kyzylkum
	IIb	Kazakhstan or Kyzylkum
	IIIb-KM I	Kyzylkum
	IVb-KM II	Kyzylkum
ЧК	I	Chatkal-Kurama
	III	Chatkal-Kurama
	IV	Chatkal-Kurama
ВЗ	II	Upper Zarafshan
КМ		Kyzylkum
СА		Afghanistan
NO		unknown

still playing an important role, yet some Afghan copper deposits began to be exploited. The subsequent Middle Bronze Age (c. 2200-1800 BC) was marked by the use of both Iranian and Afghan sources for Turkmen metals. Meanwhile, around 10% of objects were sourced from northern central Asia. Finally, copper with the Iranian origin ceased to be used during the Late Bronze Age (c. 1700-1100 BC). Afghan supplies became dominant, with an increasing number of metal objects made of copper from the northern steppe areas.

The second metallurgical region is represented by copper objects from southern Uzbekistan. Copper metallurgy began to flourish during the Sapalli period (c. 2000-1500 BC). The majority of Sapalli metals were primarily associated with Afghan sources, with a secondary copper supply from Fergana mining districts (the Chatkal-Kurama mountain ranges). Fergana deposits became increasingly important in the second half of the second millennium BC.

The third metal-producing centre is located in southwestern Tajikistan. Due to its connection with the Eurasian steppe, typology of metal artefacts from the Late Bronze Age monuments demonstrated the contact with northern pastoral groups. Nonetheless, chemical analysis suggested that Tajikistani metals were mostly derived from the use of Afghan copper deposits in the south. Only a small number of objects were associated with the Kyzylkum source between the rivers Amu Darya and Syr Darya.

Apart from the identification of copper supplies, Ruzanov (2013: 90-91) also mentioned two principal tin deposits: Afghanistan and southern Uzbekistan. The former served as the primary tin source throughout the EBA and MBA, while the latter became active during the LBA (Garner 2015). The opening of the central Asian tin mines was evidenced by a sudden change to the use of tin-bronze around 1700 BC (Table 6.3).

Table 6.5 Alloy types in southern central Asian assemblage. After Ruzanov (2013: 55, Tab.1)

Date (BC)	Cu	Cu+Sn	Cu+As	Cu+Pb	Cu+Pb+As	Cu+Sn+Sb+As	Cu+Ag	Ag	Pb	Total
4000-3000	95.40%						3.00%	1.00%		87
2900-2300	88.70%	1.61%	1.61%				8.06%			62
2200-1800	76.39%	9.72%	5.55%	6.94%					1.38%	72
1700-1100	45.07%	40.98%	5.48%	3.81%	2.32%	0.83%	1.30%		0.18%	1076

6.2.4 Irmen metallurgy in the Upper Ob and western Siberia

As discussed earlier in Bobrov's research, Irmen metalwork in the Upper Ob Basin is influenced by Karasuk traditions, particularly the presence of copper-arsenic alloys. Out of 127 analysed objects from Irmen sites, 53.5% of them belong to arsenical copper, followed by "clean" copper (17.3%), tin bronzes (11.8%), copper-tin-arsenic alloys (9.5%) and finally arsenic-antimony metals (7.9%, see Bobrov *et al.* 1997:58). The most well-studied settlement is the Chicha-1 in western Siberia, where yielded bronze weapons, tools and other metallurgical remains (scrap metals and copper droplets).

Molodin *et al.* (2003 & 2009) have published 48 analysed objects from this site and identified several alloy types. The leading group is tin bronzes (37.5%), with tin ranging from 1.2 to 12% and arsenic less than 0.3%. The second group is pure copper (29.2%) with no more than 0.4% arsenic. The copper-tin-arsenic alloys (23%) contain tin between 0.9 and 6.6% and arsenic between 0.4 and 1.4%, and finally arsenical copper with arsenic from 0.42 to 0.8%.

Therefore, there are at least two variations of metalwork among the Irmen community. The East (Upper Ob) focuses on arsenical copper and the West (western Siberia) on tin-bronze.

6.2.5 Mongolia and the Baikal

During the Final Bronze Age, copper and copper alloys from Mongolia were represented by chance finds related to Karasuk-type metalwork (Novgorodova 1989:132-133). Korenevskij (1982) had analysed 24 bronze articles from the museum collection and proposed that they are mostly composed of tin-bronze with arsenic as the major trace element. Several items contain lead and antimony as chief impurities. This result is in contrast with the Karasuk metals from the Minusinsk Basin, where most objects are considered to be arsenical copper.

Metalwork in the Baikal region, including both Cisbaikal and Transbaikal, was also characterised by Karasuk-type objects. Artefact chemistry is dominated by the low-tin copper alloys, with tin content rarely over 5% (Grishin 1971 & Sergeyeva 1981)

6.2.6 Metalwork in the Fergana valley

The Final Bronze Age Fergana valley featured a number of settlements containing traces of metallurgical activities. Bogdanov-Berezovaya (1962) had performed a qualitative analysis on metal objects and slags from the Dalverzin site. He concluded that analysed objects are marked by high levels of lead, bismuth and antimony, reflecting the chemical signatures of copper deposits in the Fergana. There are two major productions: metal objects made of smelted copper on the site, with fairly uniform composition of impurities, and copper objects alloyed with arsenic or tin. As suggested by Kuz'mina (1966:94), the distinctive composition of Fergana metals reflects an independent metallurgical centre using the indigenous copper sources even though Fergana artefacts are typologically similar to those from Kazakhstan and Kyrgyzstan.

6.2.7 Potential drawbacks of previous research

As described above, overall compositional results of the LBA metals are quite fragmented and scattered across various literature. Each publication adopts its own criteria to characterise analytical data, making it extremely difficult to cross-compare different metal assemblage on the same ground. This hinders us from deriving meaningful and coherent conclusions regarding inter-regional contact. Furthermore, a number of analytical works are still confined to the classification of alloy types, which is insufficient to articulate the complexity of metal in circulation. Despite the trace element pattern is occasionally evaluated by some authors, they often attribute chemical changes to the use of different ore sources rather than to possible metal recycling and mixing. In order to overcome these shortcomings, I will re-evaluate compositional data by means of the proposed methodology in Chapter 2 to provide more sophisticated interpretations for the Final Bronze Age metallurgical network.

6.3 Multi-regional metal production

The FBA metal artefacts are highlighted by extremely diverse copper chemistry among regions/cultures (Table 6.4). Pure copper production (CG1) primarily focusses in present-day Kazakhstan, Sichuan and the Hanzhong Basin in China. Arsenic-only metal (CG2) plays a major role in the assemblage of the Lake Baikal, Mongolia, the Minusinsk Basin, Bactria, southern Turkmenistan and Sichuan. Arsenic-antimony copper group (CG6) is dominated by the Fergana specimens. Other regional copper groups, such as nickel-bearing copper (CG11, 14 & 15) and silver-containing copper (CG9 & 12), demonstrate unique chemical fingerprints to particular metal-producing communities. The complexity of trace elements in copper may result from the emergence of new copper supplies fuelled by potential recycling and mixing between different metal stocks. To better visualise this intricate network, different pie charts of copper groups are plotted against individual geographical regions (Figure 6.4). Drawing from the distribution of copper chemistry, I propose two possible long-distance connections between steppe pastoralists to the north and urban agriculturalists to the south.

Table 6.6 Ubiquity of copper groups across regions/cultures during the Final Bronze Age

c. 1400-900 BC	*The Final Bronze Age Culture/Region in eastern Eurasia*							
	Karasuk	Lake Baikal	Irmen	N. & C. Kazak.	Semirech'e	Fergana	Bactria	Namazga VI
CG1 pure	9.2%	14.8%	**29.3%**	**65.1%**	**55.7%**	12.2%	11.3%	7.1%
CG2 As	**37.8%**	**40.7%**	**26.7%**	15.6%	12.9%	4.9%	**36.6%**	**61.3%**
CG3 Sb	1.0%		5.3%	2.2%	5.7%	18.3%	1.7%	0.4%
CG4 Ag	0.7%			4.3%	14.3%		1.7%	0.9%
CG6 AsSb	17.4%	14.8%	18.7%	5.9%	4.3%	**65.2%**	9.6%	6.6%
CG9 AsAg	3.4%	3.7%	2.7%	3.8%	2.9%		8.5%	7.8%
CG11 AsNi	6.0%	5.6%	4.0%	0.5%			11.8%	8.3%
CG12 AsSbAg	8.3%	3.7%	8.0%	1.6%	2.9%		10.7%	2.3%
CG14 AsSbNi	11.8%	5.6%	4.0%				1.7%	2.2%
CG15 AsAgNi	0.8%	1.9%					3.7%	2.2%
G16 AsSbAgNi	2.2%	7.4%					2.3%	0.7%
n	1121	54	75	186	70	82	355	695

c. 1400-900 BC	*The Final Bronze Age Culture/Region in eastern Eurasia*						
	Mongolia	N. Zone	C. China	E. China (Qianzhangda)	Hanzhong	Sichuan (Sanxingdui)	M. Yangzi
CG1 pure	12.5%	11.4%	**26.8%**	12.3%	**83.2%**	**52.9%**	**45.5%**
CG2 As	**50.0%**	11.4%	**25.9%**	**28.1%**	1.0%	**35.3%**	18.2%
CG3 Sb		2.3%	1.8%	1.3%			
CG4 Ag		2.3%	5.0%	2.1%	1.5%		
CG6 AsSb	12.5%	2.3%	3.6%	6.4%	2.0%	5.9%	
CG9 AsAg	12.5%	**22.7%**	18.6%	17.4%	5.1%		9.1%
CG11 AsNi		6.8%	0.5%	0.9%	2.6%	5.9%	
CG12 AsSbAg	8.3%	4.5%	12.7%	**29.4%**	0.5%		**27.3%**
CG14 AsSbNi	4.2%		0.5%		2.6%		
CG15 AsAgNi		**25.0%**	0.9%	1.3%			
G16 AsSbAgNi		4.5%	1.8%		0.5%		
n	24	44	220	235	196	34	11
Box>10% is highlighted				**Total N=3407**			

6.3.1 Route one: Inner Asian Mountain Corridor

As can been seen in Figure 6.5, pure copper (marked by blue in Figure 6.4) in the Steppe mainly concentrates in N. and C. Kazakhstan, occupying over 60% of the total assemblage. This ratio is gradually decreasing in both northward and southward directions. To the north, the Irmen culture in the Upper Ob and western Siberia contains 29% of CG1, and this percentage falls off rapidly to around 9% in the Minusinsk Basin.

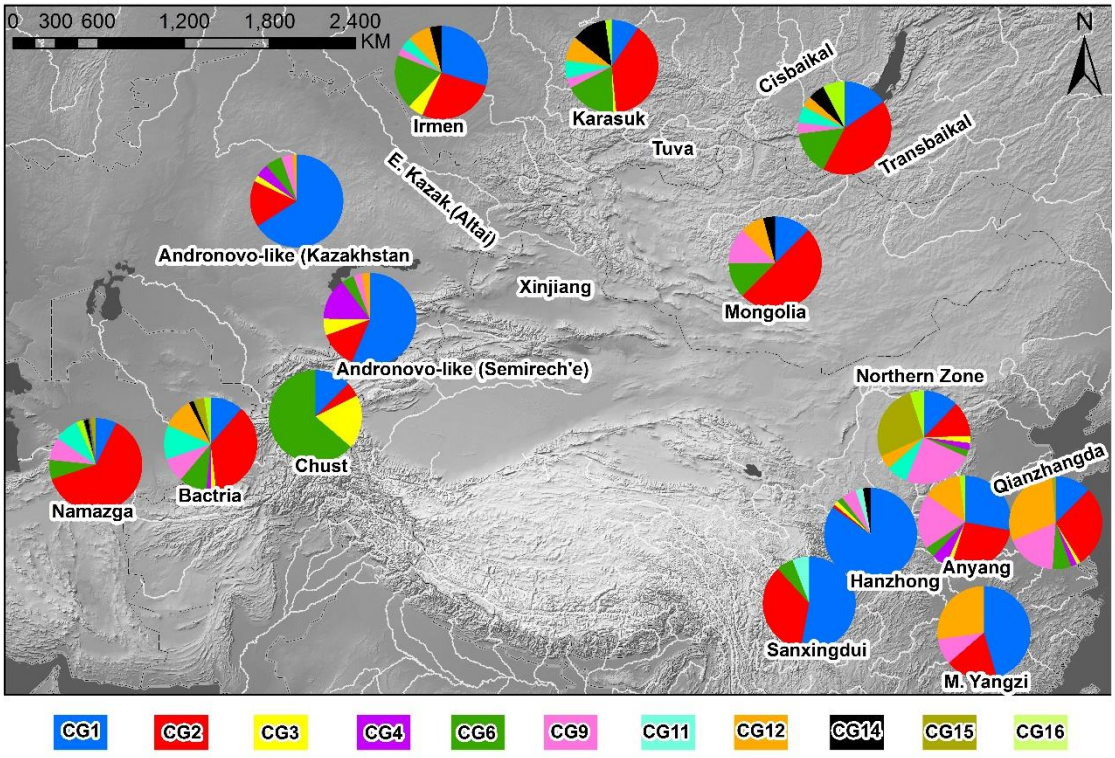


Figure 6.4 Map showing spatial distribution of copper groups during the Final Bronze Age

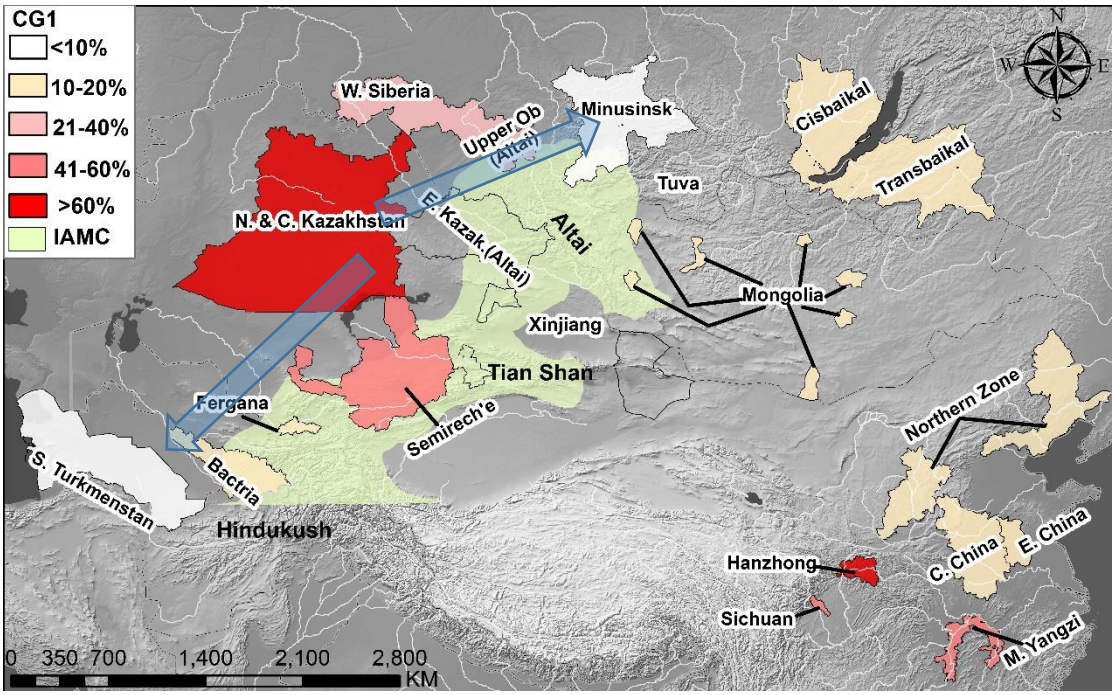


Figure 6.5 Map showing spatial distribution of CG1 during the Final Bronze Age.

This reflects the decrease in pure copper production further away from the main copper source (Kazakhstan). Likewise, a similar diminishing pattern can be identified along the southward movement from Semirech'e to southern Turkmenistan. Surprisingly, these northern and southern pathways of metal flow seem to accord with the foothills

of the mountain ranges from the Altai to Hindu Kush Mountains of Afghanistan. Frachetti (2012: 16) has termed this route as the Inner Asian Mountain Corridor (IAMC) driven by the ecological pattern of transhumant seasonal mobility, which connected local communities in the multi-faceted socio-economic interactions. As mountain-adapted herders conducted seasonal movement along the proposed IAMC, both metals and metalworking technologists could potentially be transferred from one group to another.

In addition to CG1, arsenic-only copper (CG2) also represents a key agent of metal exchange along the IAMC. Two major CG2 production regions can be delineated in eastern Eurasia: the Karasuk culture in the Minusinsk and the Namazga VI in southern Turkmenistan (Figure 6.6). While CG1 metals flow out of Kazakhstan, CG2 objects "flow into" Kazakhstan. In the north, the Minusinsk Basin contains around 37% of CG2 in the total assemblage, yet this ratio is diminishing southwards, from the Irmen culture (26.7%) to N. and C. Kazakhstan (15.6%). Similarly in the south, there is a tendency of decreasing CG2 from southern Turkmenistan, Bactria to Semirech'e and eventually to N. and C. Kazakhstan. These patterns become rather distinctive as we cross-compare the regional distribution of arsenic values. Figure 6.7 displays high levels of arsenic in both Karasuk and Namazga VI/Bactrian artefacts as opposed to low-arsenic (<0.5%) metals in Kazakhstan. This suggests that CG2 metals from Kazakhstan are likely made of recycled copper from both high-arsenic sources, and arsenic is depleted due to oxidative loss in the reoccurring copper melt.

Unlike inter-regional flow of CG1 and CG2 metals, other copper groups tend to be restricted to a regional scale. As shown in Figure 6.8, arsenic-antimony copper (CG6) is an essential component of Karasuk, Irmen and Fergana metalwork (Although Lake Baikal and Mongolia could be another potential sources, the data is currently too few to draw any further conclusions). CG6 metals from the Minusinsk Basin and western Siberia may be closely related due to their geographical affinity. A possible link between their object chemistry is shown by their arsenic levels (Figure 6.9, top). Karasuk metals are of high arsenic as opposed to depleted arsenic concentrations in the Irmen objects. The re-use of Minusinsk metals by the Irmen communities seems likely.

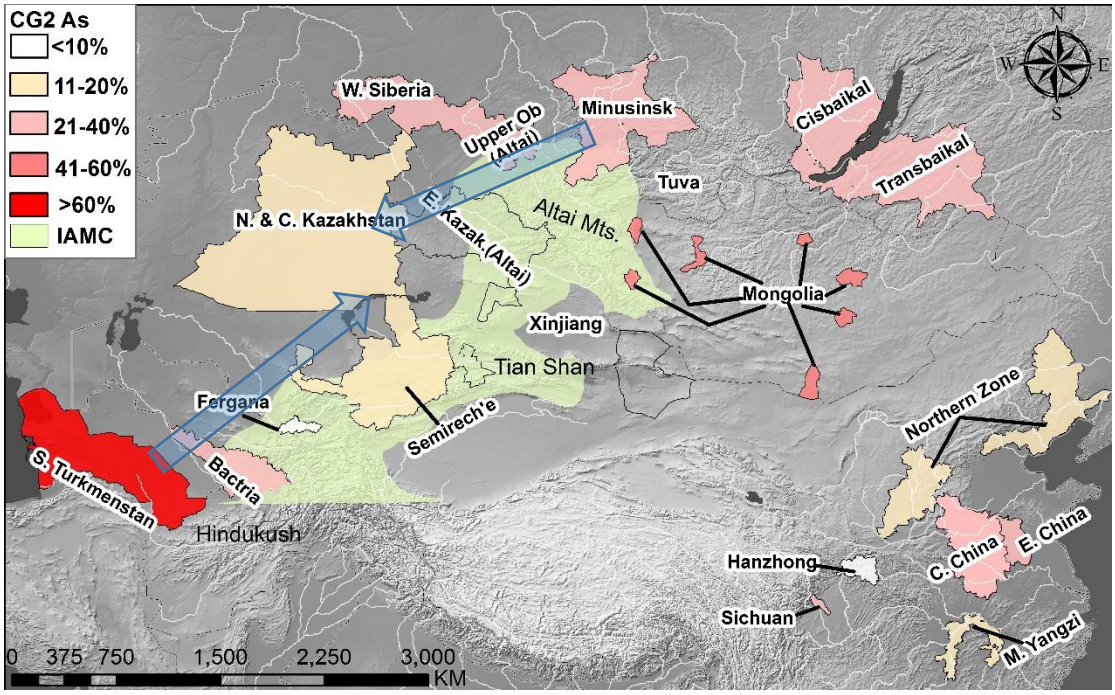


Figure 6.6 Map showing spatial distribution of CG2 during the Final Bronze Age

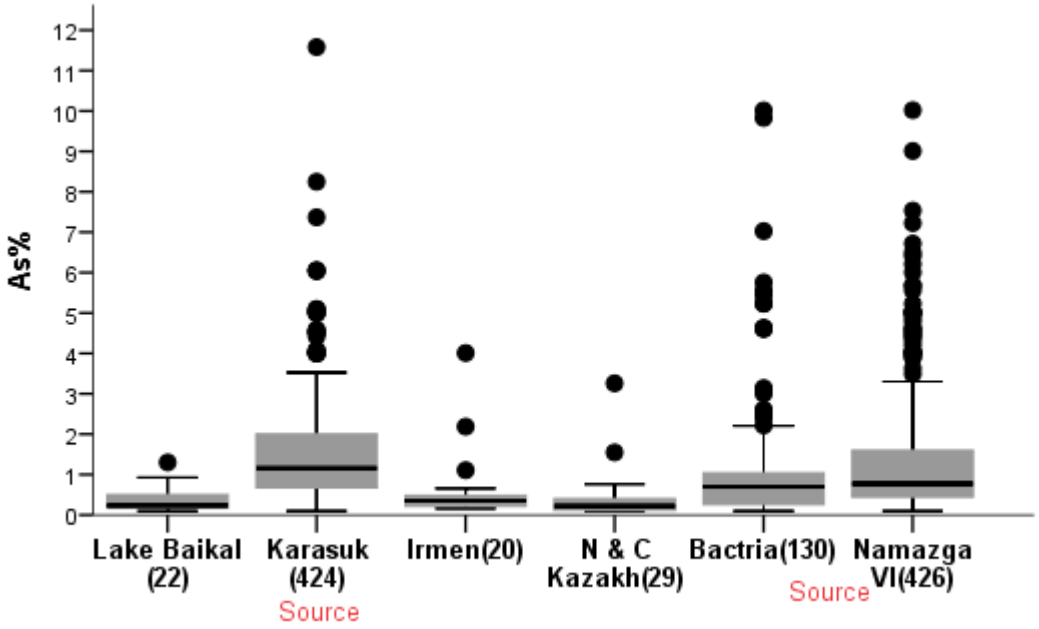


Figure 6.7 Distribution of arsenic in the CG2 metals during the Final Bronze Age.

Apart from CG6 production in the north, the Chust culture in the Fergana valley serves as a unique arsenic-antimony production centre. This is manifested by the fact that CG6 metals occupy a much higher proportion than any other regions (up to 65.2%) (Figure 6.8). Furthermore, high concentrations of arsenic and antimony in metals reflect the tendency of primary production (Figure 6.9). This chemical result accords with Kuz'mina's observation that the Fergana valley stands out as a distinctive metal-producing area exploited indigenous copper deposits rich in arsenic and antimony. It is

promising research direction investigating ancient mining and smelting sites in this region.

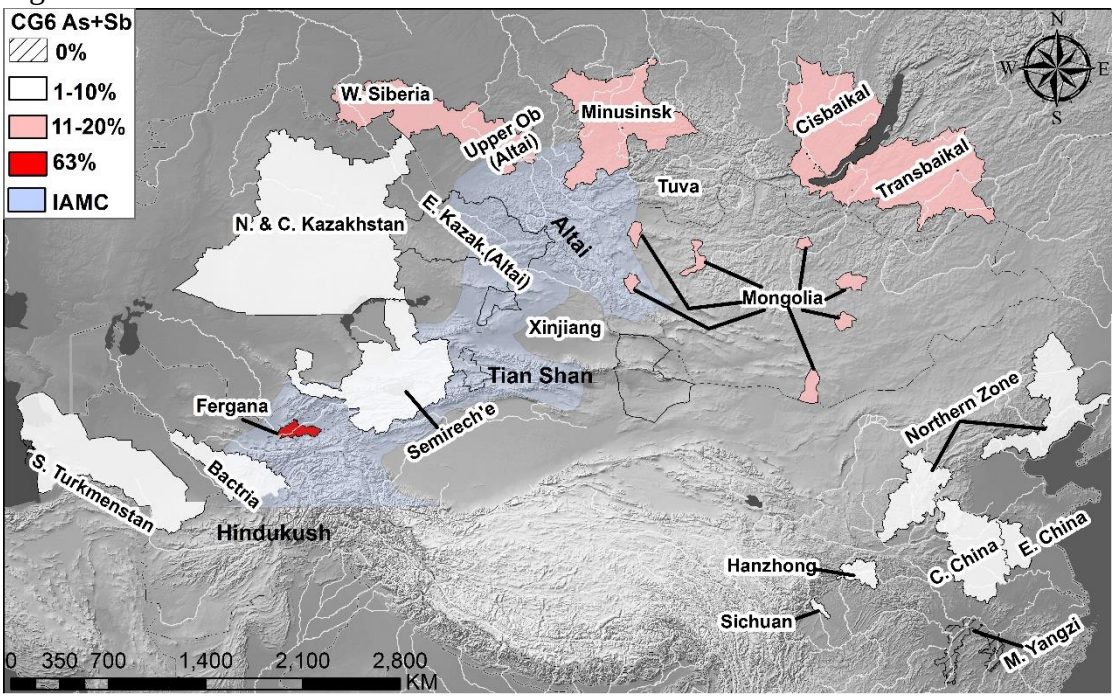


Figure 6.8 Map showing spatial distribution of CG6 during the Final Bronze Age.

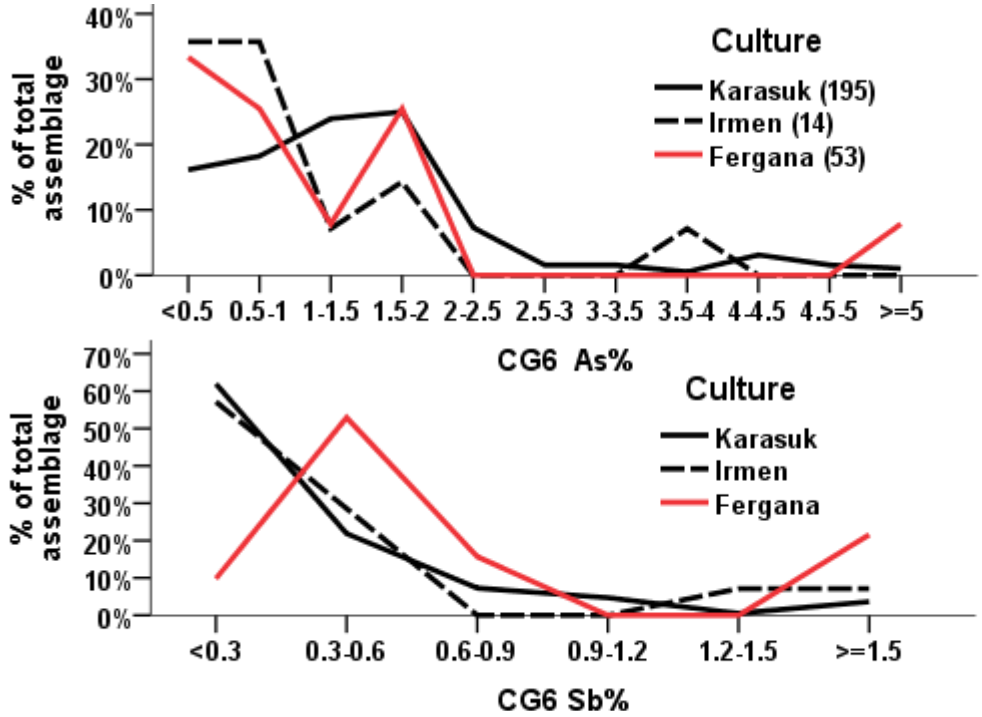


Figure 6.9 Distribution of arsenic (top) and antimony (bottom) in the CG6 metals during the Final Bronze Age.

Another important copper chemistry is characterised by nickel-bearing metals (CG11 & CG14) from the Minusinsk Basin and southern central Asia (Figure 6.10). Even though arsenic concentrations seem to be randomly distributed in CG11 metals, their

peaks usually lie above 1.5% arsenic (Figure 6.11, top). This suggests that arsenic-nickel copper can be considered as a primary metal unit in the Minusinsk, Bactria, and S. Turkmenistan. On the other hand, distribution of nickel content is similar across different regions, generally lower than 0.6% Ni (Figure 6.11, bottom).

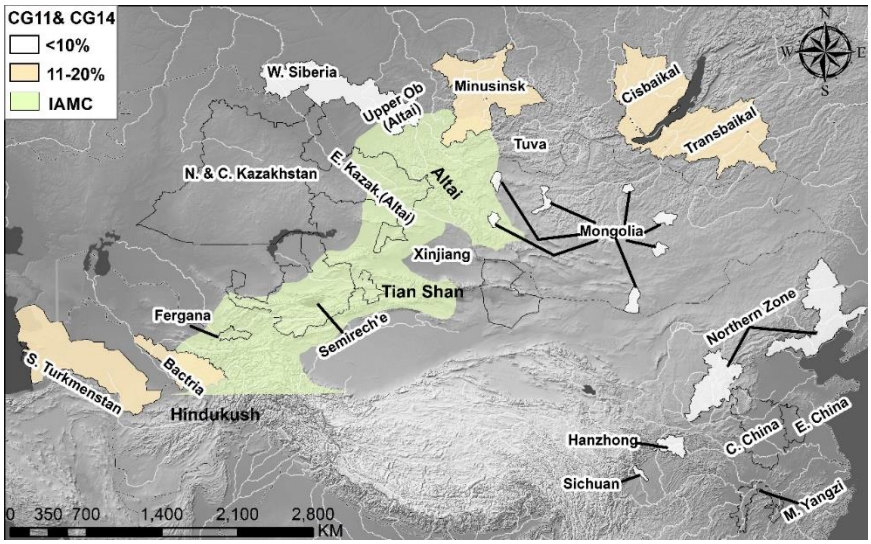


Figure 6.10 Map showing the ubiquity of CG11 and CG14 among the FBA assemblage.

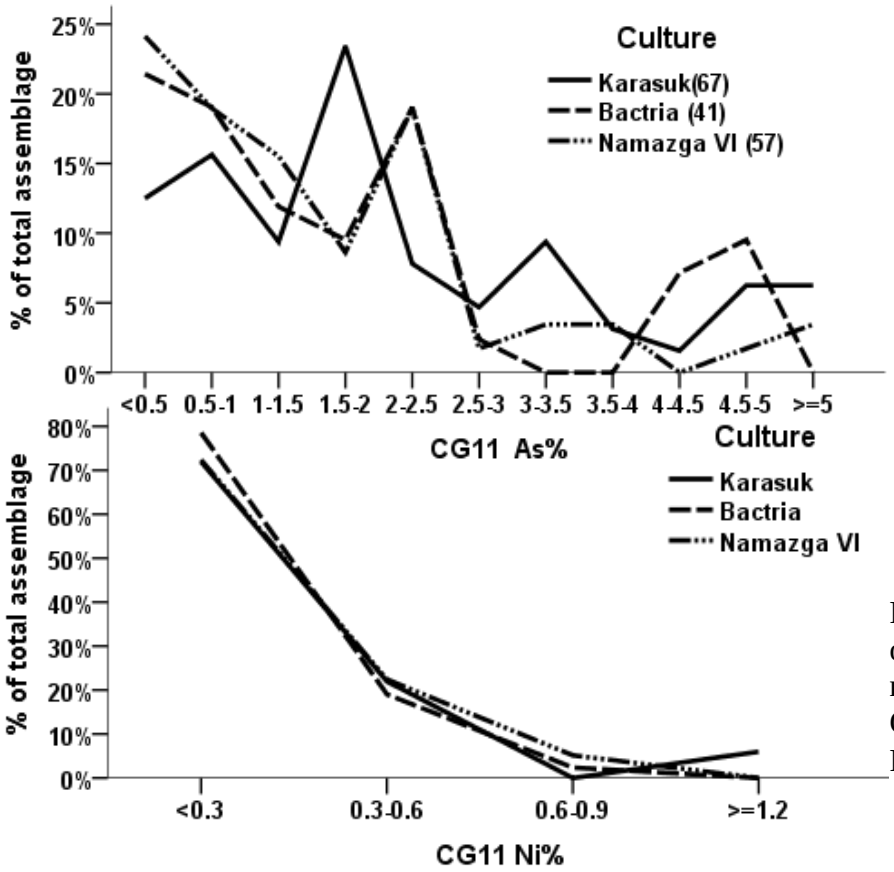


Figure 6.11 Distribution of arsenic (top) and nickel (bottom) in the CG11 metals during the Final Bronze Age.

Since nickel-containing copper objects appear in both the Minusinsk Basin and southern central Asia, it is worthwhile to explore whether they are related in any way or even come from the same source. The current archaeological evidence suggests they

were two different practices. Firstly, if we assume the flow of metal travelling along the Inner Asian Mountain Corridor, nickel-bearing copper should have existed in the intermediary zones (Kazakhstan or Semirech'e). However, the data suggests not. Nickel-containing copper more likely comes from ephemeral sources limited to a local scale: one in the Minusinsk and the other in southern central Asia. Secondly, copper-nickel sources are documented in both the northern steppe and southern arid zone. The As-Ni metals in the Minusinsk Basin probably originated from Tuva. The Khovu-Aqsa mine, with rich copper-cobalt-nickel mineralisation, was initially exploited around the 12th century BC (as mentioned in the Chapter 3). On the other hand, As-Ni objects in Bactria and S. Turkmenistan were likely utilising copper from further south. As suggested by Cuénod (2012:280), contemporary southeast Iran and Oman copper primarily featured such As-Ni production. These were potential raw material for the nickel-bearing metals in southern central Asia.

Apart from nickel, the presence of silver in copper is also a diagnostic indicator for regional production. A small number of silver-containing metals (CG9 & CG12) are unique to the Bactrian metalwork. Most objects contain depleted arsenic content (<0.5%), reflecting certain degree of recycling (Figure 6.12). Silver can either come from the smelting of silver-rich copper ores, or from the added lead (such as galena, a lead sulphide mineral with appreciable amount of silver). The latter scenario is more probable for the central Asian assemblage because a small group of metal artefacts are made of leaded copper (See Section 6.5.3).

6.3.2 Route two: the Mongolian arid zone

Besides the pathway along the IAMC, the transfer of metals seems to adopt the other route from the Minusinsk Basin, and through the Mongolian Gobi desert into the Northern Zone of China. This passage is reflected by the co-existence of arsenic-only copper (CG2) and arsenic-silver copper (CG9) in Mongolia. CG2 represents a primary feature of the Minusinsk production, while copper with trace amounts of silver is commonly reported in Chinese leaded tin bronzes (see Section 6.3.3). Minusinsk metals generally contain high arsenic concentrations as opposed to low-arsenic Mongolian objects probably made from recycling or mixing of metal (Figure 6.13).

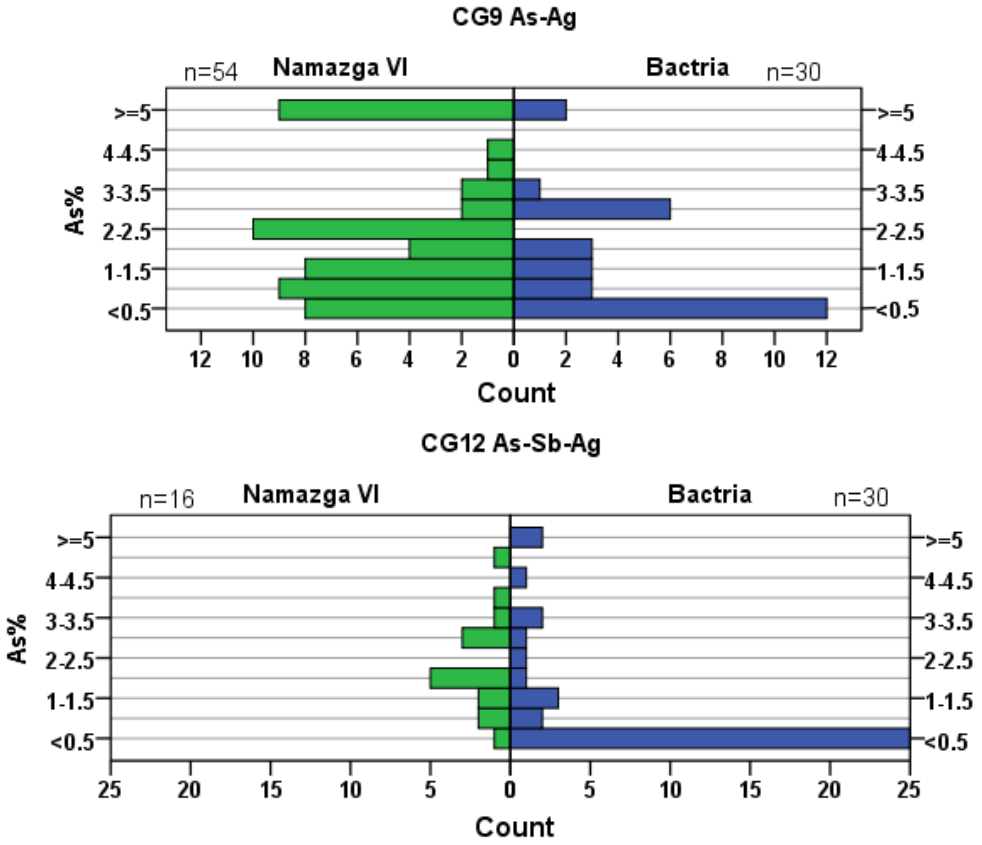


Figure 6.12 Comparison of arsenic content in CG9 (top) and CG12 (bottom) metals from Turkmenistan and Bactria.

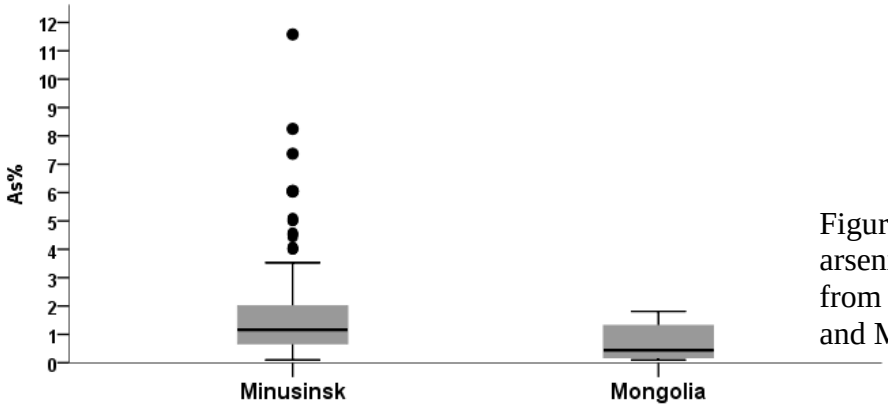


Figure 6.13 Distribution of arsenic in the CG2 metals from the Minusinsk (n=424) and Mongolia (n=12).

On the other hand, Mongolia may also receive metals from China, where leaded tin bronzes generally bear trace levels of silver. Silver-bearing copper (CG9 and CG12) actually serves as the principal component of the late-Shang metallurgy in the Central Plains of China. It is a promising attempt to connect Mongolian CG9 objects with Chinese supplies as more analytical data from Mongolia and the Northern Zone becomes available in future.

The presence of nickel in some Northern Zone artefacts (CG15) deserves special attention as copper with this trace element is of the Minusinsk origin. Given that nickel-containing objects are extremely rare in all Chinese specimens, I suspect this constituent could be introduced into the Northern Zone metals through recycling/mixing of

Karasuk artefacts from the Minusinsk Basin. Typologically, there are many Karasuk copies uncovered from the Northern Zone, which witnesses an intense contact with the Steppe (Wu 2008).

6.3.3 Circulation of metals in ancient China

Although the study of Chinese bronzes is beyond the scope of this thesis, it is worthwhile to briefly outline chemical signatures of Chinese metallurgy as the Final Bronze Age has shown an increasing level of interactions between ancient China and the Eurasian steppe. The late-Shang (Anyang) culture in the Central Plains of China, with its sophisticated piece-mould bronze casting for ritual vessels, had formed a unique socio-political organisation in eastern Asia (Barnard &Tamotsu 1975). Meanwhile, the bronze-producing communities in eastern China (Qianzhangda), the Hanzhong Basin, Sichuan (Sanxingdui) and Middle Yangzi also contribute to the diversity of ancient Chinese bronzes.

According to Figure 6.4, Hanzhong has the largest pure copper production (CG1) among the whole Chinese specimens (nearly 80%). This ratio is gradually diminishing in Sichuan and the Middle Yangzi, and eventually becomes relatively insignificant in the Central Plains. As both Hanzhong and Sichuan are situated in the Yangzi river system, the transportation of CG1 might have taken routes along waterways. Studies on the style of Chinese bronzes also demonstrate a close link between societies along the Yangzi River (Bagley 1999).

Arsenic-only artefacts (CG2) are widespread in Anyang, Qianzhangda and Sanxingdui sites, and their arsenic concentrations are rather low (As<0.5%, see Figure 6.6 & 6.14). I suspect that the refining process might have been carried out by ancient Chinese metalworkers, leaving low arsenic in the finished objects. In this regard, identifying the recycling of Chinese bronzes becomes extremely difficult due to the underlying thermodynamic properties of arsenic. Arsenic at low concentrations has a relatively strong affinity to copper and becomes difficult to be removed by simply firing purification. As a result, evidence for the recycling of low-arsenic Chinese metals is invisible. We can; however, combine lead isotopes and trace elements to address the possibility of metal mixing from different sources. Liu (in prep.) has demonstrated that the so-called “highly radiogenic lead” from the Sanxingdui bronze, defined by Jin (2008), corresponds to the arsenic-only copper group (CG2) in the Anyang bronzes.

This may suggest a possible metal exchange between Sichuan and the Central Plains through the use of CG2 metals.

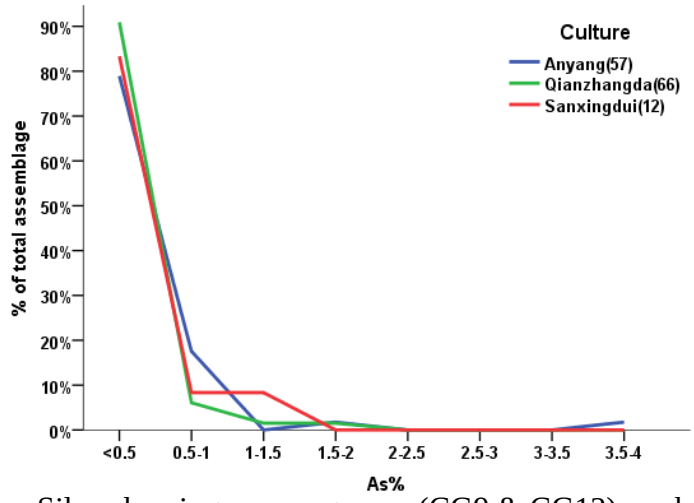


Figure 6.14 Distribution of arsenic in the CG2 metals from ancient Chinese bronzes.

Silver-bearing copper groups (CG9 & CG12) mark the metal production in the Central Plains of China (Figure 6.15). This copper chemistry occupies around 30 to 46% of total bronze artefacts from Anyang and Qianzhangda. The arsenic content in these specimens shares an identical distribution pattern, suggesting a common origin of metalworking tradition (Figure 6.16). The presence of silver had become a constant companion of Chinese bronzes over a millennium (c.1500-300 BC). It is assumed that silver is brought into copper alloys through the intentional addition of lead. As leaded tin-bronze was the alloy of choice in ancient China, trace amounts of silver were inevitably present in Chinese artefacts (see Section 6.5.3).

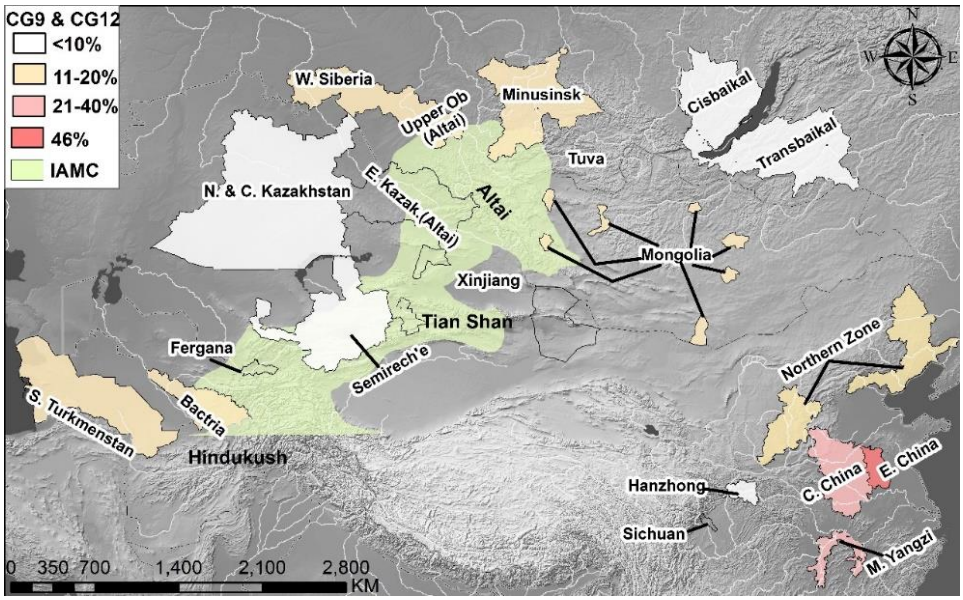


Figure 6.2 Ubiquity of silver-bearing copper (CG9&CG12) across the LBA assemblage.

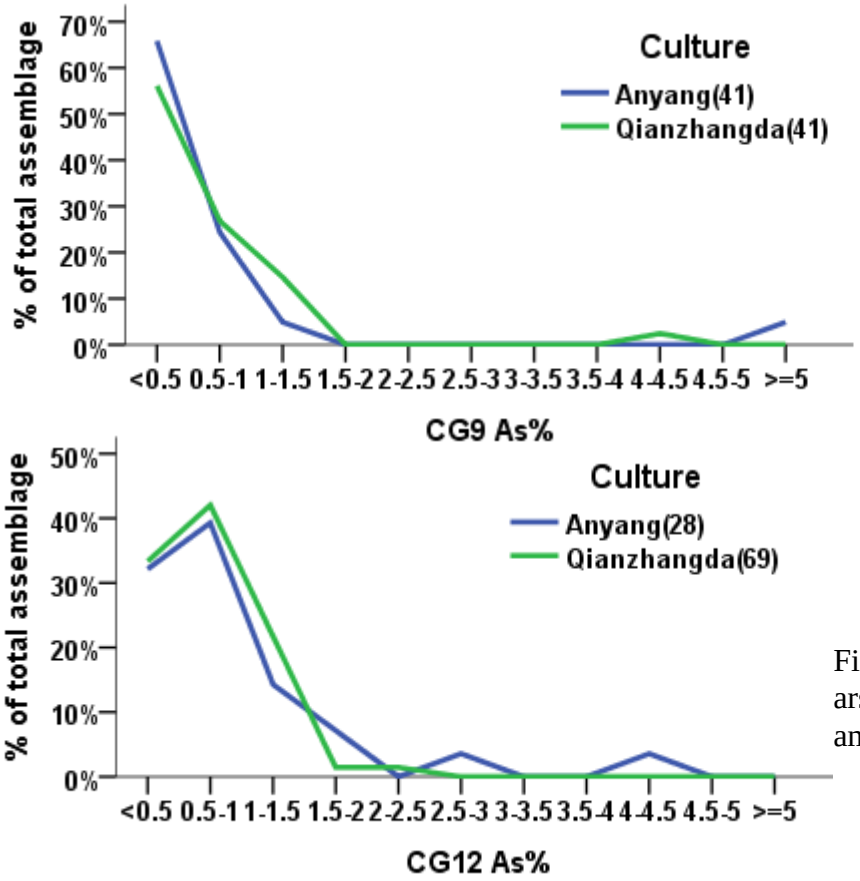


Figure 6.3 Distribution of arsenic in the CG9 and CG12 among Chinese bronzes.

6.4 Alloying practices in the Final Bronze Age of eastern Eurasia

Eastern Eurasia during the Final Bronze Age was marked by three alloying traditions: (1) tin-bronze in Kazakhstan and Mongolia; (2) arsenical copper in the Minusisnk Basin and southern Central Asia; (3) leaded tin-bronze in central China and its adjacent areas (Table 6.5). Alloying practices in the intermediate regions (e.g. the Irmen culture in the Upper Ob/W. Siberia) tend to bear a mixing character.

Table 6.5 Ubiquity of alloy types across regions/cultures during the Final Bronze Age.

c. 1400-900 BC	Cu	Cu-Sn	Cu-Sn-Pb	Cu-Pb	Total N
Karasuk	**73.6%**	18.7%	2.2%	3.9%	1128
Lake Baikal	**50.0%**	37.0%	11.1%	1.9%	54
Irmen	**59.2%**	32.9%	3.9%	2.6%	76
Mongolia	16.7%	**73.3%**	10.0%		30
E. Kazak.	6.3%	**87.5%**	6.3%		32
N. & C. KazaK.	35.5%	**58.5%**	3.0%	0.4%	234
S. Kazak. & Kyrgyz.	27.5%	**60.0%**	6.3%	2.5%	80
Fergana	**60.7%**	20.0%	13.1%	2.1%	145
Bactria	45.2%	38.2%	5.6%	10.1%	356
Namazga VI	49.0%	32.9%	5.3%	11.7%	720
Xinjiang	36.7%	46.7%	10.0%	6.7%	30
N. Zone	6.7%	25.6%	**65.4%**	2.4%	254
C. China	3.0%	29.6%	**59.9%**	7.5%	706
E. China		17.0%	**78.7%**	4.3%	235
Hanzhong	13.3%	26.5%	**57.1%**	3.1%	196
Sanxingdui	3.8%	14.1%	**66.7%**	15.4%	78
M. Yangzi	41.7%	16.7%	**41.7%**		12
		Sn>1%	Sn & Pb>1%	Pb>1%	**4366**

6.4.1 Tin-bronze

According to ubiquity distribution of alloy types, E. Kazakhstan and Mongolia are the two most important tin-bronze production regions (>80%, Figure 6.17). E. Kazakshtan had been recognised as one of the most essential mining districts for the exploitation of cassiterite deposits in antiquity (Stöllner *et al.* 2011). Mongolia, on the other hand, possesses abundant alluvial tin along the Onon River of northeastern Mongolia, connecting tin deposits in the Transbaikal (Sergevva 1981:52). Mongolia, especially its eastern part, may play an important role in providing tin for the Baikal region and even the Northern Zone of China.

Outside these tin-bronze "hotspots", the ubiquity of tin-bronze gradually falls off when moving away from the potential primary sources in E. Kazakhstan. To the south, N. & C. Kazakhstan and Semirech'e have approximately 60% of total objects belonging to copper-tin alloys, followed by 38% in Bactria, and then 33% in S. Turkmenistan. To the north, the ratio of tin-bronze decreases in the Upper Ob (33%) and further drops to 18% in the Minusinsk Basin. This north-south movement of tin corresponds to the flow of copper (CG1 and CG2) along the IAMC (see Figure 6.6 & 6.17). The Altai and relevant sites in Kazakhstan serve as the crucial tin-bronze supplier to tin-less regions. Alternatively, Mongolian tin may also contribute to the tin-bronze production in the Baikal region and northern Xinjiang, but these routes remain hypothetical as very little chemical data is available in these regions.

The previous section has shown how a simple division between presence and absence of tin enables us to derive possible movement of tin-bronze. Distribution of tin profiles may further support this idea of north-south transportation along the IAMC (Figure 6.18). E. Kazakhstan, as a candidate for primary tin extraction, shows a bi-modal distribution of tin: a peak with lower amount of tin (around 1-7%) and the other with higher tin (around 10-13%). These two ranges reflect a combination of human choices in making copper-tin alloys. Ancient metalworkers may produce tin bronzes for the sake of functionality (colour, hardness and workability), and thus final tin concentrations may vary depending on different artefact types. Alternatively, low-tin bronzes could be the result of recycling or mixing with tin-less copper. In E. Kazakhstan, high-tin bronzes (10-13%) represent genuinely primary production. N. & C. Kazakhstan artefacts also reveal such high-tin distribution similar to that of E. Kazakhstan, but there is an increasing amount of objects with tin lower than 1%.

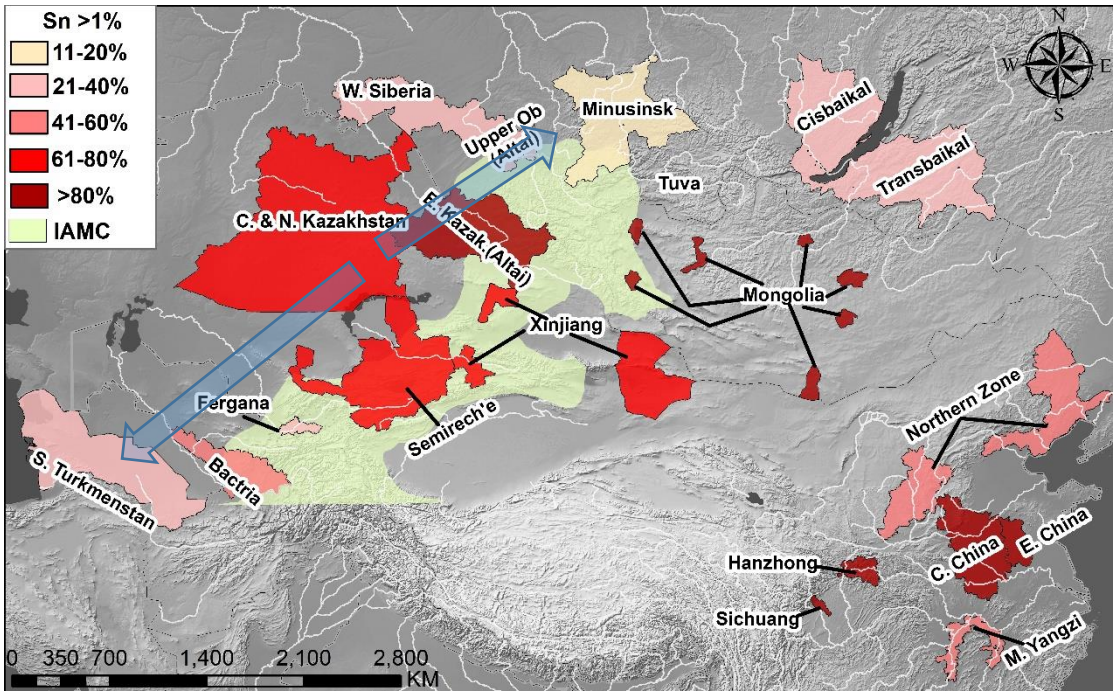


Figure 6.17 Map showing spatial distribution of metal artefact with over 1% tin during the FBA.

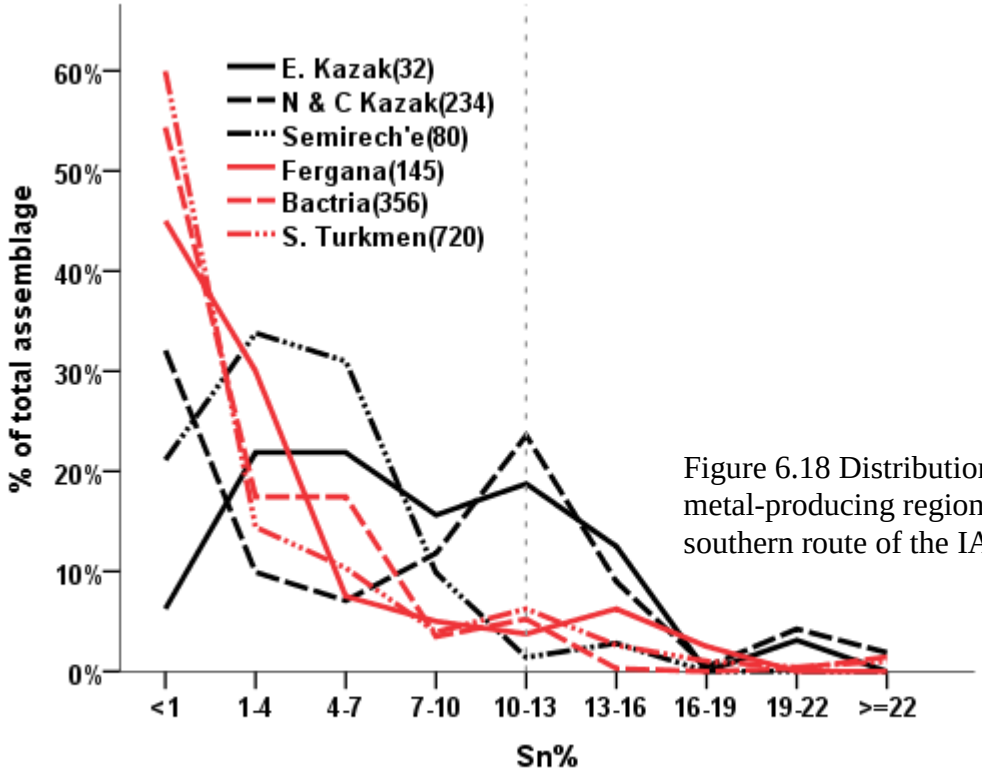


Figure 6.18 Distribution of tin across metal-producing regions along the southern route of the IAMC.

On the one hand, overlapping high-tin peaks between E. Kazakhstan and N. & C. Kazakhstan indicate the direct transportation of tin ingots and/or finished products from E. Kazakhstan. The similar metalworking practice is probably shared by two regions.

On the other hand, low-tin bronzes in N. & C. Kazakhstan reflect the recycling or mixing of metals.

When moving away from the primary tin in Kazakhstan, we encounter diminishing tin concentrations in Semirech'e. The primary tin peak (10-13%) disappears, and is replaced by low-tin peak (1-7%). This further depletion of tin takes place in the regions of Fergana, Bactria and S. Turkmenistan, where nearly 50% of the metal objects contain less than 1% tin. This suggests a growing tendency towards the re-use of tin-bronze as the distance from the Altai sources increases. A similar pattern of tin losses occurs in tin-bronze artefacts distributed along the northern pathway (Figure 6.19). It begins with high-tin metals from Kazakhstan, and then followed by Irmen tin-bronze in the Upper Ob and western Siberia, where objects mostly have less than 7% tin. Ultimately, copper-tin alloys undergo serious recycling in the Minusinsk Basin, with over 70% of analyses less than 1% tin.

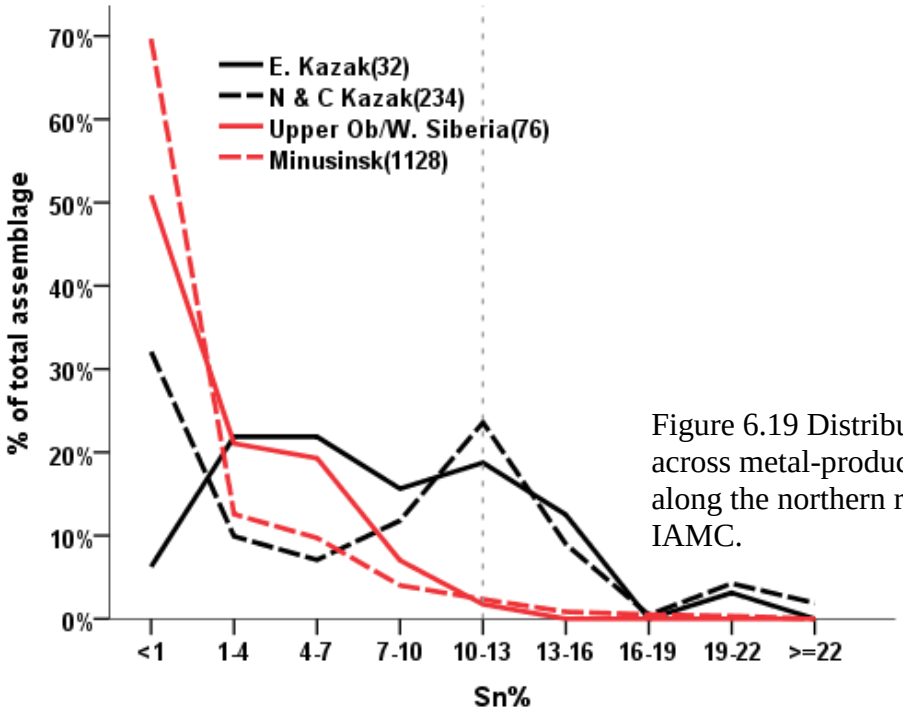


Figure 6.19 Distribution of tin across metal-producing regions along the northern route of the IAMC.

6.4.2 Arsenical copper

The transmission of arsenical copper takes the opposite direction to that of tin bronze. Figure 6.20 plots the ubiquity of copper-based objects with more than 1% arsenic. The Minusinsk Basin and southern Central Asia stand out as hot spots, and from which the proportion of arsenical copper objects is gradually diminishing towards tin-rich Kazakhstan. Apart from these two regions, Xinjiang may also play an important role in

the network of copper-arsenic alloys, yet the current data is insufficient to draw any further conclusions.

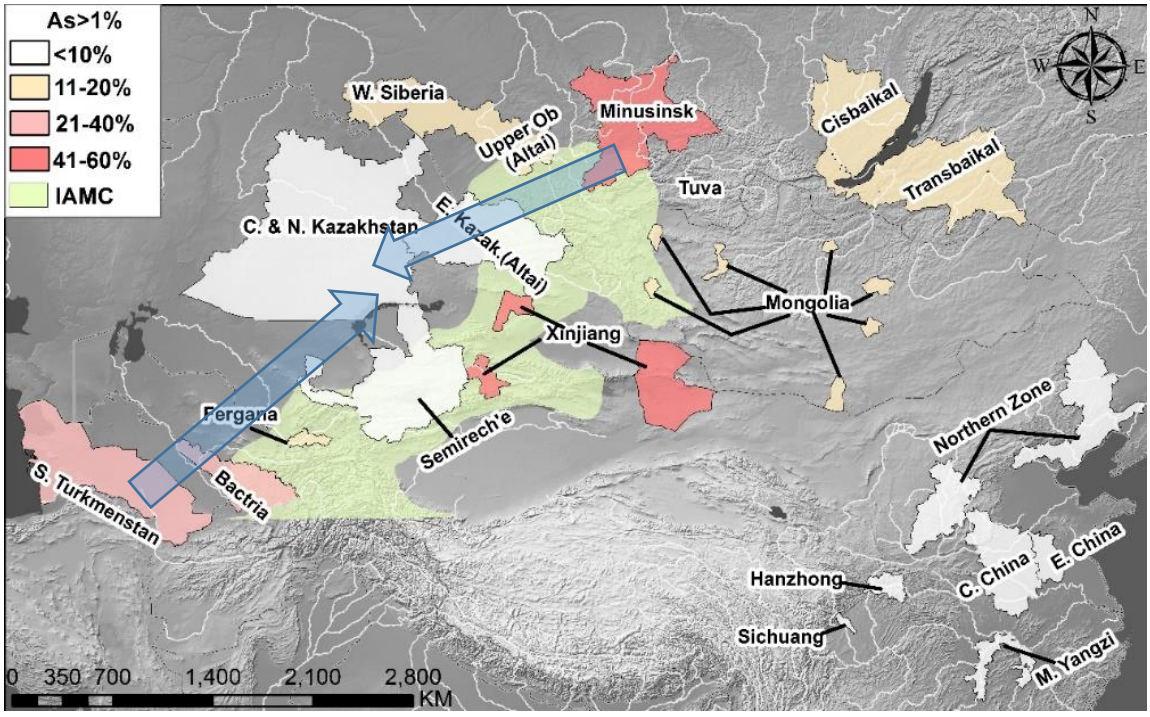


Figure 6.20 Map showing distribution of arsenical copper during the FBA.

Distribution of arsenic profiles reveals several "transitional" metal-using regions in which the mixture between arsenical copper and tin-bronze takes place to form the end-products with intermediate arsenic concentrations. To the north, the Irmen tin-bronze artefacts are composed of arsenic levels intermediate between tin-rich Kazakhstan and arsenic-rich Minusinsk copper-tin alloys (Figure 6.21, top). Likewise, to the south the arsenic content in Bactrian tin bronzes falls between tin-rich (Kazakhstan) and arsenic-rich regions (S. Turkmenistan) (Figure 6.21, bottom). As a result, both Irmen and Bactrian communities possibly served as intermediaries to transfer different alloy types across the northern steppe or southern oasis zones.

6.4.3 Leaded tin-bronze

The last crucial copper-alloy is copper with lead as a major alloying element (both leaded copper and leaded tin-bronze). The best example is the Chinese leaded tin-bronze which has been a subject of study for decades. The primary goal to explore the chemistry of Chinese bronzes is to find the metallurgical link between ancient China and the Eurasian steppe. I argue that Chinese bronze vessels were carried north and re-cast into steppe-style objects. This statement is supported by a gradual diminishing proportion of leaded metals from central China, through the Northern Zone, then

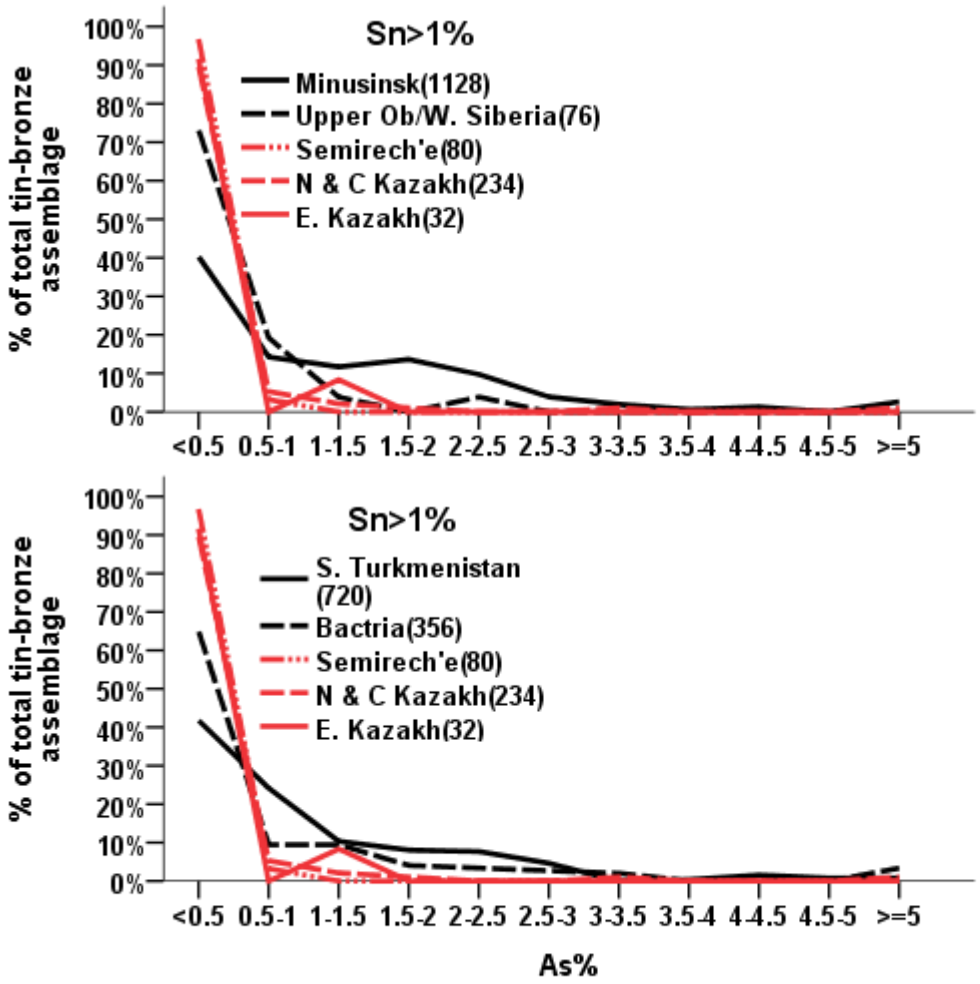


Figure 6.21 Distribution of arsenic in tin-bronze objects along the IAMC.

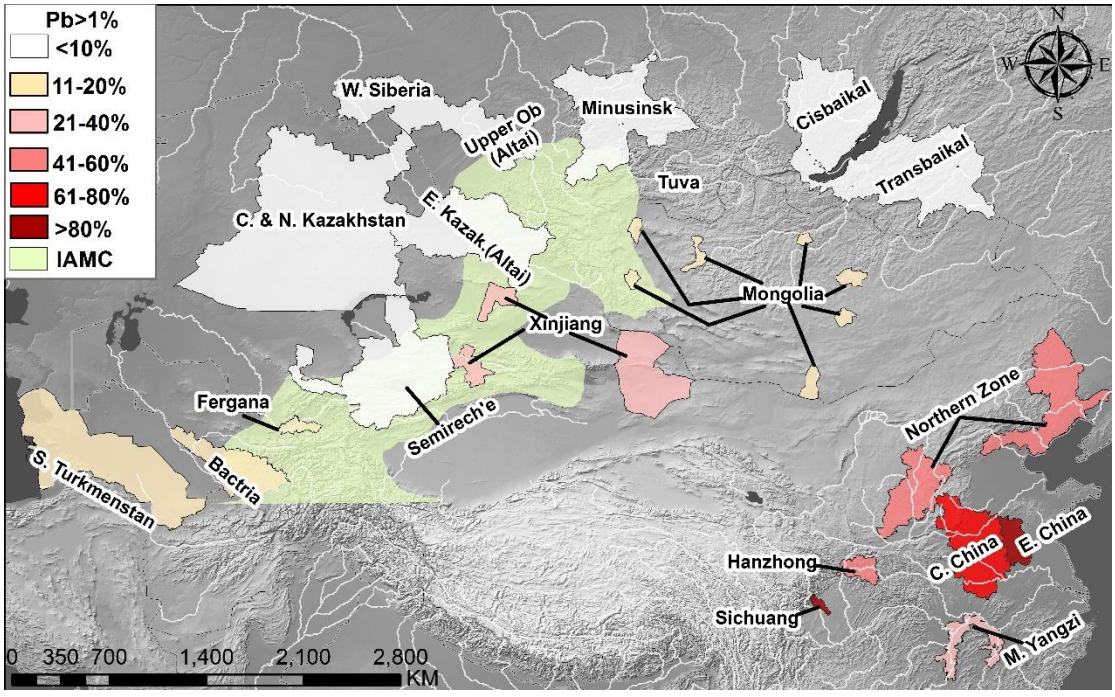


Figure 6.22 Map showing distribution of leaded metals during the FBA.

Mongolia and Xinjiang, and this copper alloy eventually becomes insignificant in the rest of the steppe zone (Figure 6.22). Rather than a deliberate lead addition, the lead

content in Mongolian and Xinjiang objects is brought in by the mixture between copper and Chinese leaded tin bronzes, as suggested by relatively low lead concentrations (Figure 6.23). The Northern Zone, on the other hand, was a frontier region between the Steppe and the Central Plains of China. It is interesting to notice that while artefacts in the Northern Zone mainly feature steppe characteristics (such as single-bladed knives, shaft-hole axes, helmets, zoomorphic ornaments etc.), their chemical composition is favoured by leaded tin-bronze instead of commonly seen arsenical copper or tin-bronze used by the steppe communities. This suggests the northerners were likely to adopt the leaded tradition from the Central Plains. This observation becomes more convincing when we explore the variation in lead isotope ratios of the Northern Zone metals (see Section 6.5.3).

Another separate region for leaded metals is situated in southern Central Asia. The proportion of such alloys (both leaded copper and leaded tin-bronze) represents no more than 15% of the total assemblage, and the lead content is generally less than 3% (Figure 6.24). As a result, lead could arguably be brought into end-products through smelting of copper ores containing lead or/and recycling of high-lead artefacts from elsewhere.

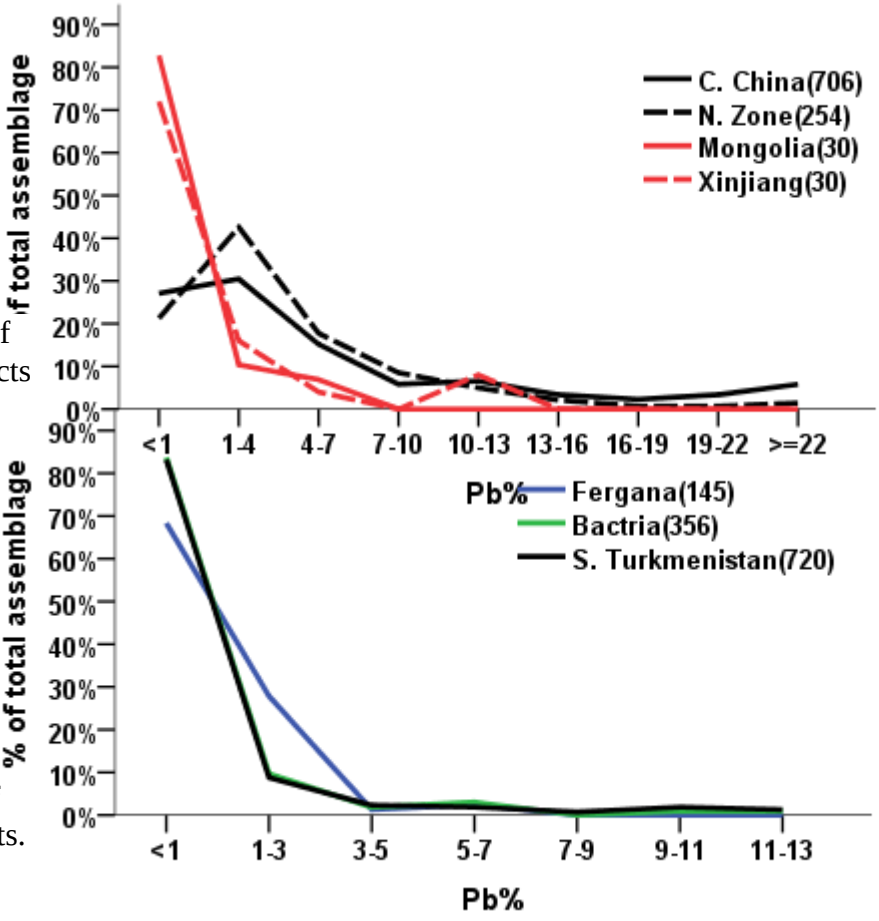


Figure 6.23 Distribution of lead in eastern Asian objects

Figure 6.24 Distribution of lead in central Asian objects.

6.4.4 Alloy types in conjunction with copper groups

Combining alloying elements with copper groups can provide another new perspective on how bronze metallurgy was transferred from one area to another during the Final Bronze Age. To begin with, we first pay attention to the distribution of tin concentrations across copper groups in N. & C. Kazakhstan (Figure 6.25). There seems to be no major difference between tin content in CG1 and CG2. Both of them are marked by a pronounced high-tin peak at 10-13% tin, suggesting a tendency of the primary production. In this regard, tin-bronze is probably made from the deliberate addition of metallic tin in copper.

As pure copper is the largest chemical group among the Kazakh specimens, CG1 tin-bronze artefacts are most likely to be traded into neighbouring tin-free areas. Distribution of tin in CG1 metals indeed indicates the spread of CG1 tin-bronze to the north and south. Both Irmen and Karasuk CG1 objects manifest a decreasing pattern of tin concentrations, which probably is the consequence of recycling of primary tin-bronze (Figure 6.26). Interestingly, some Karasuk specimens contain a high-tin signal (10-13% tin, roughly 10 objects). These might be direct imports from Kazakhstan or local artefacts made of Kazakhstani tin ingots.

The dissemination of CG1 tin-bronze to the south is evidenced by diminishing tin content in Semirech'e, Bactria and S. Turkmenistan (Figure 6.27). The losses of tin may be due to the fact that metalworkers in Semirech'e initially re-cast CG1 tin-bronze into locally designed artefacts. These metal objects were then passed onto southern Central Asia (traded, looted, exchanges, gifted, etc.), where local smiths re-modified them into preferred forms.

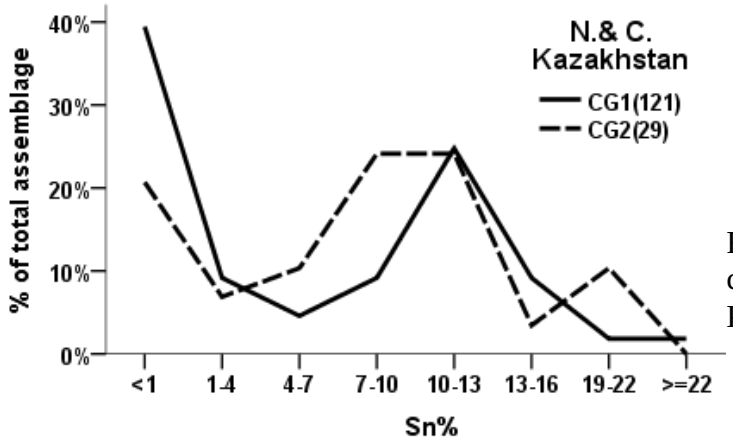


Figure 6.25 Distribution of tin across copper groups in N. & C. Kazakhstan.

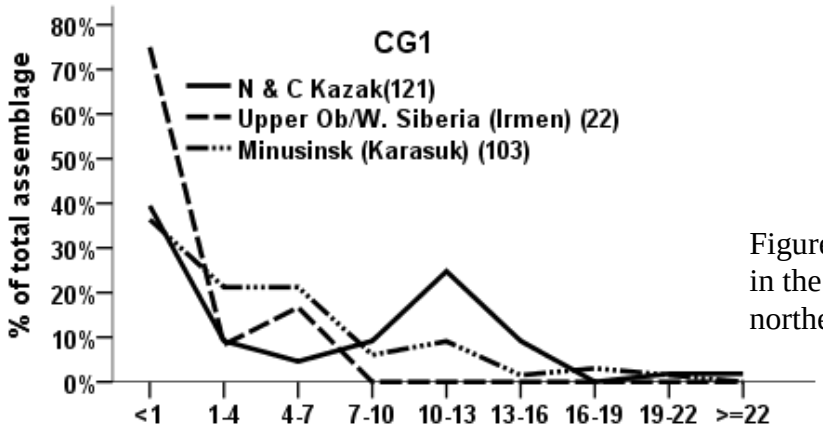


Figure 6.26 Distribution of tin in the CG1 artefacts along the northern route of the IAMC.

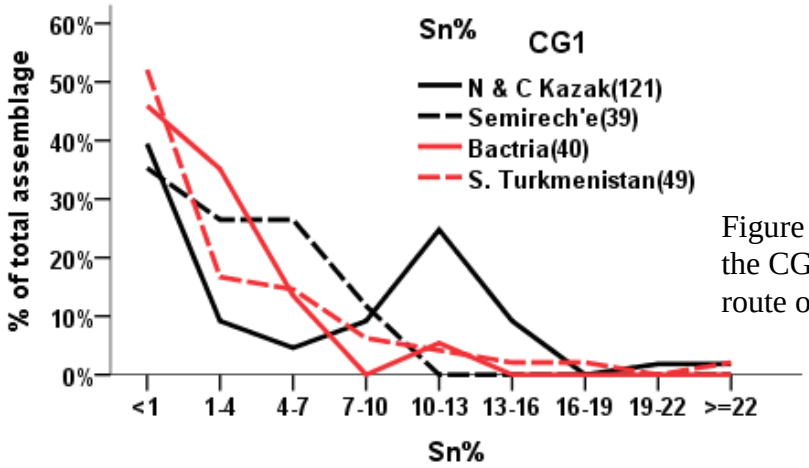


Figure 6.27 Distribution of tin in the CG1 objects along the southern route of the IAMC.

6.5 Object Typology and chemistry

So far we have endeavoured to trace the flow of copper and copper alloys regardless of their actual typologies. However, this may not reflect how metals were actually used in the past as objects with specific social meanings could be subject to certain alloying recipes. In other words, can different chemical signatures reflect artefacts' functionality (utilitarian items), significance (prestigious goods) or/and origins (local versus imported products)? It has been shown in previous chapters that tin-bronze was applied to the making of the Seima-Turbino weapons, whereas the Andronovo communities preferred decorative items made of copper-tin alloy. How did the Final Bronze Age societies value their metal artefacts?

6.5.1 Artefact chemistry across regions/cultures

Karasuk metal objects from the Minusinsk Basin can be roughly divided into four categories: weapons, singled-bladed knives, tools and personal adornments. Except for weapons for which we have only 9 specimens, the other types are quite numerous for a comparative study. Figure 6.28 depicts the distribution of arsenic across artefact types. Knives and ornaments share a similar arsenic profile, featuring an approximately normal distribution. Arsenic concentrations in tools also follow a similar trend but are slightly skewed to the left possibly due to more recycling. At present, it is difficult to

judge whether arsenic in the Karasuk metals is an accidental element or deliberate addition without knowing the chemistry of potential copper ores and slags in the Minusinsk Basin. However, it is fair to say that copper-arsenic alloys are generally applied to all artefacts regardless of their typology. This phenomenon may suggest that the Karasuk metalworkers had the access to appreciable copper-arsenic resources that could sustain the metal consumption within communities.

Likewise, the distribution of tin does not indicate a significant difference between categories (Figure 6.29). Although tools and decorative items contain slightly more tin (>7% tin) than that of knives, the majority of them are typically low-tin objects resulting from the recycling of tin-rich metals.

Metal artefacts from E. Kazakhstan, despite being very few in number, enclose invaluable information regarding how tin-bronze was circulated at this time. Figure 6.30 presents the distribution of tin across E. Kazakhstani object types. It is worth noticing that ingots are actually characterised by copper-tin alloys, with tin ranging from 4% to over 19%. This suggests that the transfer of tin to other tin-free areas is likely to be in the form of tin-bronze rather than metallic tin. Copper-tin ingots are also found in N. & C. Kazakhstan in which the tin concentration reaches up to around 13% (Figure 6.31). Meanwhile, there are also metal fragments containing more than 19% tin. These strands of evidence imply that the term "ingot" is not a strict concept in antiquity. Ancient metalworkers would take advantage of any broken metal pieces for bronze casting. Fragments recovered from both Bactria and S. Turkmenistan also show a range of tin between 1 and 13% tin (Figure 6.32 & 6.33). Since these tin values fall in the majority of Bactrian tin-bronze artefacts, small pieces of metal could have served as raw material.

Previous research has emphasised the positive correlation between decorative items and the use of tin-bronze in the development of ancient metallurgy (Pigott 2011). However, the overall distribution of tin in the Final Bronze Age of the eastern Eurasian steppe does not seem to support this statement. We often encounter a similar pattern of tin variations across different objects types (Figure 6.30 to 6.33). Although some ornaments are preferentially alloyed with high amount of tin (>13%), they usually appear as the exceptions rather than the rules.

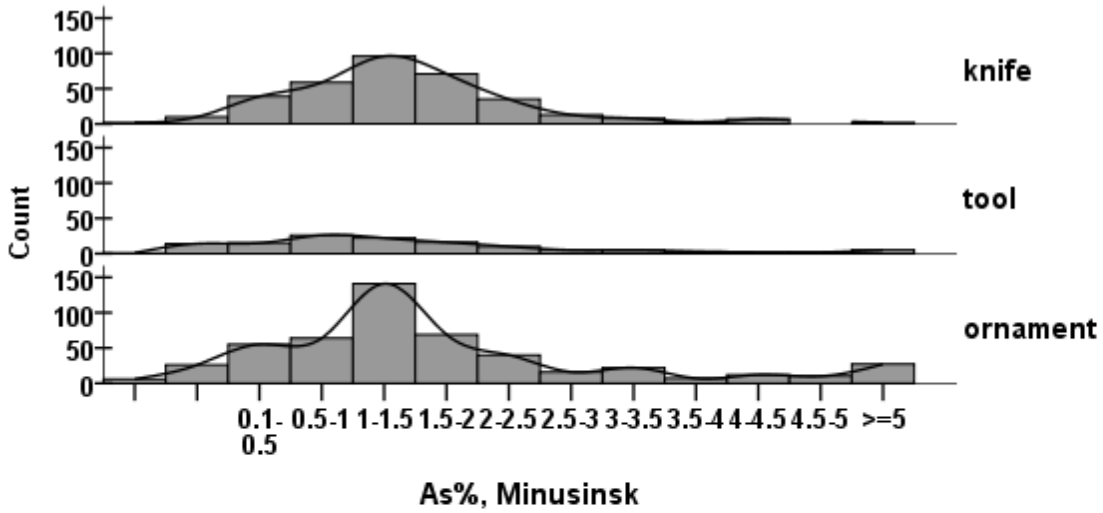


Figure 6.28 Distribution of arsenic across artefact types in the Minusinsk.

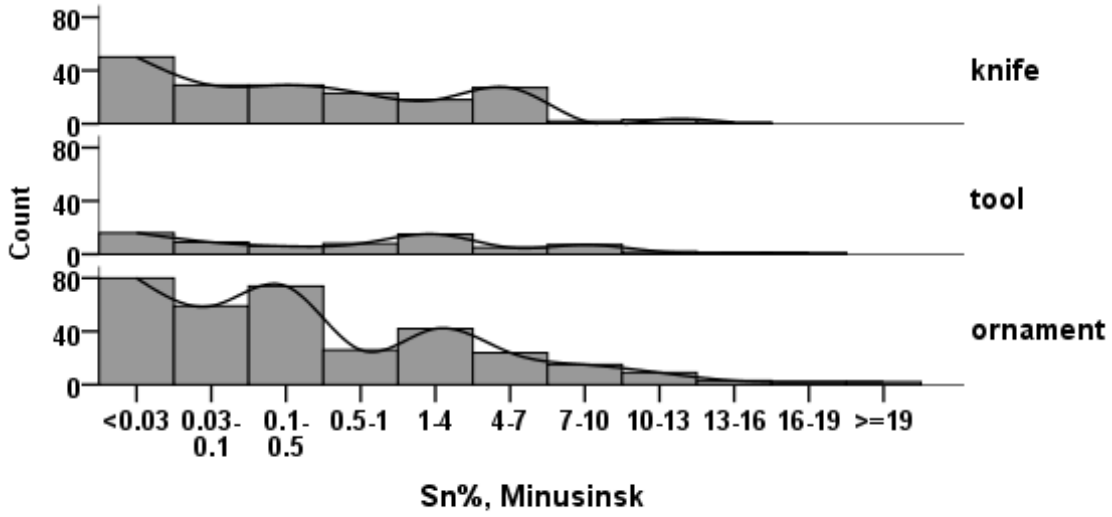


Figure 6.29 Distribution of tin across artefact types in the Minusinsk.

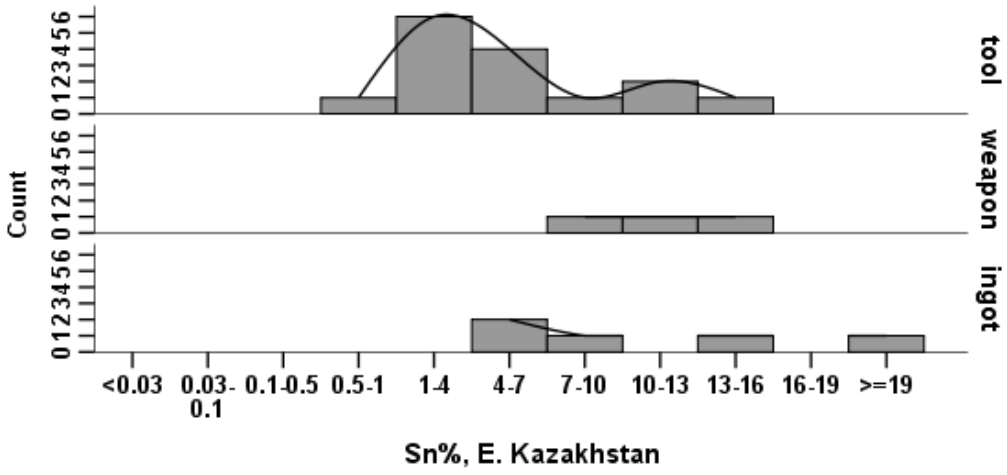


Figure 6.30 Distribution of tin across artefact types in E. Kazakhstan.

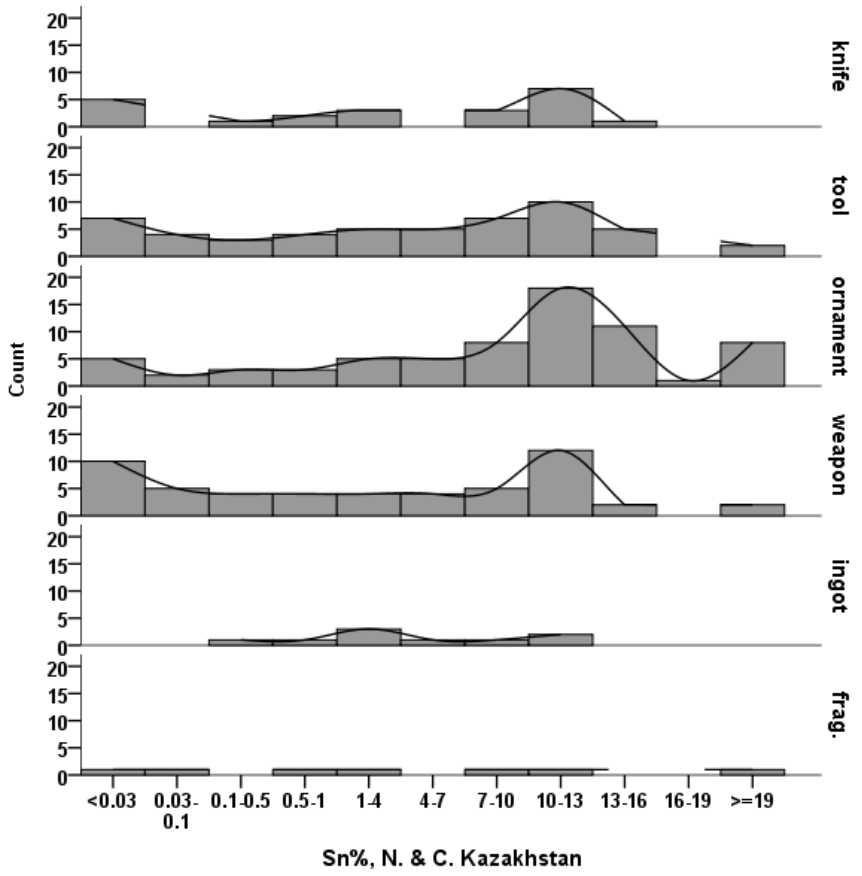


Figure 6.31 Distribution of tin across artefact types in N. & C. Kazakhstan.

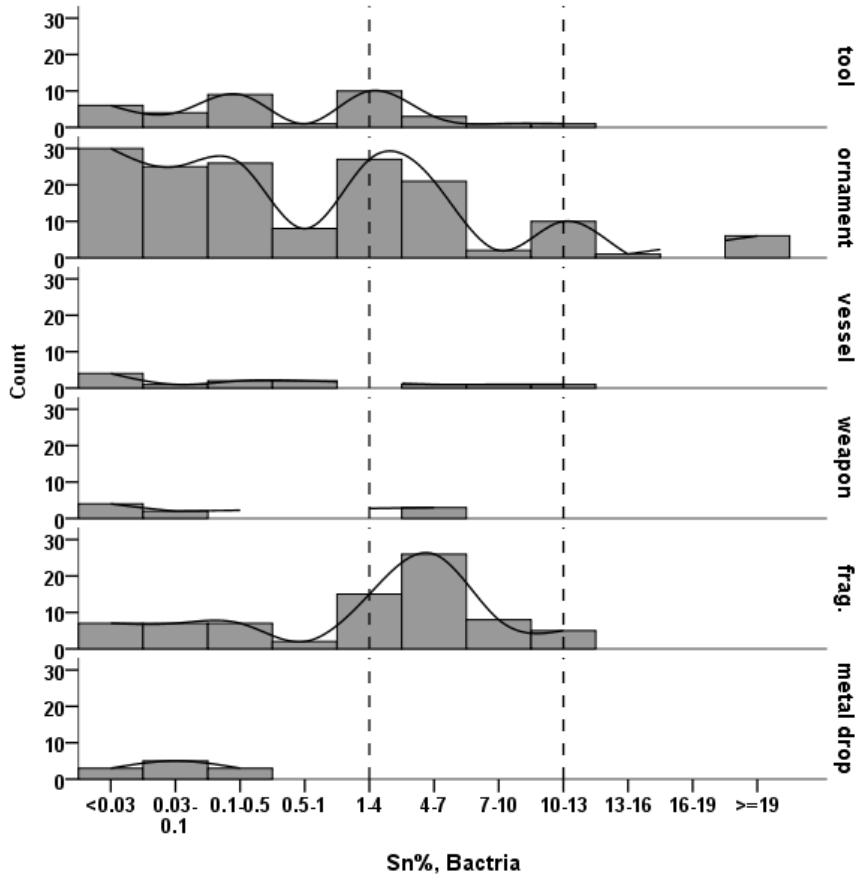


Figure 6.32 Distribution of tin across artefact types in Bactria.

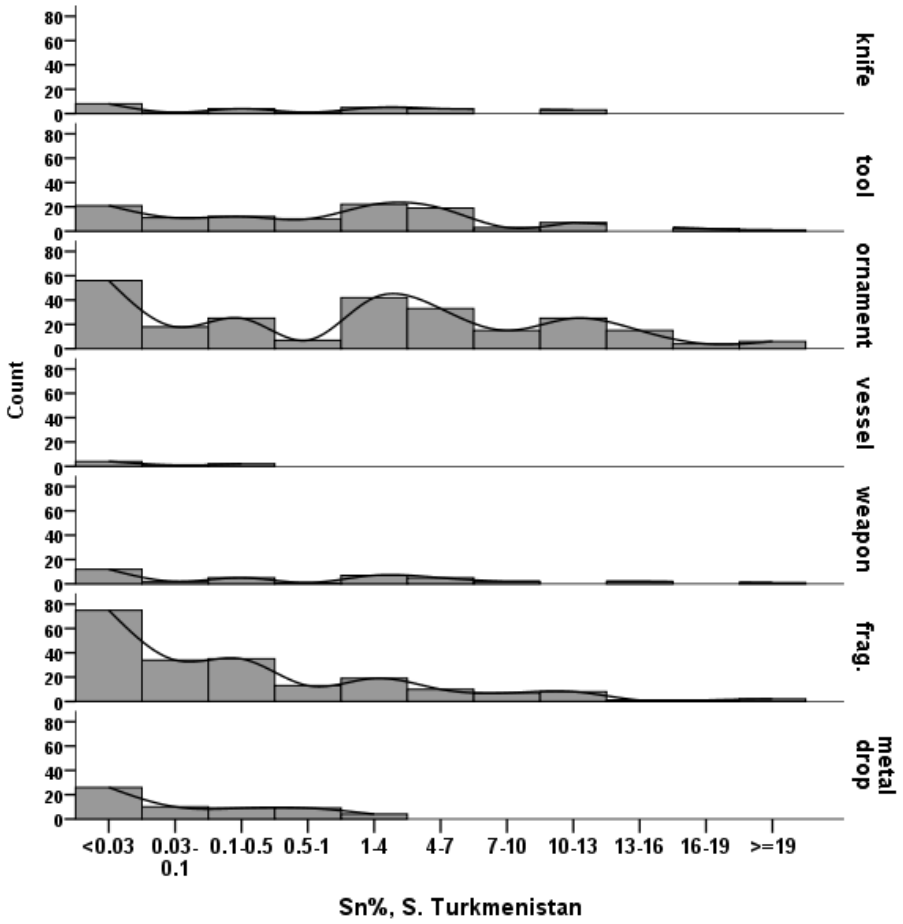


Figure 6.33 Distribution of tin across artefact types in S. Turkmenistan.

6.5.2 Karasuk-type single-bladed knives

Material evidence from the FBA cemeteries has shown a great connectivity of artefact typology across the communities in eastern Eurasia (Wu 2008; Kuz'mina 2007, 2008). Steppe-style metal objects constantly occurred in the archaeological context of urban civilisations in central Asia and ancient China. One of the most widespread steppe artefacts is the Karasuk-type single-edged knife. From approximately 1300 BC onwards to 1100 BC, Karasuk-type knives acquired their popularity among mobile pastoralists in the eastern steppes. While the motifs of single-edged knives vary between regions, their overall form shares strikingly similar elements: the single-edged blade with concave thickened spine, the rising guard with pronounced butt, the handle with geometric patterns, and the pommel crowned by zoomorphic, ring-form, or mushroom-like terminal (Figure 6.34). While the typological study on this item has become a routine practice in Eurasian archaeology, artefact composition can offer new insight into the nature of metal production, consumption, and circulation.

Composition of knives demonstrates two major production centres: arsenical copper in the Minusinsk/Baikal and tin-bronze or leaded tin-bronze in Mongolia/Northern

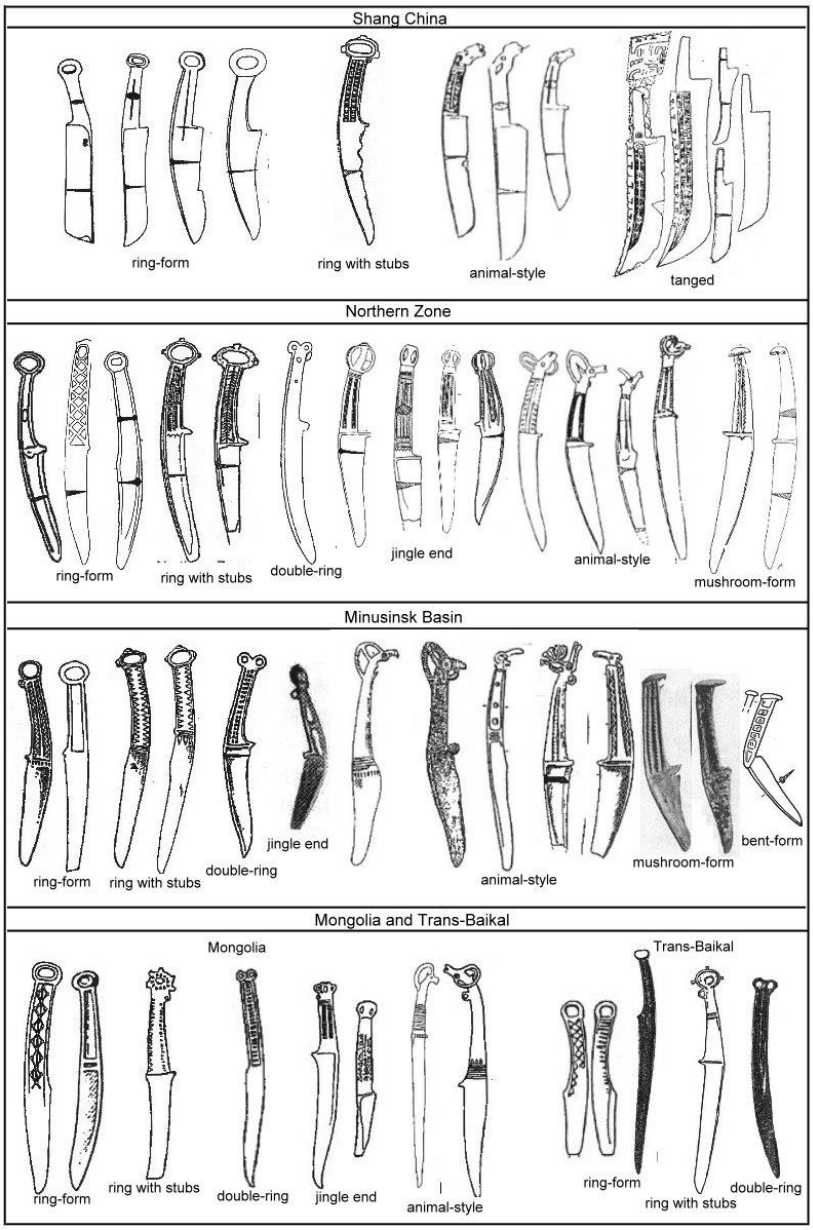


Figure 6.34 Single-bladed knives sorted by regions and pommel types. Compiled from Wu (2008).

Zone. Knives from the former highlight elevated arsenic and nickel content compare with low-arsenic and low-nickel in the latter (Figure 6.35). By contrast, knives from Mongolia and the Northern Zone are characterised by relatively higher tin and lead concentrations as opposed to low-tin knives in the Minusinsk and Baikal (Figure 6.36). These chemical patterns indicate a two-way communication in which the northern knives with high arsenic and nickel were carried south and mixed with tin bronzes and leaded tin bronzes in Mongolia/Northern Zone, and vice versa. Such interactions are confirmed by the diluted effect in northern (low Sn and Pb) and southern (low As and Ni) knives.

While copper sources for northern knives most likely originated from the Minusinsk Basin as suggested by their high arsenic concentrations, it remains unclear where the sources for southern knives come from. We currently do not have enough trace element data to trace the provenance of metal supplies for southern knives, yet alloying compositions seem to point out an injection of lead from the Northern Zone (Figure 6.36).

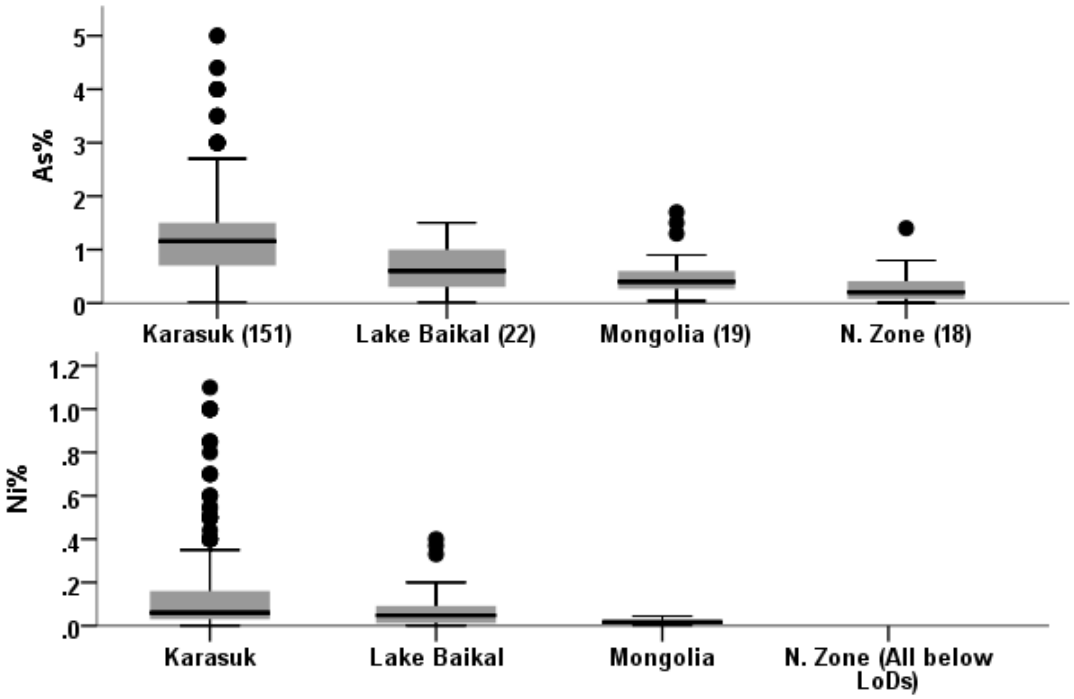


Figure 6.35 Distribution of arsenic and nickel in single-edged knives across regions/cultures.

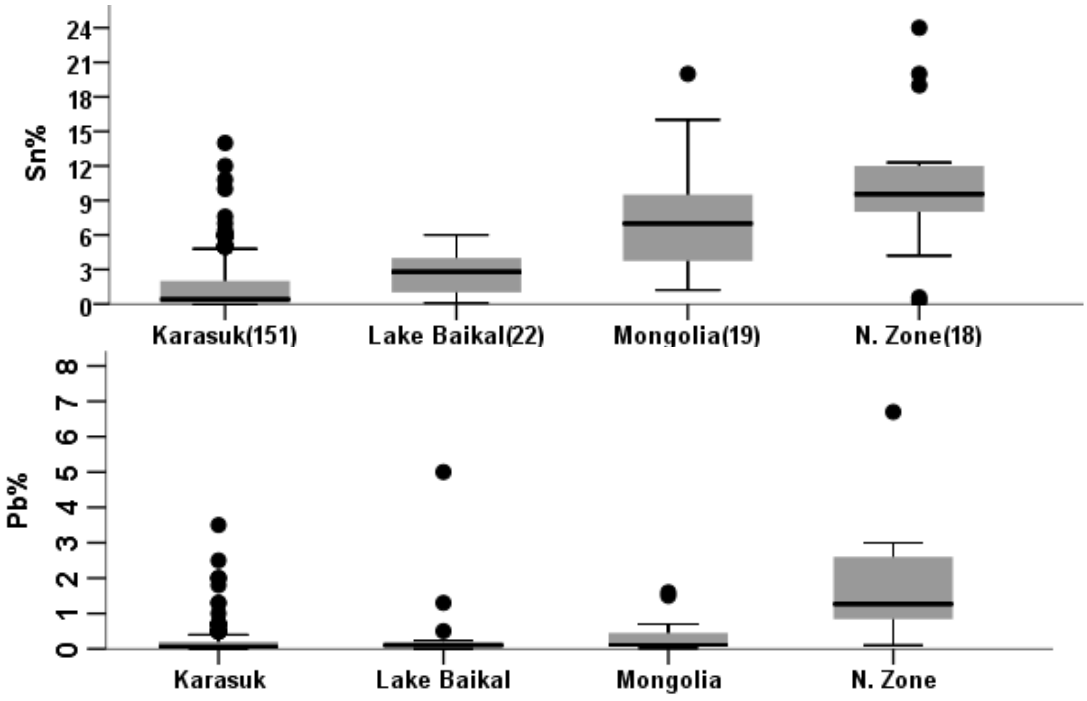


Figure 6.36 Distribution of tin and lead in single-edged knives across regions/cultures

6.5.3 Steppe-style artefacts and Anyang ritual vessels in the Northern Zone

The Northern Zone has been considered as a crucial transitional region between the steppe pastoralists and settled agriculturalists in the Central Plains of China (Wu 2007, 2008). Many tombs in northern Shaanxi and Shanxi provinces, dated to the late second millennium BC, contain both steppe-style objects and Shang Anyang ritual vessels. This unusual combination of burial goods bears testimony to the interaction between steppe people and Shang settled farmers. We can add more information on how metals were circulated using lead isotope data. Figure 6.37 illustrates a plot of the log of (1/Pb) against $^{207}Pb/^{206}Pb$, divided by styles of artefacts. Unlike the conventional bi-plots of the lead isotope ratios which do not take lead concentrations into account, this new way of presentation, proposed by Pollard & Bray (2014), is able to identify the possible mixtures of different lead sources. Since the right side of the diagram represents isotopic ratios of metal artefacts with lower than 1% Pb, points located in this area probably indicate isotopic signatures of copper sources. By contrast, points on the other half of the diagram are more likely to be associated with added lead.

As objects with the similar isotopic values would roughly form a horizontal line parallel to the x axis, one is able to observe a cluster of data along this line if a particular lead source is present. According to the diagram, the Northern Zone seems to have three main sources of lead indicated by Band A (0.85-0.87), Band B (0.73-0.76) and Band C (0.68-0.71). Interestingly, the majority of the Anyang-style artefacts chiefly correspond to lead from B and C. By contrast, objects with steppe characteristics are mainly related to source A and B, and many of them fall between these two isotopic signals. These facts imply three important pieces of information. Firstly, Anyang-style leaded tin-bronze vessels found in the Northern Zone are actually direct imports from the late-Shang culture in the Yinxu. Isotopic ranges of Band B and C have been recognised as the so-called “highly radiogenic lead” featuring the making of the Yinxu vessels sourcing from Southwest China (Jin 2008). Secondly, the Northern Zone metalworkers probably re-melted the Yinxu leaded tin-bronze vessels to cast metal objects with steppe tastes as suggested by the overlapping isotopic ratios within Band B. Finally, steppe-style artefacts, situate between lead from Band A and B, demonstrate the considerable mixture of lead from these two sources.

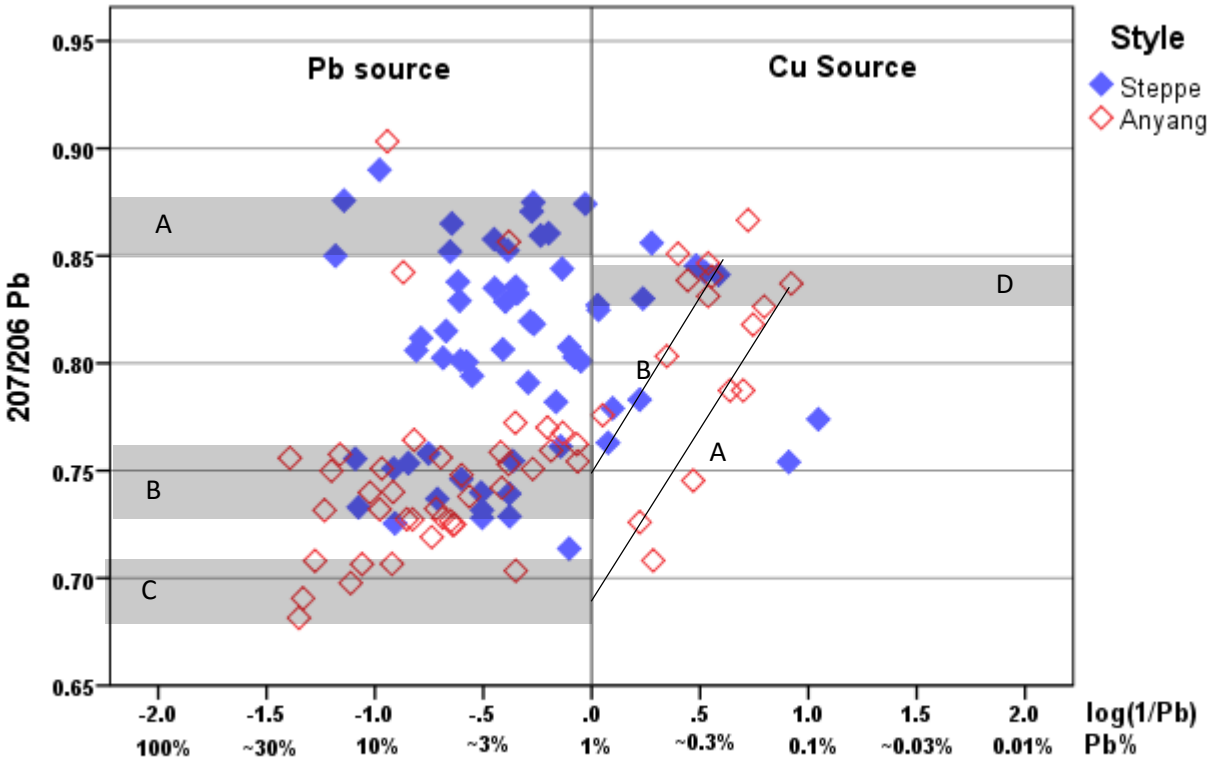


Figure 6.37 Plot showing the relationship between $^{207}Pb/^{206}Pb$ and Pb concentrations of artefacts from the Northern Zone.

Isotopic signatures of low-lead artefacts also display certain degree mixing character of bronzes found in the Northern Zone. Band D represents a possible copper source with isotopic ratios around 0.84. From which there are two linear mixing lines corresponding to the change of lead isotopic values due to the added lead. While Line A suggests that copper is mixed with a lead source from Band C, Line B is likely related to the addition of lead from Band B.

In order to pinpoint the sources of lead, I plot a similar graph by adding isotope data from the contemporary sites in Sichuan (Sanxingdui) and Hanzhong (Figure 6.38) Leaded tin-bronze artefacts from Sichuan nicely sit on top of Band C, with some falling in Band B, but none of them in Band A. This suggests that while both lead from B and C may come from south of the Central Plains, the lead source of Band A is likely to be from the North. Furthermore, there are probably two copper sources during the late-Shang Period. One is represented by the northern Chinese copper (Band D) and the other by the Sanxingdui copper (Band E). Copper and lead in Sanxingdui assemblage, in particular, might originate from the same metallogenic region as they share a similar range of isotopic ratios (around 0.70, see Band C and E).

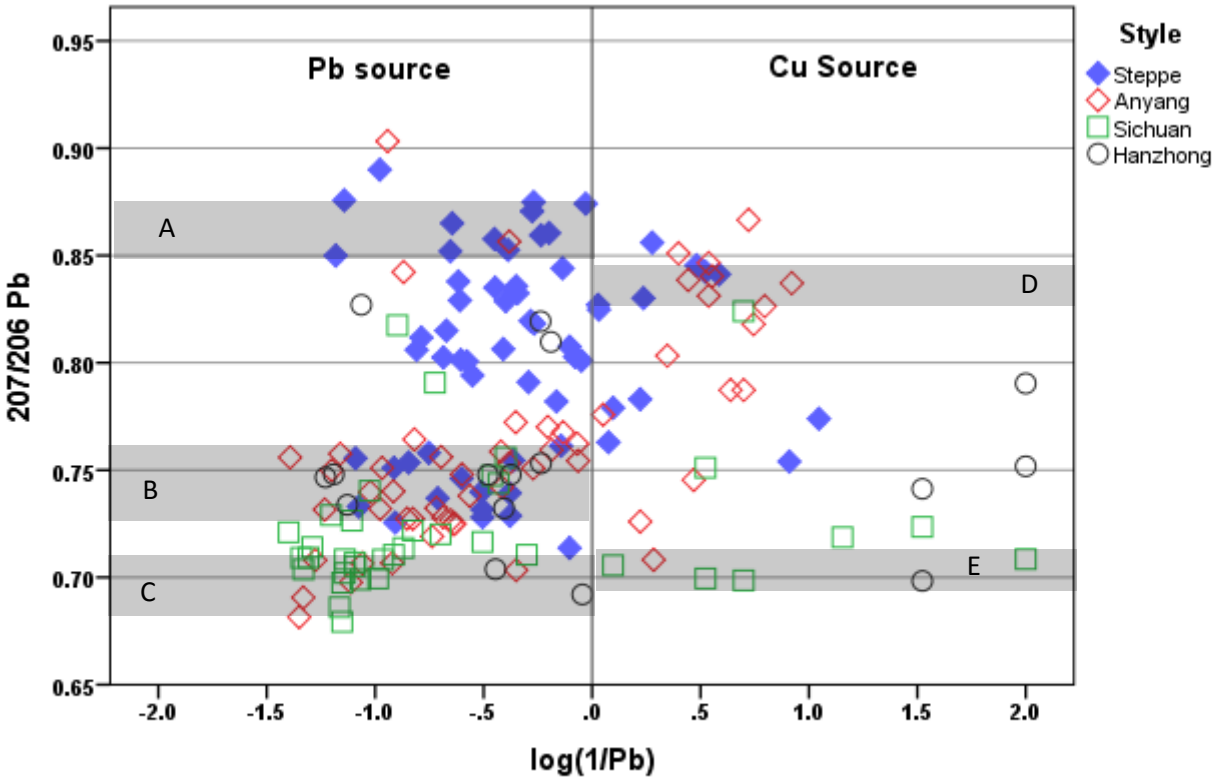


Figure 6.38 Plot showing the relationship between $^{207}Pb/^{206}Pb$ and Pb concentrations of artefacts from the Northern Zone, Sichuan and Hanzhong.

In sum, on the one hand, metalworkers in the Northern Zone might have their own supplies of lead and copper (Band A and D), which did not come from Anyang. On the other hand, the northerners received leaded tin bronzes from Anyang either by traded or looted, and melted them down to cast their favourable steppe-style weapons, tools and ornaments. This practice is reflected by a considerable mixture between lead sources (artefacts between Band A and Band B), as well as the mixing between copper and lead (line A and B). This dynamic pattern of metal exchange provides a new perspective on how northern pastoralists obtained metals and how they managed such large network with different resources. Communities in the Northern Zone might have a highly political and socio-economic power that was comparable to the Shang in the Central Plains.

These steppe-style items containing the signal of Chinese lead were furthered exchanged into Mongolia where local people might re-melt them again to produce their preferred objects as shown by the decreasing lead concentrations in Mongolian single-bladed knives (Figure 6.36). This long-distance interaction through the transfer of Chinese lead is quite remarkable, and it is promising to further explore lead isotope

ratios of Siberian and Mongolian artefacts to confirm the intensity of such Chinese influence.

6.6 Conclusions

While previous research has advocated the east-west connection across the Eurasian steppe in terms of the Valikovaya pottery tradition and EAMP metalwork, this chapter develops a different perspective on a strong north-south movement of metals along the foothills of the Inner Asian Mountains Corridor (IAMC). This long-distance communication is marked by the interplay between three metallurgical centres: Minusinsk Basin, Kazakhstan, and southern Central Asia. Kazakhstan, as a main supplier of pure copper sources and tin-bronze, exported its metals into the Minusinsk Basin and southern Central Asia (Figure 6.5 & 6.17). In return, arsenic-only copper (CG2), derived from the Minusinsk Basin and southern Central Asia, flowed into Kazakhstan (Figure 6.6 & 6.20). Artefacts from the peripheral areas of these cores display a mixed chemical signature with intermediate arsenic and tin (e.g. the Irmen culture in the Upper Ob).

Metal exchange in the Final Bronze Age of the eastern Eurasian steppe is organised in such north-south transportation, especially along the Inner Asian mountain passages (from the Altai and Sayan, along the Tien Shan, the Paimr and to the Hindu Kush; see Frachetti 2012). Contrary to the traditional view that these mountain ranges were formidable physical barriers for communication, alpine pastures along this great mountain chain provided much needed fodder and water for herders who could freely exchange items and ideas with other pastoral or semi-pastoral groups during the seasonal migrations. Hence, these upland corridors integrated three metallurgical centres into an interlocking system: the Minusinsk Basin, the Kazakh steppe, and southern central Asia. Through the exchange between tin-bronze (Kazakhstan) and arsenical copper (Minusinsk and central Asia) production, metals were recycled in favour of the local tastes.

One of the most intriguing phenomena during this period was the rise of the Karasuk metallurgy in the Minusinsk Basin. There was not only an increase in metal production, but also new forms of metal artefacts as prestigious decorative items and personal weapons (Legrand 2006). These metal objects highly resembled those from the Seima-Turbino metal collection in terms of singled-bladed knives, yet it is difficult to claim

any direct lineage between Karasuk and ST metals as they were several hundred years apart (Chernykh 2008: 50). What we can be certain about is the advent of Karasuk culture initiated a new mode of production featuring copper-arsenic alloys. As shown in Figure 6.39, prior to the Karasuk period, Minusinsk artefacts are dominated by the use of tin-bronze with either pure copper (CG1) or copper with arsenic (CG2) as the base metal. This alloying practice and corresponding raw copper are shifted towards arsenical copper with antimony or/and nickel as chief impurities (CG6, CG11 and CG14). This change in copper chemistry may suggest the exploitation of new resources in the Minusinsk Basin as no other areas in the eastern Eurasian steppe yield such large quantity of antimony- and nickel-bearing copper artefacts.

The emergence of the Karausk metallurgy has a far-reaching effect on development of the Northern Zone metallurgy. This is best exemplified by the spread of Karasuk-type knives. Original knives from the Minusinsk Basin contain appreciable arsenic content, while knives produced in Mongolia and the Northern Zone feature depleted arsenic with increasing amounts of tin and lead. This suggests that while the idea of making single-edged knives could potentially travel across tremendous distances, the choice of raw material and alloying substances are determined by the accessibility of metal sources. Southern knives (Mongolia and the Northern Zone) are probably made of the recycled Chinese bronze vessels as shown by the higher lead concentrations and overlapping isotopic signatures with the Anyang specimens.

Many scholars have suggested the spread of the Karasuk-style metal artefacts into Transbaikal, Mongolia and the Northern Zone of China in terms of the mobility of the Karausk economy (Novgorodova 1970; Chlenova 1972; Legrand 2004). Although the nature of stockbreeding cultures indeed plays an important role in transmitting metallurgy, which we have seen in both the Middle and Late Bronze Ages, I argue that the rise of the Karauk metalwork may also be explained by the formation of complex societies in both Mongolia and the Northern Zone of China. Houle (2009) considers that the construction of khirigsuurs (a Mongolian version of the kurgans, dated to 1400-700 cal. BC) and deer stone stelae signified communal rituals among mobile pastoralists. These infrastructures reinforce social and political integration between fragmented pastoral groups. In my view, these Mongolian monuments,

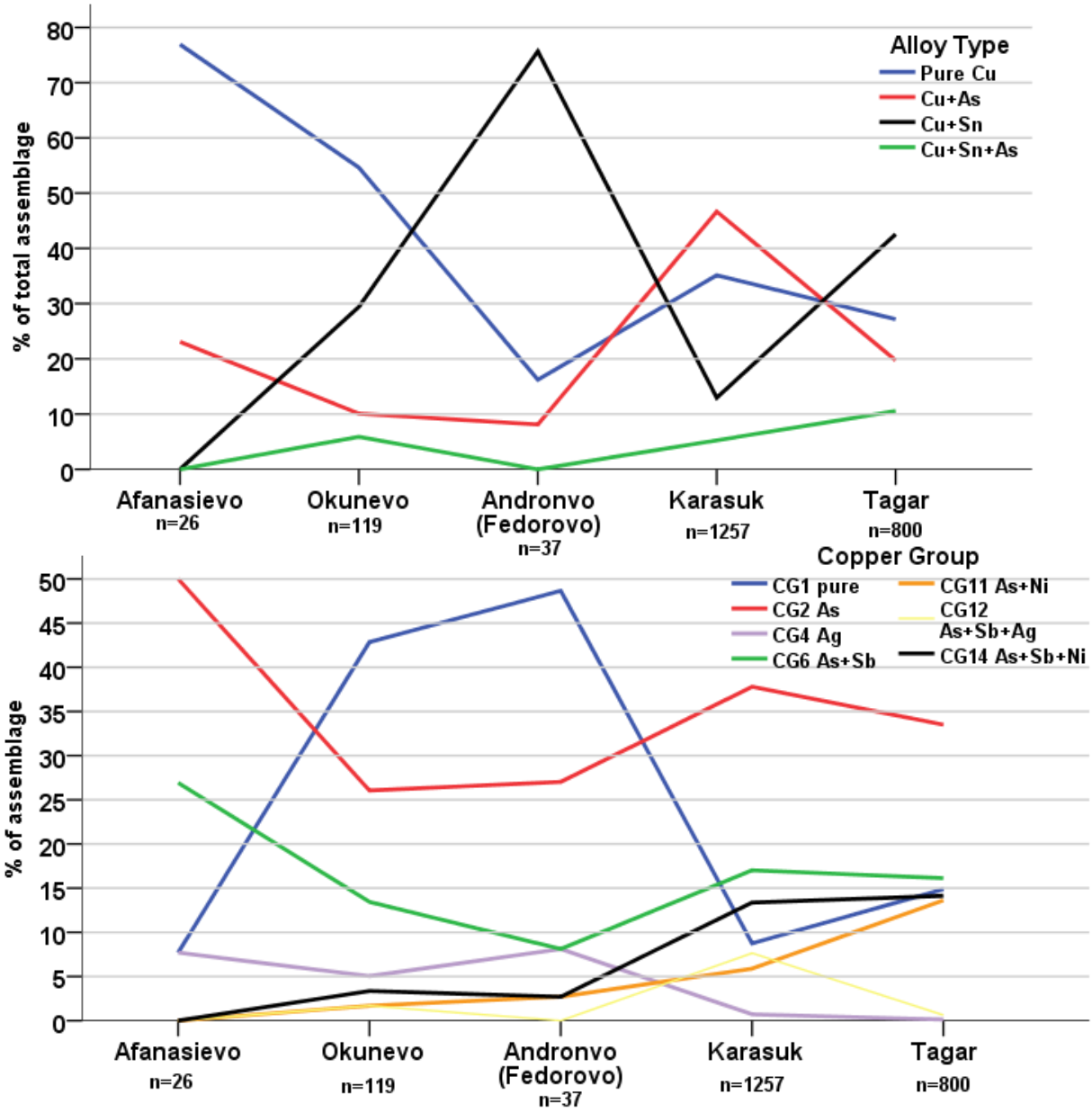


Figure 6.39 Chronological variations of the ubiquity of alloy types (top) and copper groups (bottom) in the Minusinsk Basin. The cut-off value for copper alloys is 1wt% tin/arsenic. See Chapter 7 for the metallurgy of the Tagar culture.

especially stone stelae, may serve as meeting places where steppe people exchanged goods and ideas during the ritual or social events. In fact, Mongolian deer stones often depict Karasuk-type weapons (knives, daggers and axes) as the expression of a warrior or chief carrying personal weapons and ornaments (Novogrodova 1989: 175, see Figure 6.40). It is probable that local leaders required to obtain specific Karasuk metal artefacts for the purpose of maintaining their power or ties with other tribes.

A different mode of the complex society occurred in the Northern Zone of China during the Karasuk period. The region, marked by mixed herding and farming economy, was a frontier between the Eurasian steppe and the Central Plains of China (Watson 1971; Lin 1986; Shelach 2009; Linduff & Yang 2012; Rawson 2015). Roughly before 1500

BC, metal production sporadically emerged in Inner Mongolia (the Zhukaigou culture) and northeastern China (Lower Xiajiadian culture) on a small scale (Linduff 1995; Linduff & Mei 2014; Li 2015). However, many metal-producing communities came to existence from 1300 BC onwards, synchronous with the expansion of the Karasuk metals (known as Weiingzi, Weifang Phase III and Lijiaia cultures, see Wu 2007). Based on several strands of archaeological and textual evidence, Cao (2014) argues for the formation of complex societies in the Loess Highland of central North China, mostly covering present day Shanxi and Shaanxi provinces. According to him, this area not only served as a middleman between the Central Plains of China and the Steppe, but developed an extensive inter-regional trading network through a unique horse-raising expertise. The Highland people exchange their horses for metals from the southern settled societies and possibly re-melted and re-cast these imported objects into local style weapons, implements or ornaments. Cao (2014:293-296) also stresses the importance of the Mongolian steppe as an independent production centre for the so-called Karausk-like metal artefacts (objects are found outside the Minusinsk Basin, but resemble Karasuk type, see Legrand 2004: 146).

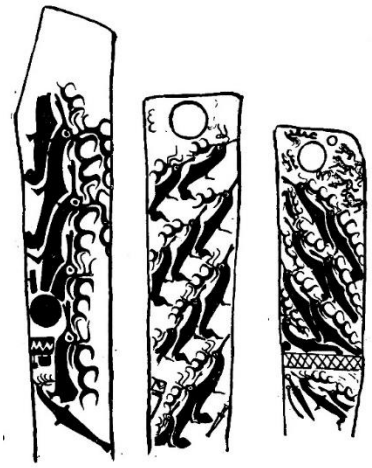


Figure 6.40 Depictions of Karasuk-type daggers and knives on deer stones. From Novogrodova (1989: 204).

Both Houle's and Cao's studies highlight the flourishing local metal production that embarked on a long-distance trading network driven by the rise of complex societies. This specific social environment makes the transmission of Karauk metallurgy possible. However, this spread of new technology is based on the imitation of shapes of Karasuk-style single-bladed knives or daggers rather than actual recycling of Karasuk metals. Bronze weapons found in Mongolia or Northern Zone are cast locally in favour of tin-

bronze or leaded tin-bronze as opposed to Minusinsk arsenical copper (the former prefers tin-bronze and the latter leaded tin-bronze). This observation further strengthens the main idea of the whole thesis arguing the local responses to outside influences.

7. The Rise of Horse-Riding Communities and the Spread of Copper-Based Artefacts across Eastern Eurasia

7.1 Background

The Early Iron Age of the Eurasian steppe zone (c. 1000 to 300 BC) is characterised, 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—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.

Though nominally the Iron Age, the material culture of the period remains dominated by artefacts made from non-ferrous metals, primarily copper and bronze. These items, characterised by personal tools and weapons, horse harness, mirrors, and various zoomorphic plaques and ornaments (Bunker *et al.* 1997; National Tokyo Museum 2005; Wu 2008), have been extensively studied in terms of typology and style. For the Eurasian Bronze Age, such discussions have often been integrated with compositional analyses of the metals themselves. However, in the Iron Age these two streams of study have largely remained separate, used to address different kinds of question at very different scales. This comment is particularly applicable in the eastern Eurasian steppe, where even in Bronze Age archaeology stylistic and typological analysis has remained the primary focus of study. In these studies the evidence of interaction is frequently emphasised, but the character of contact is rarely explored and the orientation of exchange often remains a matter of assumption.

7.2 Previous archaeometallurgical studies on the Early Iron Age metals

Although research conducted by Chernykh and his colleagues has made tremendous contributions to the understanding of Eurasian prehistory and set the standard for the study of metallurgy in Eurasia for decades, it must be acknowledged that the resolution of coverage in later prehistory, particularly in eastern Eurasia, has been generally lower and the analysis far less complete. While the metallurgical provinces of western Eurasia, were carefully constructed on a solid foundation of typology, technology and metal chemistry, the later Bronze Age 'provinces' of eastern Eurasia are built, almost exclusively, on the external characteristics of the objects (Chernykh 2009, 281-284). While the chemistry of Iron Age copper and bronze objects is simply not discussed.

Of course, Chernykh is not the only researcher to have studied the archaeometallurgy of the steppe zone, and various other Russian archaeologists have chemically explored the composition of non-ferrous metal artefacts from the Bronze and the Early Iron Age assemblage in the eastern Eurasian steppe. However, compared with the consistent structured approach taken by Chernykh and his colleagues, these smaller studies are often inconsistent with one another in their methods and interpretations. Bogdanov-Berezovaya (1963) applied a cut-off 1% to tin and arsenic to classify metal from the Minusinsk Basin into three alloy types: copper, arsenical tin-bronze, and tin-bronze, then described the observed ranges of trace elements in each alloy type. Sergeeva (1981) employed cluster analysis to statistically divide chemistry of metal from around Lake Baikal into different groups. Pyatkin (1983) also applied a statistical method to the data, using Spearman's rank correlation coefficient, to measure the degree of similarity between chemical groups of Tuvinian bronze. Khavrin (2008) on the other hand, gave very descriptive accounts on the raw data on Minusinsk bronzes. He constantly emphasised objects with high trace or alloying elements but does not clearly explain what standards were used to make these judgements.

7.3 Potential problems of current scholarship

At present, discussions of the Early Iron Age steppe metallurgy remain heavily focused on the comparison of artefact typology, particularly the animal-style art. This approach tends to be somewhat subjective and opinions on the development of the EIA metallurgy are varied by each scholar. Some proclaimed that the origin of animal-style metals came from Siberia (Loehr 1951, 1956), and others argued for either central China (Karlgen 1945; Barnard 1983) or the Northern Zone (Wu 2007, 2008). Despite

these comprehensive studies on artefact typology, no one has ever systematically looked into metal composition as a means to trace metal circulation in the Early Iron Age of eastern Eurasia. Even though some compositional studies described above documented chemical signatures of steppe metals, they tend to be fragmented and small in scale, making it difficult to synthesise their results in order for a cross-regional/cultural comparison. Furthermore, they all make from the assumption that it is possible to directly correlate artefact chemistry with the geological sources of metal ores. It is an old problem I have criticised over and over again in preceding chapters. The EIA metalwork lacks a coherent narrative to reconstruct a metallurgical network linking individual cultures/regions in eastern Eurasia together. Therefore, drawing on a new framework proposed in this thesis (Bray *et al.* 2015), this chapter attempts to address a broad scale pathway of communication and exchange across eastern Eurasia. On the basis of the chemical data, it aims to elucidate the metallurgical network through the identification of directional flow of copper and tin supplies. Whether metal objects, technologies and ideas were transferred one area to another through the movement of people or by some other means remains to be seen.

7.4 Chronology of the EIA bronze data

A database of 4469 chemical entries (2011 of which have trace elements) has been collected for the purpose of the discussions. The datasets cover the core areas of pastoral groups in the Altai, Tuva, the Minusinsk Basin, Cisbaikal, Transbaikal, Kazakhstan, Mongolia and Xinjiang. Other data from semi-sedentary communities (the Hexi Corrioder, the Northern Zone of China) and agricultural societies (the Central Plains of China) are also included for comparison (Figure 7.1).

Unfortunately, there is no common chronology of eastern Eurasian pastoral cultures in the Early Iron Age. We have to rely on the dates of some key monuments to decide the relative chronology of analysed artefacts. The first stage is represented by the Arzhan kurgans in the Tuva Republic, dated between the 9th and mid-7th centuries cal. BC (Alekseev *et al.* 2001; Zaiteseva *et al.* 2007). Metal artefacts uncovered from these remarkable graves, especially their horse harnesses and animal-style ornamentation, have been used to relatively date similar objects from adjacent areas. Contemporary cultures include Bainovo and Podgornovo phases of the Tagar culture in the Minusinsk Basin (Svyatko *et al.* 2009), the early stage of "nomadic" cultures in the Altai (Moskova

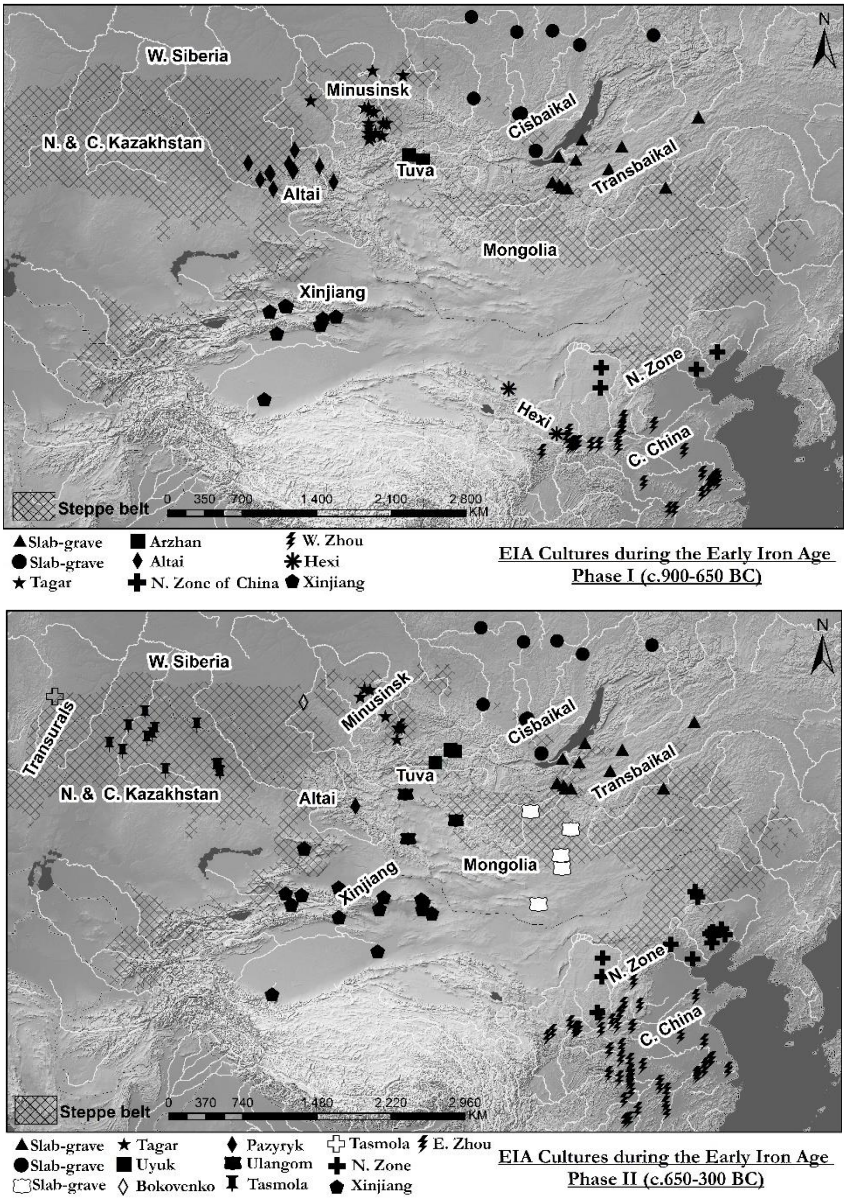


Figure 7.1 Maps showing distribution of chemical data points during the Early Iron Age. The upper: Phase I (c. 900-650 BC). The bottom: Phase II (c. 650-300 BC).

& Rybakov 1992: 164), and Slab-Grave cultures in the Lake Baikal region (Tsybiktarov 1998). This is not ideal because chronologies in the Altai and Lake Baikal regions are still much debated and some data from the Slab-Grave cultures might belong to the second half of the first millennium BC. For this reason, the same data from the Baikal region is used to discuss the circulation of metal during the second stage of the Early Iron Age. We hope future radiocarbon-dating research in these regions will provide better resolutions to refine these divisions.

The second stage (c. 650 to 300 BC) marks the heyday of horse-riding communities in eastern Eurasia. Similar types of metal artefacts, ranging from weaponry, horse trappings to small belt ornaments, are found throughout the territory of the steppe and forest zones. One of the most remarkable monuments is the Pazyryk kurgans in the

Altai Mountains showing sophisticated steppe craftsmanship in terms of zoomorphic wooden carving and bronze casting (Rudenko 1970). Foreign items from the ancient Near East and China dictate a long-distance interaction between steppe societies and urban civilisations.

7.5 Ubiquity of copper groups during the Early Iron Age

The proposed copper grouping allows us to broadly characterise copper chemistry employed by different regions. Table 7.1 displays the ubiquity of copper groups across different EIA metal-producing areas during Phase I. This simple chart highlights two distinct copper usages: copper containing arsenic, antimony, and nickel as trace elements (CG6, CG11&CG14) in the Steppe in contrast with silver-bearing copper (CG9&CG12) in ancient China. CG1 and CG2 are both present in the Steppe and settled communities.

Situations become more complicated when entering Phase II (Table 7.2). While previous trends basically remained unchanged, we are able to identify an increasing interaction within the Steppe and between the Steppe and China as shown by the presence of nickel-bearing copper (CG14) and copper with all trace elements (CG16). The subsequent discussions aim to scrutinise subtle variations in regional copper chemistry and show how each copper group may suggest possible pathways of metal flow.

7.5.1 Copper group 1

Figure 7.2 (left) depicts the ubiquity of CG1 during Phase I. One may immediately identify objects with no substantial impurities concentrating in the Cisbaikal. This metal supply seems to be distributed westwards along the northern edge of the Sayan-Altai Mountains. It is difficult to trace the original metal sources in the Cisbaikal. According to Sergeeva (1981), the Lena River Basin is rich in copper sandstone deposits, which might serve as the potential source. During Phase II, the Transurals becomes a major region to provide CG1 metals to the east, especially CG1 production in Kazakhstan (Figure 7.2, right). It has been noted in Chapter 5 that clean copper production was extremely active in the Transurals during the Late Bronze Age. It is possible that CG1 sources were still in use in the later times.

Table 7.1 Ubiquity of copper groups across metal-using regions during the Early Iron Age Phase I.

900 to 650 BC	*Steppe*					*Ancient China*	
	Cisbaikal	**Transbaikal**	**Minusinsk**	**Tuva**	**Altai**	**N.Zone**	**C.China**
CG1	**24.7%**	6.5%	**11.3%**	4.9%	**20.1%**		**11.5%**
CG2 As	**24.7%**	**26.0%**	**25.0%**	**11.1%**	**59.7%**		**32.3%**
CG6 AsSb	**29.9%**	**25.1%**	**21.1%**	**13.2%**	**10.8%**	**66.7%**	6.5%
CG9 AsAg	6.5%	5.4%	1.0%	1.1%		8.3%	**18.8%**
CG11 AsNi		3.0%	**16.4%**	**30.6%**	4.3%		0.8%
CG12 ~~AsSbAg~~	6.5%	**11.4%**	1.0%	0.0%	1.4%	**25.0%**	**23.8%**
CG14 AsSbNi	1.3%	**10.8%**	**21.1%**	**31.3%**	0.7%		1.2%
CG16 AsSbAgNi	1.3%	**10.2%**	0.6%	0.7%	0.7%		
Total N	77	167	512	144	139	12	260
CG1&CG2: steppe/China. CG6&CG11&CG14: steppe. CG9&CG12: China.							**N=1311**

Table 7.2 Ubiquity of copper groups across metal-using regions during the Early Iron Age Phase II.

650 to 300 BC	*Steppe*										*Chinese*	
	Cisbaikal	**Transbaikal**	**C. Mongolia**	**Minusinsk**	**Tuva**	**W. Mongolia**	**Altai**	**Upper Ob**	**N. & C. Kazakh**	**Transurals**	**N.Zone**	**C.China**
CG1	**24.7%**	6.5%	**11.5%**	**10.3%**	**12.9%**	1.7%	8.3%	2.8%	**19.5%**	**76.1%**	7.2%	4.6%
CG2 As	**24.7%**	**23.8%**	**7.7%**	**43.6%**	**22.6%**	7.4%	**29.2%**	**16.5%**	**59.5%**	6.0%	9.1%	**11.5%**
CG6 AsSb	**29.9%**	**25.6%**	3.8%	19.5%	6.5%	9.7%	**22.9%**	**44.0%**	**11.3%**	**11.9%**	**12.1%**	1.5%
CG9 AsAg	6.5%	5.4%	3.8%	1.2%	—	0.6%		3.7%	3.1%	—	8.1%	**37.7%**
CG11 AsNi	—	3.0%	3.8%	7.8%	**22.6%**	12.5%	8.3%	5.5%	0.5%	—	4.0%	3.8%
CG12 AsSbAg	6.5%	**11.3%**	7.7%	0.7%	—	1.1%	6.3%	1.8%	1.0%	1.5%	**22.2%**	**17.7%**
CG14 AsSbNi	1.3%	**10.7%**	**15.4%**	**15.0%**	**25.8%**	**51.7%**	**16.7%**	**21.1%**	—	3.0%	2.0%	—
CG16 AsSbAgNi	1.3%	**10.1%**	**38.5%**		6.5%	**11.9%**	4.2%	2.8%	—	—	**15.2%**	**10.8%**
Total N	77	168	26	574	31	176	48	109	195	67	99	130
CG1&CG2&CG6&CG11&CG14: steppe. CG9&CG12: China.												**N=1700**

Further east, the presence of CG1 is difficult to be detected due to potential mixture between different amounts of impurities.

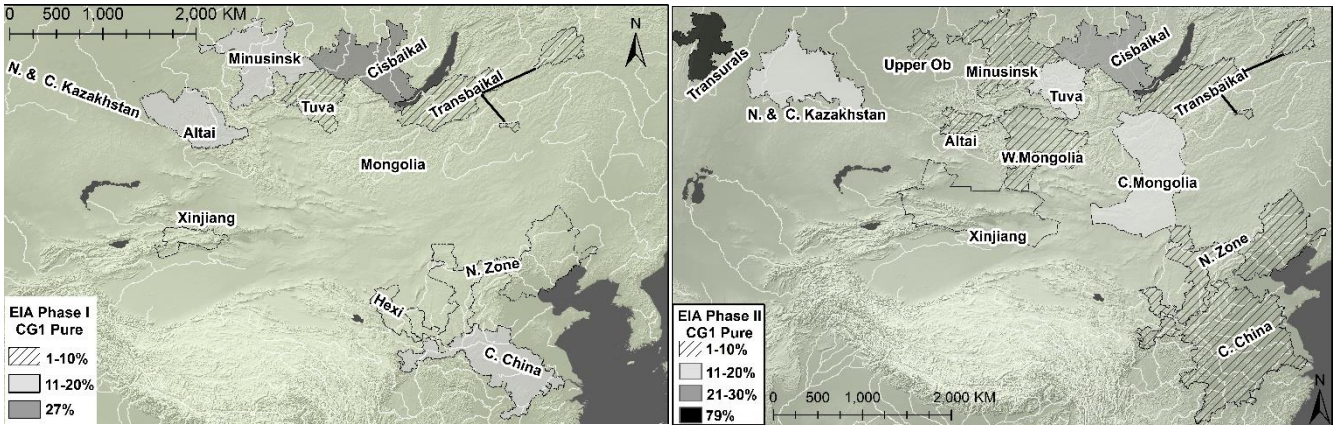


Figure 7.2 Maps showing distribution of CG1 during the Early Iron Age. Left: Phase I. Right: Phase II

7.5.2 Copper group 2

CG2 arsenic-only copper is commonly observed in all metal-using societies in eastern Eurasia. Its distribution patterns show a chronological variation. During Phase I, the Altai region appears to be one of the most important production centres with the highest proportion of such metal (Figure 7.3, left). The ubiquity of CG2 then decreases as we move away from the Altai to the Minusinsk Basin, Tuva and Baikal regions, where CG2 metals occupy a similar ratio in the individual assemblage.

The other focus of CG2 is situated in central China (western Zhou), but it seems to be a different practice with the Altaian source based on two reasons. One is a great distance between these two centres and current chemical data is insignificant to connect two CG2 production together. Secondly, unlike relatively high-arsenic CG2 copper in the Altai, Chinese metals tend to contain less arsenic (see Section 7.6.1). Therefore, it is better to interpret arsenic-only copper in central China as an independent centre from the Steppe.

Phase II signifies a dramatic change of CG2 production in the Steppe. The Altaian centre seems to decline and the focus is shifted to Kazakhstan and the Minusinsk Basin (Figure 7.3, right). To some extent, the rise of pastoral groups in Kazakhstan in the second half of the first millennium BC may contribute to this increasing metallurgical activity in exploiting CG2 metals.

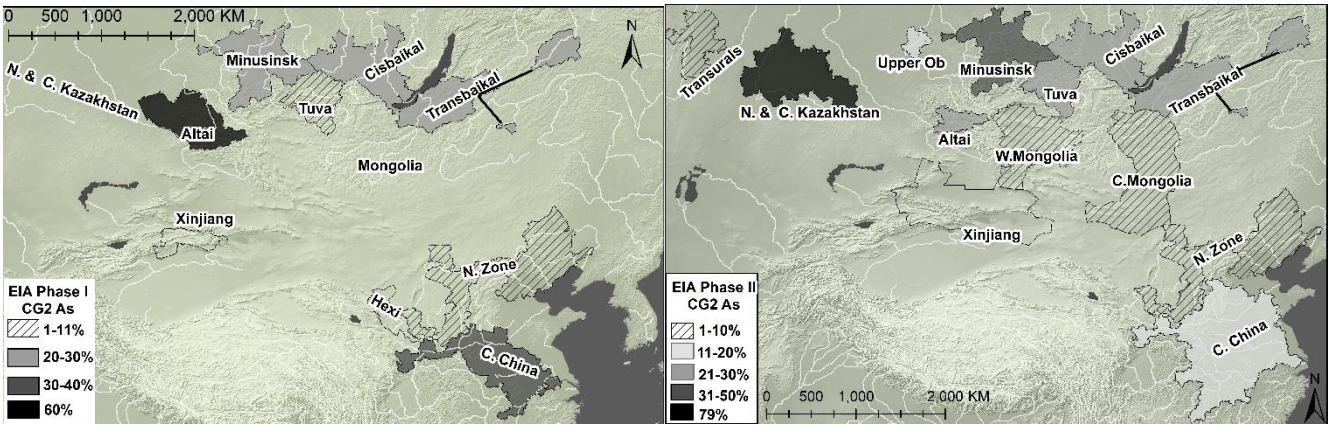


Figure 7.3 Maps showing distribution of CG2 during the Early Iron Age. Left: Phase I. Right: Phase II.

7.5.3 Copper group 6

Distribution of CG6 metals during Phase I concentrates in the Minusinsk Basin, the Cisbaikal and the Transbaikal, yet becomes less numerous in the Altai and Tuva (Figure 7.4, left). The Northern Zone might serve as another important CG6 source, and its existence may imply certain long-distance connections with the Steppe. However, we only have 12 chemical analyses from northern Shaanxi, making it difficult to do any further discussion (Liu 2015). The development of metallurgy in the Northern Zone during this period is still poorly understood. Not until the 7th century BC can we identify a drastic increase in metal production along the northern frontiers of China.

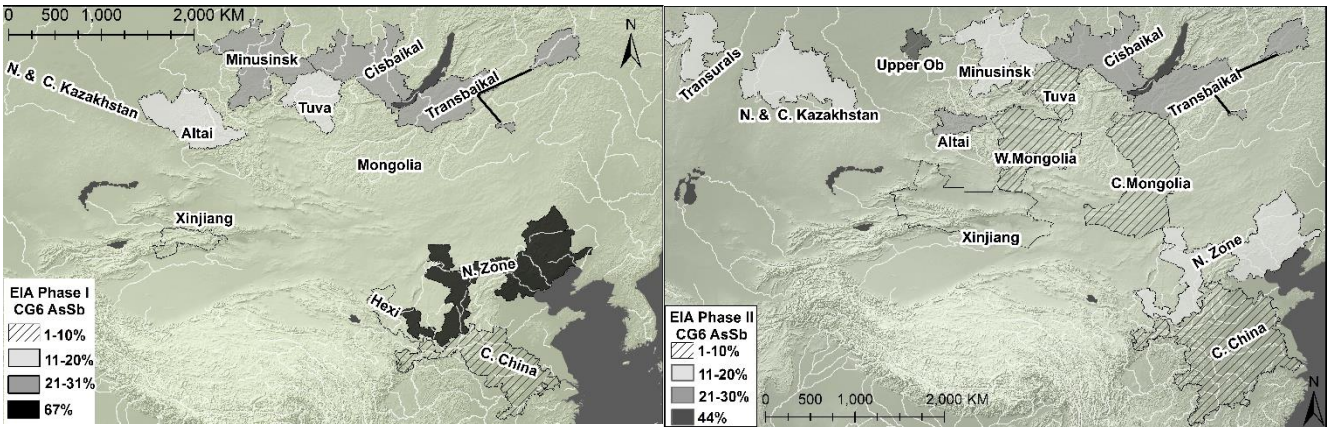


Figure 7.4 Maps showing distribution of CG6 during the Early Iron Age. Left: Phase I. Right: Phase II.

Distribution of CG6 during Phase II marks the rise of the metal production in the Upper Ob, which may provide such copper to the neighbouring Altai and Minusinsk through well-developed river systems in that area (Figure 7.4, right). Interestingly, the Northern

Zone stands out again as the concentrated region for arsenic-antimony copper. This signal is probably representative based on a total of 99 specimens in the database. However, this copper source is independent from the Steppe as the transitional region in Mongolia does not contain significant amount of such copper.

7.5.4 Silver-bearing copper

Silver-bearing metals (CG9 and CG12) had been the typical chemical composition of ancient Chinese bronzes since the late-Shang period (see Chapter 6). It has been argued that silver is brought by the addition of lead because some specimens of galena could contain up to a few percent silver by weight. It is beyond the scope of this thesis to discuss the true origins of silver but extra caution is needed when dealing with Chinese leaded bronzes.

Throughout the Early Iron Age, silver-containing copper is mainly restricted to central China and the Northern Zone in which CG9 is centred on the Central Plains and CG12 is slightly biased to northern China (Figure 7.5 & 7.6). A recent analysis on copper prills in slags from smelting sites in Northeast China shows a substantial amount of arsenic, antimony and silver (Dong 2012). This may explain why the Northern Zone is characterised by CG12 artefact chemistry.

In the Steppe, Transbaikal is the only place to have copper with silver as a chief impurity (CG12). As we shall discuss later, leaded copper also occurs in this region (see Section 7.9). These strands of evidence point out the possible transfer of CG12 metals from China to the Transbaikal. Burial practices that resemble the Slab-grave cultures in the Baikal are found in Northeast China (Zhi 1988). This may illuminate a flow of Chinese metals through the grasslands of Manchuria.

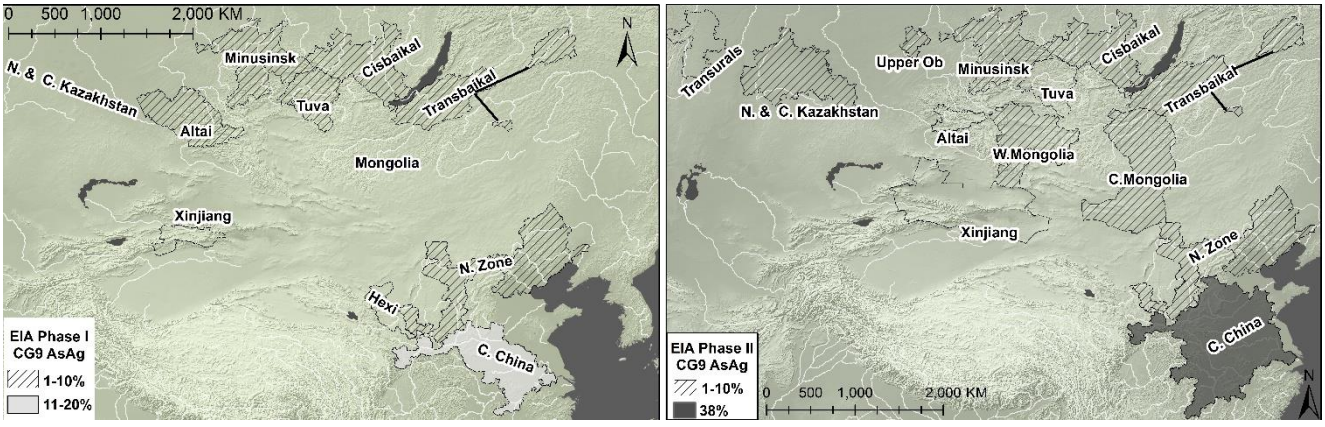


Figure 7.5 Maps showing distribution of CG9 during the Early Iron Age. Right: Phase I. Left: Phase II.

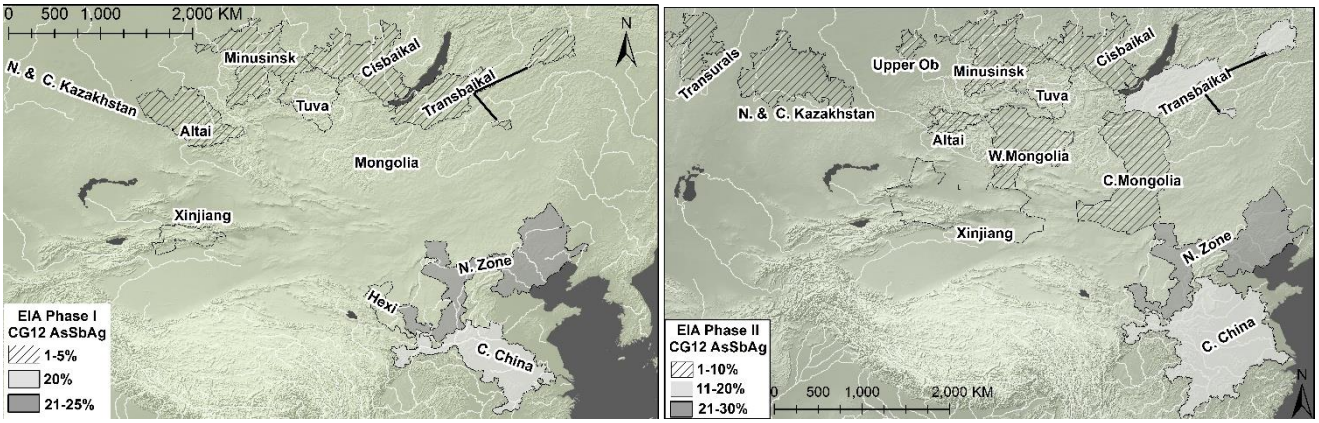


Figure 7.6 Maps showing distribution of CG12 during the Early Iron Age. Left: Phase I. Right: Phase II.

7.5.5 Nickel-bearing copper

Nickel-containing copper (CG11 and CG14) had been a diagnostic property of the Minusinsk metals since the Karasuk period (see Chapter 6). This type of production was inherited by the following Tagar culture and further extended into Tuva and western Mongolia. During Phase I, Tuva emerged as one of the most important metal production regions in the Steppe. The metal assemblage is dominated by both CG11 and CG14 objects (Figure 7.7 & 7.8). This corresponds to the sudden rise of complex societies in Tuva as shown by sophisticated burial rituals and offerings in the Arzhan kurgans. The supremacy of nickel-bearing copper in Tuva is still maintained during Phase II, but western Mongolia becomes increasingly important area operating this mode of production. Apart from the Minusinsk-Tuva and western Mongolia, copper-arsenic-nickel objects (CG14) are also widespread across the eastern steppes during Phase II. This chemical signature is found throughout the all steppe communities except for Cisbaikal, Kazakhstan and Transurals. It is possible that a part of CG14 (As+Sb+Ni) is a hybrid of CG11 (As+Ni) and CG6 (As+Sb). That is, when CG11 metals from Tuva or western Mongolia are transferred to other steppe regions, they are likely to be mixed with local CG6 sources. Interestingly, compared Figure 7.8 with Figure 7.4, CG14 metals tend to coincide with areas having strong CG6 production such as the Minusinsk Basin, the Upper Ob, Altai, and the Transbaikal. .

7.5.6 Copper group 16

This copper group contains all four trace elements which may manifest its true nature as the product of mixing. It shows up in the Early Iron Age Phase II, primarily in central Mongolia, with decreasing proportions towards western Mongolia, the Transbaikal and

the Northern Zone (Figure 7.9). As already mentioned in Chapter 6, herding communities in Mongolia were in close contact with the northerners in China since the late second millennium BC, as suggested by transportation of horses and metals (Cao 2014). This north-south interaction became even more visible during the Early Iron Age Phase II when metal production flourished through the territory of western and central Mongolia. The presence of nickel-bearing copper (CG14) in Mongolia might intermix with silver-containing copper (CG12) from the Northern Zone to create the chemical signature of CG 16. In turn, this production was redistributed to other areas along the movement of Mongolian mounted pastoralists. Despite being difficult to prove this hypothesis, it provides a workable direction for further study.

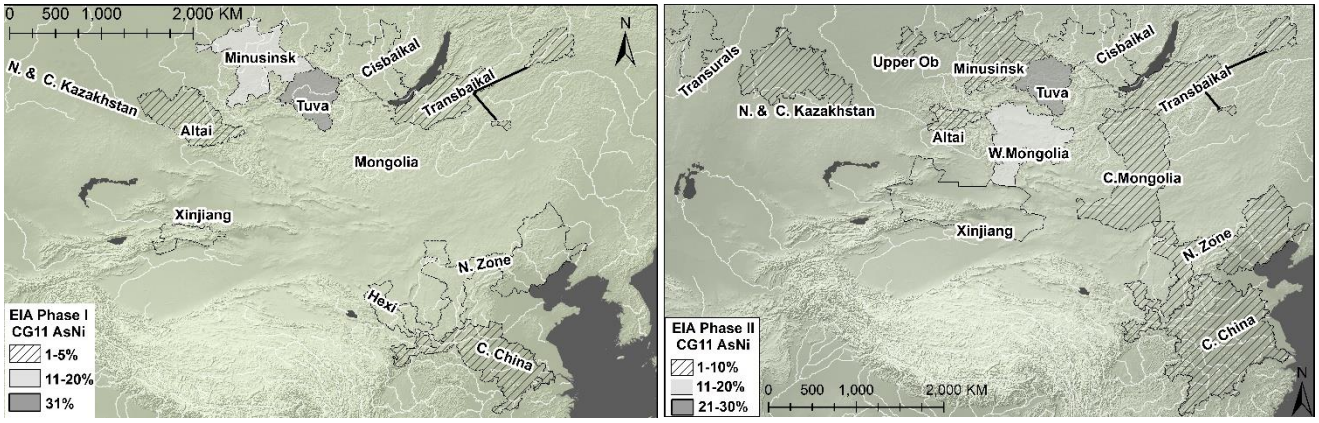


Figure 7.7 Maps showing distribution of CG11 during the Early Iron Age. Left: Phase I. Right: Phase II.

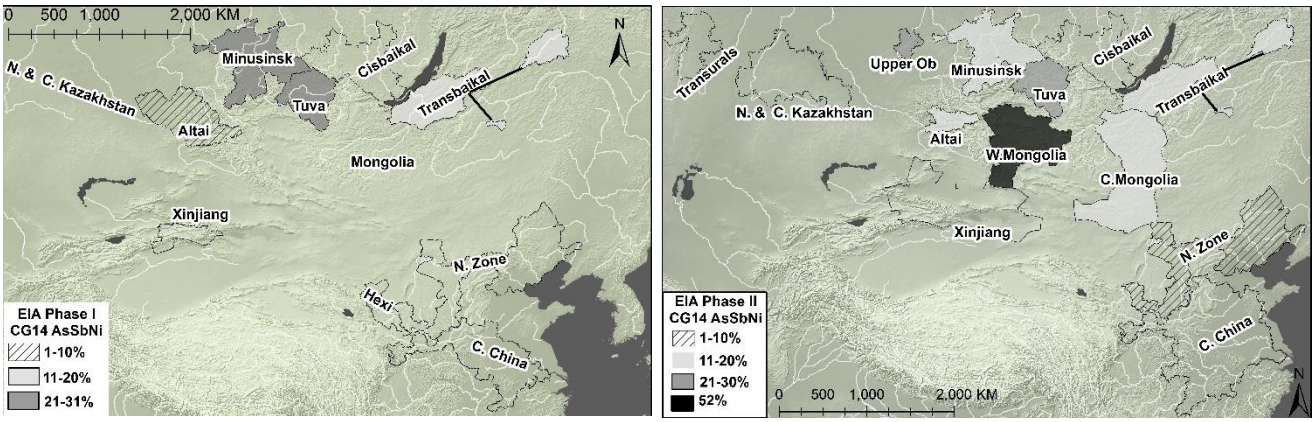


Figure 7.8 Maps showing distribution of CG14 during the Early Iron Age. Left: Phase I. Right: Phase II.

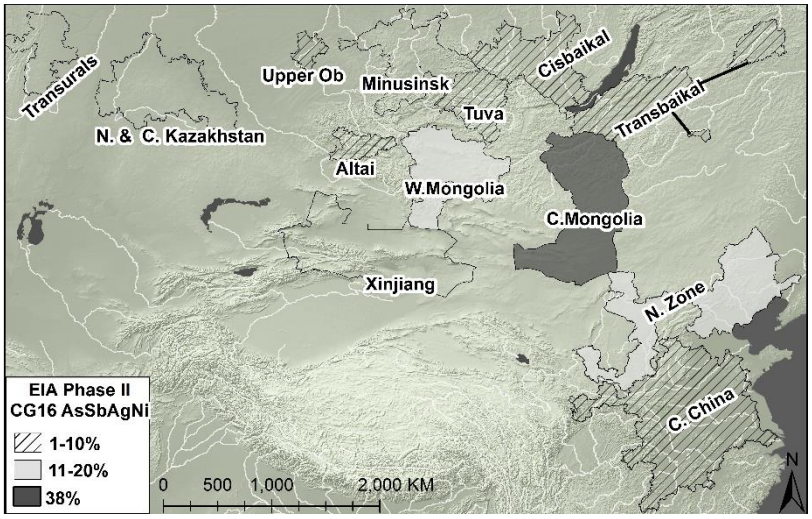


Figure 7.9 Map showing distribution of CG16 during the Early Iron Age Phase II.

7.6 Circulation of copper groups

Having characterised chemical signatures of regional metal production, the next step to explore how metals are distributed over different areas through the observation of metal losses.

7.6.1 Copper group 2 (Phase I)

Figure 7.10 plots the profile of CG2 arsenic across regions during Phase I. It is clear that the distribution pattern of arsenic in the Altai differentiates itself from those of other areas. It consists of two pronounced peaks at 0.5 to 1% and 1.5 to 2% arsenic, which are responsible for over 50% of the Altai CG2 metals. These relatively high arsenic levels may imply a primary CG2 production in the Altai, where metalworkers have easy access to obtaining and smelting the high-arsenic copper ores or they deliberately select arsenic-rich minerals to produce copper-arsenic alloys. Although Tuva also contains a high peak at 1.5 to 2% arsenic, it is possibly the consequence of outliers due to a small sample size.

Moving away from the Altai, arsenic concentrations in other CG2 metals drop significantly below 0.5%. This low-arsenic tendency might be the result of recycling Altai CG2 metals, leading to the arsenic losses. This depletion of arsenic is evidenced by the median arsenic level across regional assemblages (Figure 7.10). Arsenic in the Altai has a median of approximately 1.5%, much higher than those in other regions (0.5%). Interestingly, there is no major difference between the arsenic medians in Tuva, Minusinsk, and Lake Baikal regions. This may suggest a rapid transmission of the Altai CG2 metals due to the highly mobile lifestyle of herders. The similarity of arsenic

levels in these areas may witness shared material culture in distributing steppe-type artefacts.

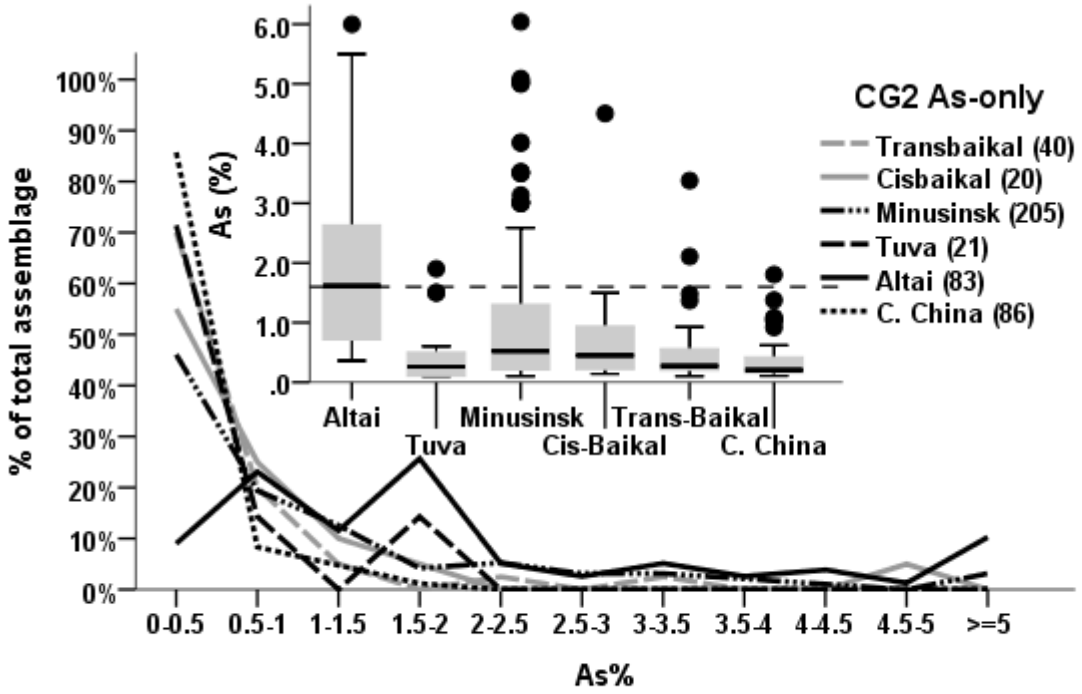


Figure 7.10 Distribution of CG2 arsenic during the EIA Phase I.

7.6.2 Copper group 2 (Phase II)

During Phase II, the circulation of CG2 metals underwent a dramatic change (Figure 7.11). Although the Altai still engaged in the primary production as shown by the identical high-arsenic peaks as previous period, Kazakhstan emerged as another possible candidate to provide CG2 metals, with both high ubiquity and arsenic levels (see Figure 7.3). Western Mongolia, adjacent to the Altai region, also participated in the manufacture of principal CG2 metals. The decline in the Altaian CG2 metalwork could be explained by the expansion of pastoral groups in Kazakhstan and Mongolia who took control of copper resources in the Altai through mobile seasonal migrations. Since the Altai Mountains have been always offering sought-after grasslands for herders, it is highly plausible that raw material was managed by different groups during different periods.

In contrast, recycling of CG2 copper is likely very common in the Ob river, the Minusinsk, Tuva, the Cisbaikal and the Transbaikal, where the profile of arsenic values presents a diminishing trend (Figure 7.12).

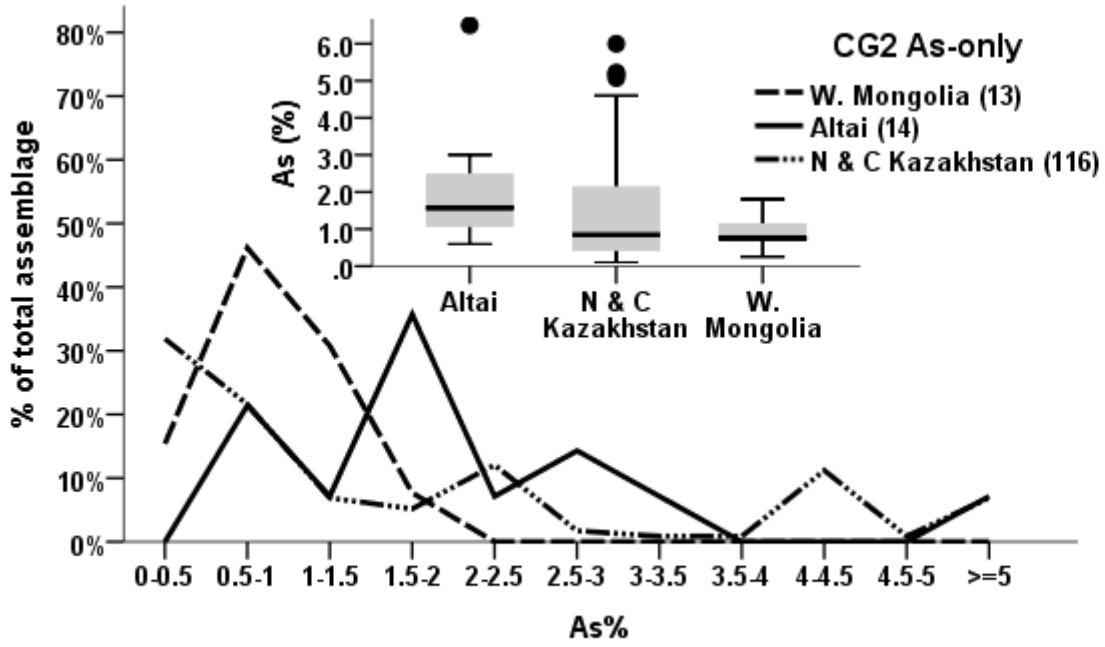


Figure 7.11 Distribution of CG2 arsenic during the EIA Phase II. Primary production.

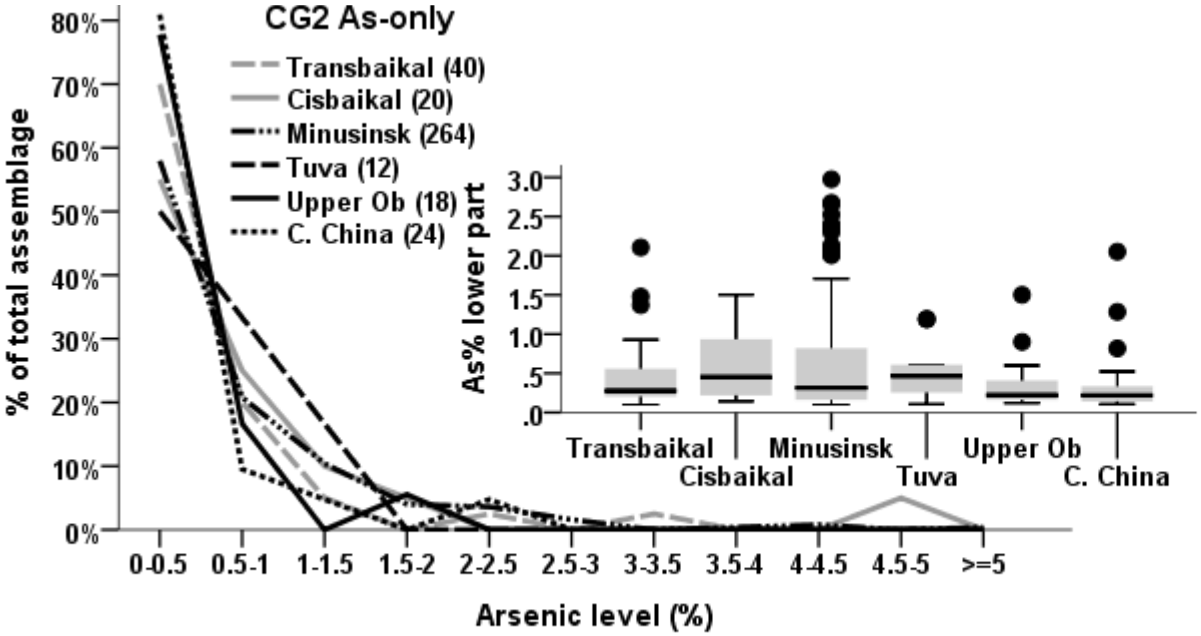


Figure 7.12 Distribution of CG2 arsenic during the EIA Phase II. Non-primary production.

7.6.3 Copper group 6 (Phase I)

The ubiquity plots in Figure 7.4 can roughly inform us of a broad CG6 distribution in the Minusinsk Basin and Lake Baikal regions. However, with a careful observation of trace-element data we might tease out more subtle variations. As shown in Figure 7.13, most regions display a primary signal of CG6 in terms of diagnostic arsenic peaks ranging between 0.5 and 2.5%. Metal composition falling into this interval may indicate a similar life history of metal flow through the direct exchange rather than recycling between regions. The only exception is the Transbaikal showing a more recycling

pattern. From this perspective, we may argue that CG6 metals can be considered as relatively indigenous production in the steppe regions.

Figure 7.13 also notes a special copper-arsenic alloy in Tuva with extremely high arsenic contents (up to 15%). A bi-plot of As and Sb in the CG6 metals demonstrates that while most objects are confined to the values with As<3% and Sb<1%, some metal objects from Tuva are marked by high arsenic and/or antimony concentrations (Figure 7.14). These objects come from the famous Arzhan I kurgan burials and belong to the category of horse harness. These are possibly deliberately-made arsenic-antimony copper alloys.

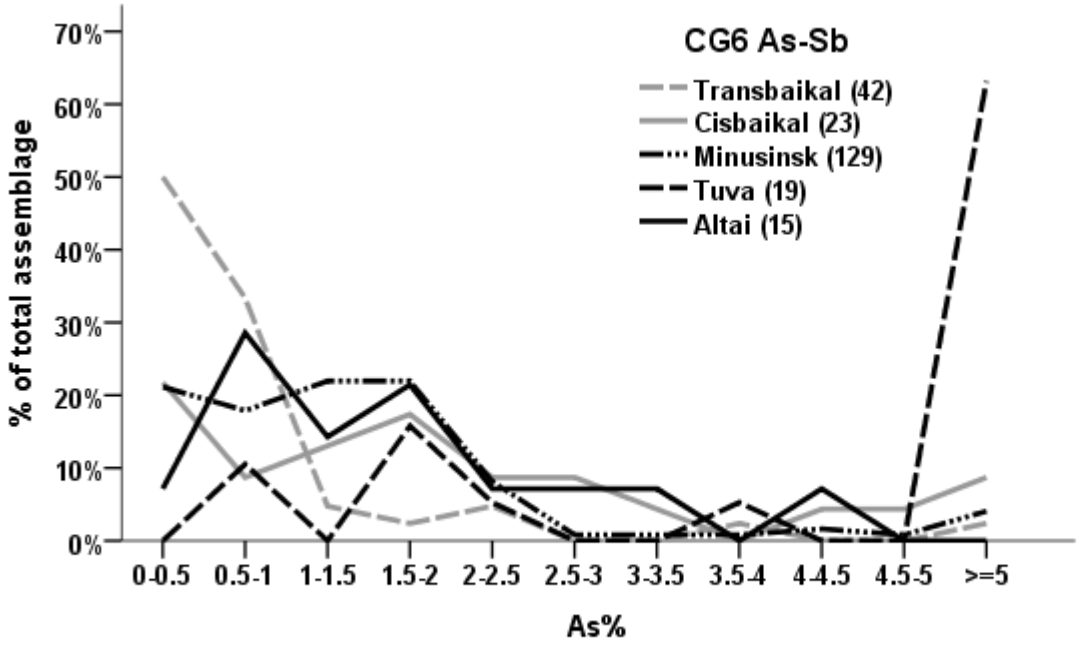


Figure 7.13 Distribution of CG6 arsenic during the EIA Phase I.

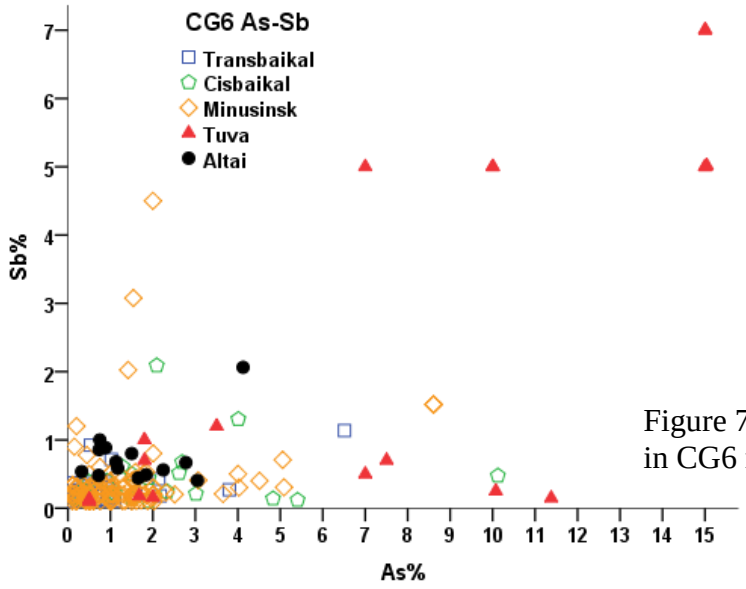


Figure 7.14 Bi-plot of arsenic and antimony in CG6 metals during the EIA phase I.

7.6.4 Copper group 6 (Phase II)

CG6 metals during this period were extended to the Upper Ob and western Mongolia. The profile of arsenic suggests the primary production in the Minusinsk and the Cisbaikal (Figure 7.15, top). While arsenic-rich CG6 objects are present in western Mongolia, its total number is relatively small compared with other copper groups (Table 7.2). Surprisingly, the ubiquity of CG6 metals displays a hot spot in the Upper Ob, but its arsenic content is represented by a typical declining trend with low values (Figure 7.15, bottom). At present, it is difficult to interpret this inconsistency and the answer may lie in the influence from further west in western Siberia, where a powerful metal-producing community had emerged by the 5th country BC (known as the Sargat culture, see Koryakova & Epimakhov 2007:287-311).

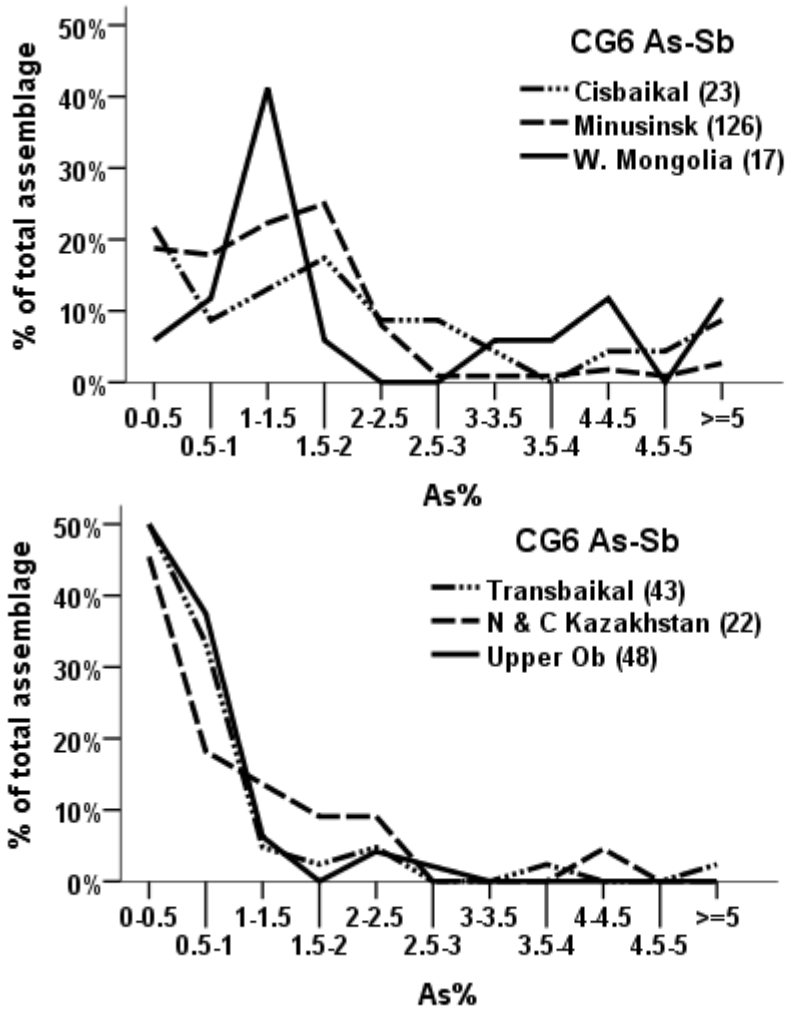


Figure 7.15 Distribution of CG6 arsenic during the EIA Phase II. Top: primary production. Bottom: non-primary production.

7.6.5 Nickel-bearing copper (CG11 & CG14)

During Phase I, nickel-containing metals mark the essential component of metalworking practices in Tuva and the Minusinsk Basin. The profile of CG11 and CG14 arsenic illustrates the similar nature of the metal's character in both regions, with a common peak at 1-2% arsenic (Figure 7.16). Likewise, nickel content in both regions also displays the similar distribution (Figure 7.17). These characteristics suggest a close affiliation of cupro-nickel metalwork between Tuva and the Minusinsk Basin. This specific copper chemistry is also extended into the Transbaikal, where imported Tuva-Minusinsk metals are recycled or mixed with other metal sources, as shown by both relatively lower arsenic and nickel contents (Figure 7.16 & Figure 7.17, right).

Current archaeometallurgical evidence illuminates the importance of copper-nickel production in Tuva and Minusinsk Basin. Many Early Iron Age copper mining, smelting, casting sites have been excavated near the copper-nickel-cobalt deposits in Khovu-Aksy, eastern Tuva (Sunchugashev 1969: 44). Meanwhile, the chemical analysis of copper ingots from Tamir, a Tagar smelting site in the Minusinsk, shows the high concentrations of arsenic greater than 1% and nickel around 0.1 to 0.6% (Sunchugashev 1975: 124-125). Some sites are multi-functional, yielding remains of copper ores, slags, and casting clay moulds. Judging from their production scales and pottery shards, they might have been temporary workshops set up by mobile herders who migrated with their flocks in search for summer pasture in mountainous areas (Sunchugashev 1969).The organisation of metal production probably lacks division of labour work, leading to the combinations of mining, smelting, and casting practices in a single site.

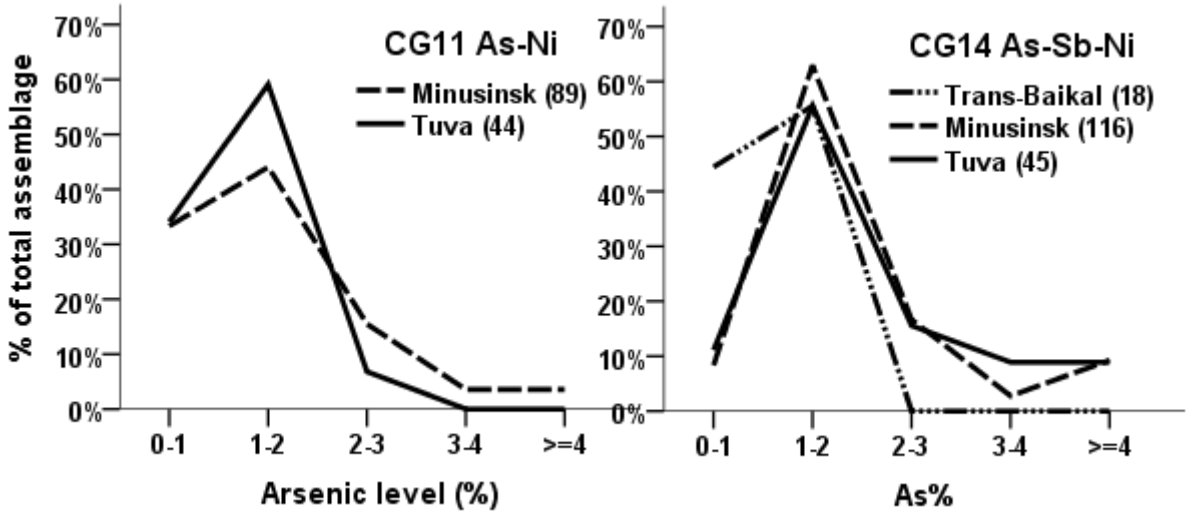


Figure 7.16 Distribution of CG11 & CG14 arsenic during the EIA Phase I.

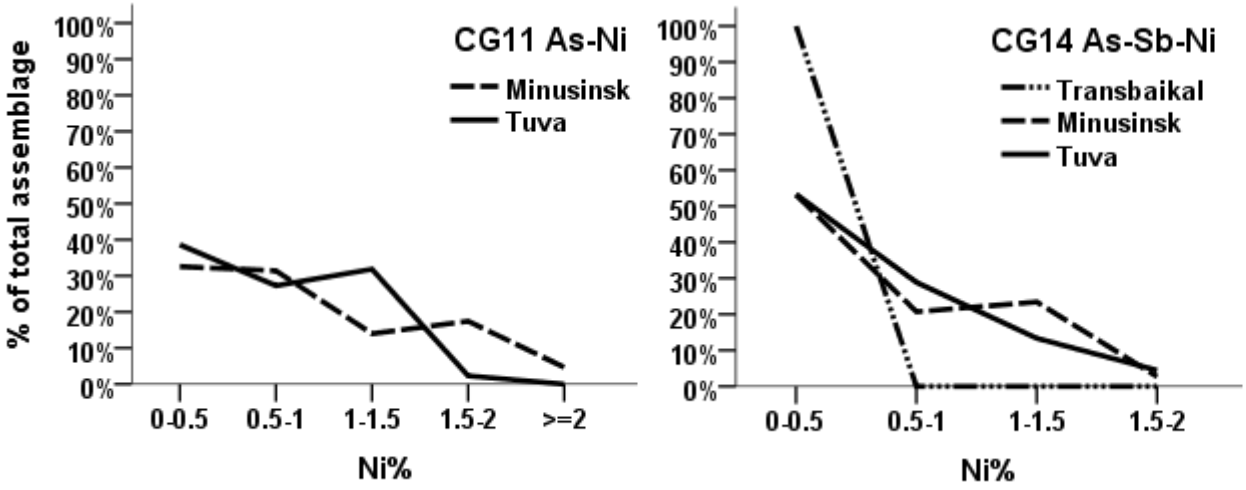


Figure 7.17 Distribution of CG11 & CG14 nickel during the EIA Phase I.

Phase II is marked by copper-nickel production in the Minusinsk Basin and western Mongolia. Arsenic concentrations in both regions are highly related in terms of similar distribution pattern with overlapping peaks at 1-2% arsenic (Figure 7.18, top). CG14 metals from the Minusinsk and W. Mongolia might be transferred to the Transbaikal to the east and the Upper Ob to the west, where observed arsenic values are slightly depleted as shown by slightly left-skewed arsenic peaks (Figure 7.18, bottom). This possible recycling/mixing trend is reflected by low nickel content in Transbaikal and the Upper Ob in comparison with relatively high-nickel objects in the Minusinsk and W. Mongolia (Figure 7.19).

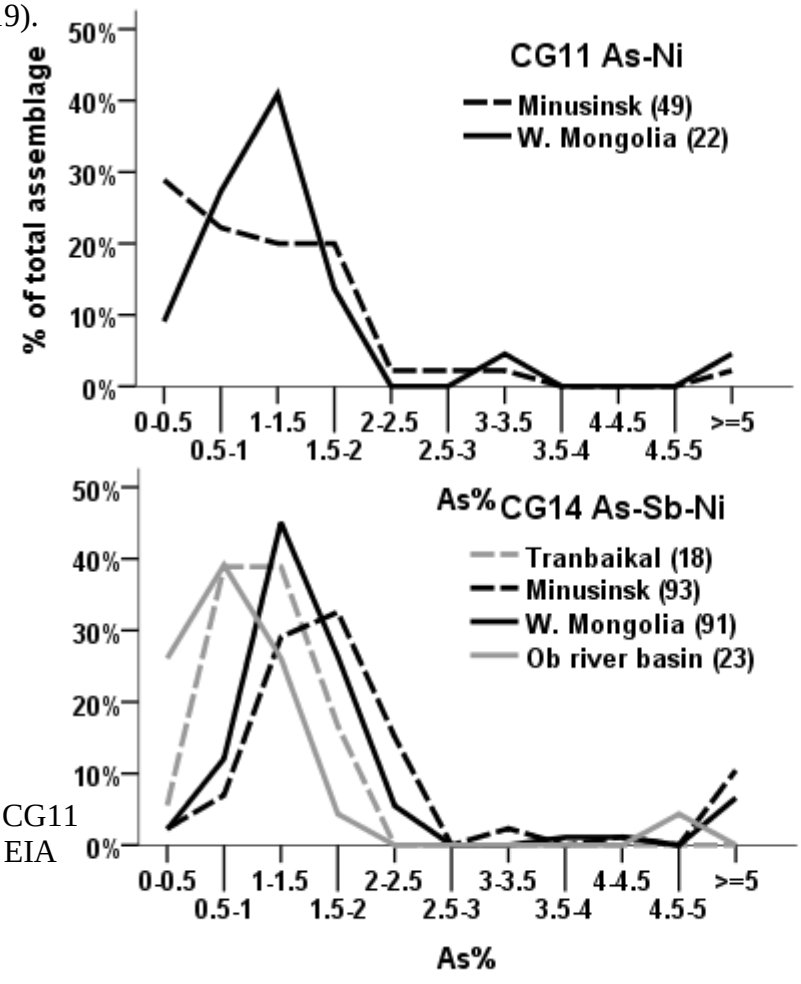


Figure 7.18 Distribution of CG11 & CG14 arsenic during the EIA Phase II.

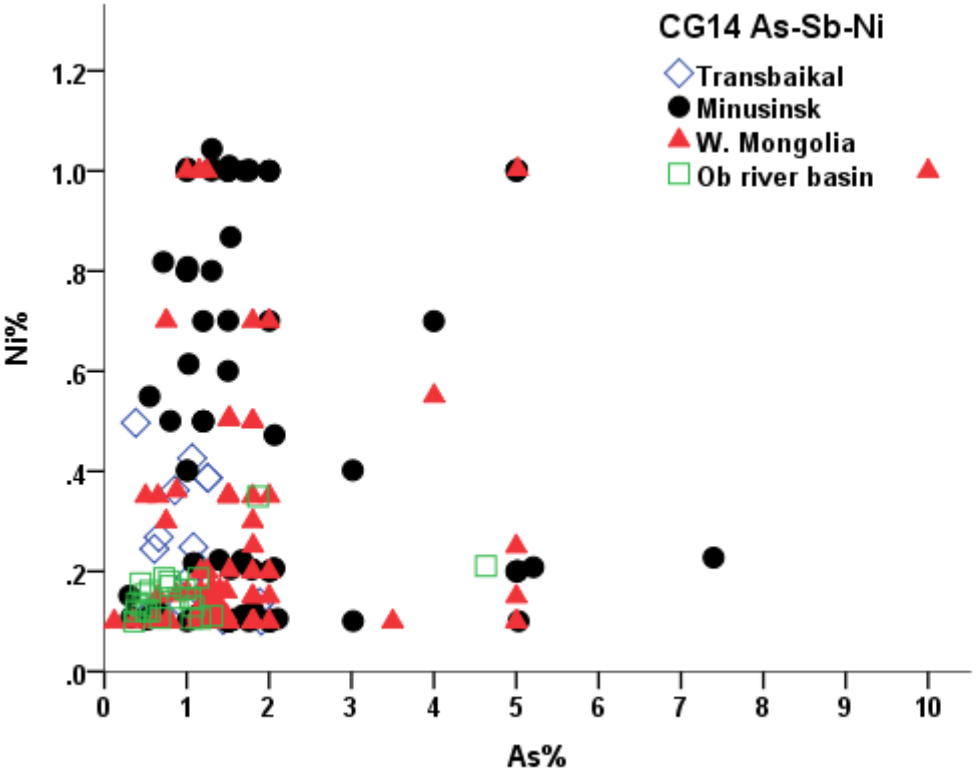


Figure 7.19 A bi-plot of arsenic and nickel in CG14 metals during the EIA Phase II.

7.6.6 Copper group 16 (Phase II)

As suggested above, this copper category represents a probable metal exchange between Mongolia and ancient China. Despite relatively few analyses in this copper group, a simple box-plot demonstrates a potential flow of metal from central Mongolia with high arsenic to the adjacent regions in western Mongolia, the Transbaikal, and the Northern Zone of China (Figure 7.20). Metal composition of the Northern Zone objects features relatively low arsenic (around 0.5%), indicating more recycling or mixing activities. As a result, a detail investigation into this copper chemistry may shed some light on the steppe link in ancient China. With enough compositional data, it is possible to reconstruct the routes of this metal supply from Mongolia to the Northern Zone.

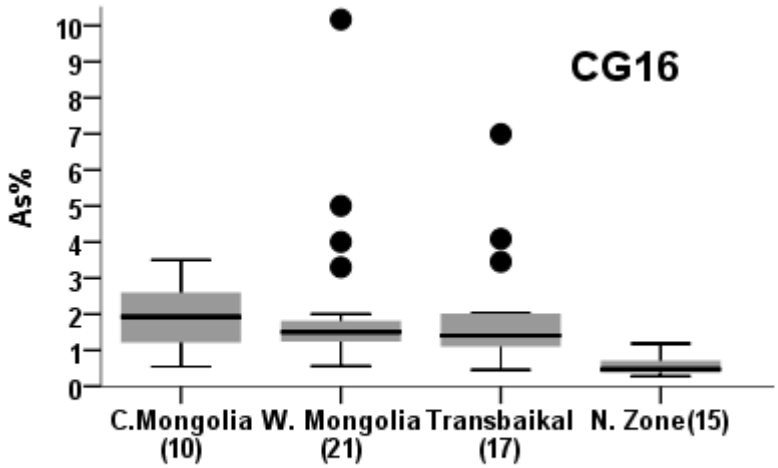


Figure 7.20 Comparison of arsenic concentrations in CG16 metals during the EIA Phase II.

7.7 Distribution of alloy types

Examining the alloy types used by different pastoralist groups can also provide valuable information regarding the circulation of alloying material (tin or lead) either as the metallic form or finished objects. Regions with easy access to those raw materials are likely to generate high proportions of tin-bronze or leaded tin-bronze in their assemblage.

7.7.1 Phase I: 900 to 650 BC

Table 7.3 illustrates the ubiquity of alloy type in a given region. This simple representation strikingly reveals two separate metallurgical traditions in the Early Iron Age of eastern Eurasia. The first is the use of unalloyed copper (mostly arsenical copper) and tin-bronze in the Steppe, which is in stark contrast to the Chinese tradition of leaded tin-bronze. In other words, the addition of lead in copper seemed to be dedicated to Chinese metalwork while steppe societies knew little about this idea. The influence of the leaded technique extended to some semi-sedentary groups in northern China and the Hexi Corridor.

Table 7.3 Ubiquity of alloy types across metal-producing regions during the Early Iron Age Phase I

900 to 650 BC	**Cu**	**Cu-Sn**	**Cu-Sn-Pb**	**Cu-Pb**	**Total N**
Cisbaikal	**52.4%**	26.8%	15.9%	3.7%	82
Transbaikal	20.2%	**53.6%**	17.9%	8.3%	168
Minusinsk	**45.2%**	**43.2%**	9.0%	2.3%	622
Tuva	**94.8%**	3.9%		1.3%	144
Altai	16.5%	**59.7%**	21.6%	2.2%	139
Xinjiang	**42.5%**	**50.0%**	7.5%		40
Hexi Corridor		7.1%	**64.3%**	28.6%	14
N. Zone	8.7%	34.8%	**52.5%**	1.3%	23
C. China	3.3%	24.9%	**69.4%**	2.3%	765
		Sn>1%	**Sn & Pb>1%**	**Pb>1%**	**1997**

Plotting the ubiquity percentages on the map can further show the spatial relationships between different copper-alloy practices (Figure 7.21). The tin-bronze production in the Altai region dominates over those in other steppe regions. Nearly 60% of the Altai objects are alloyed with tin. This proportion drops when moving eastwards away from the Altai. The first stops would be the Minusinsk Basin and Xinjiang which still contain fairly high proportions of tin-bronze (nearly half of the total assemblage). Then, the spread of tin-bronze seems to bypass Tuva and reach the Cisbaikal. Interestingly, the

tin-bronze proportion revives in Transbaikal, which can be explained by rich alluvial tin along the Upper Onon River (Wolf 1982).

The addition of lead, including both leaded copper and leaded tin-bronze, was the feature of Chinese metallurgy. This application was widespread in both settled societies in central China and semi-sedentary communities in the Northern Zone and the Hexi Corridor. In the Steppe, leaded objects (Cu-Pb and Cu-Sn-Pb) chiefly concentrate in the Altai and Lake Baikal regions. While lead in the former region may come from local polymetallic copper deposits, leaded artefacts from the Baikal may indicate the recycling of Chinese leaded tin-bronze (See section 7.8)

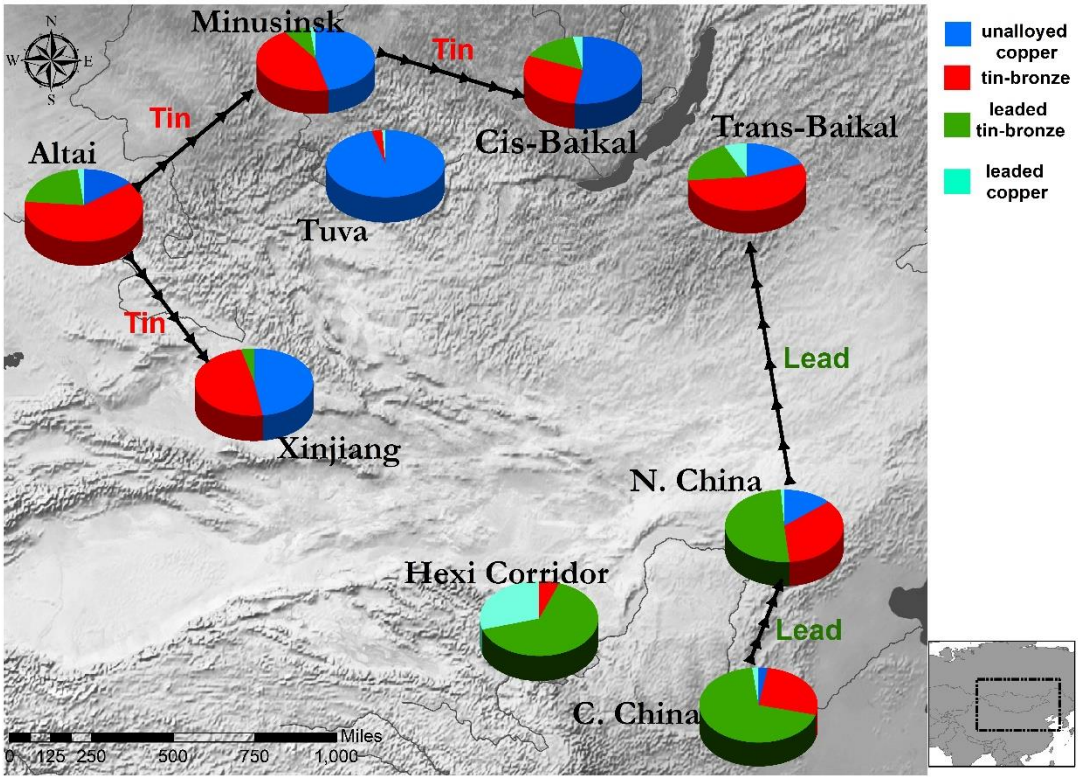


Figure 7.21 Distribution of alloy types during the EIA Phase I.

In order to get a better picture of the usage of tin and lead, it is important to look into the profile of elements to reveal more information. The profile of tin suggests two main categories of tin usage. The first class of tin-bronze is the primary production regions in which ancient metalworkers had access to tin resources to deliberately produce tin bronze/leaded tin-bronze within certain controlled ranges (Figure 7.22, top). Central Chinese metalwork is a best example that shows a unimodal distribution of tin between 7% and 19%. Such a wide range of tin distribution is due to the fact that the analyses include various types of Chinese bronzes which require different levels of tin. Dissemination of tin in Altai shows a certain degree of fluctuation possibly due to a

smaller sample size compared to Chinese specimens. Nevertheless, Altai can still be considered as a principal tin-bronze production characterised by several prominent peaks (one at 10-13% and the other at 16-22%). This fact corresponds to the ubiquity analysis that tin-bronze in the Altai is more substantial than other steppe areas.

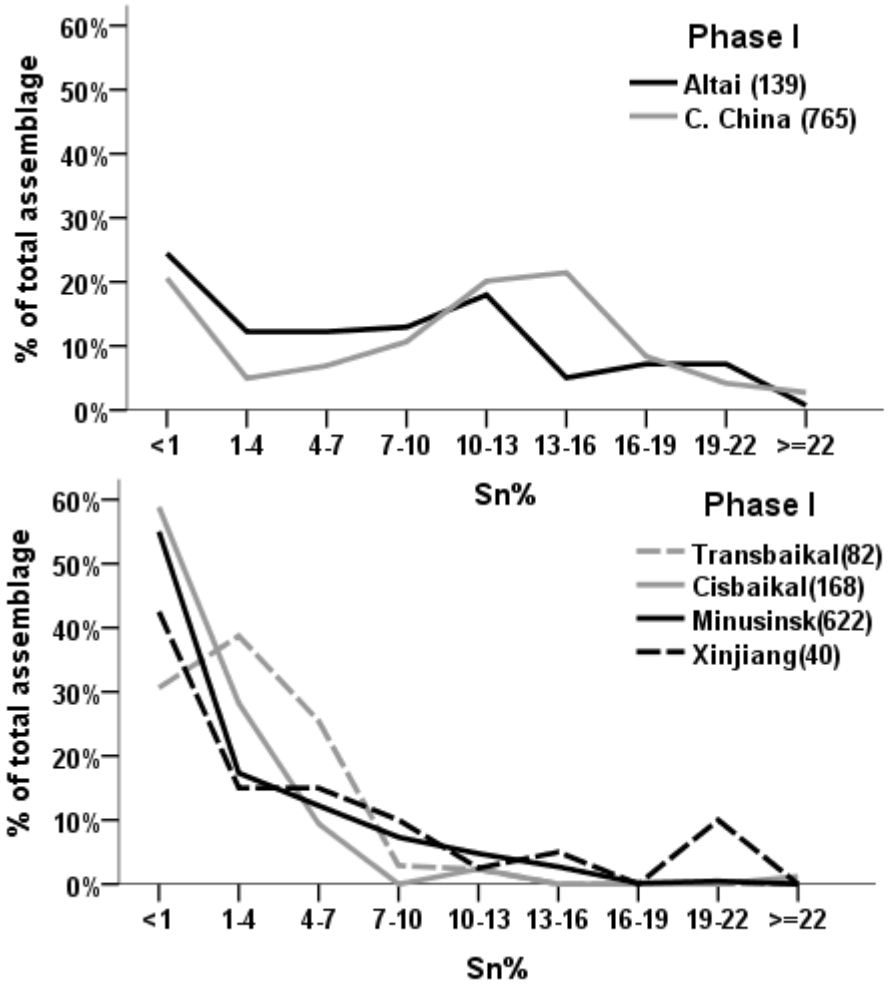


Figure 7.22 Distribution of tin across regions during the EIA Phase. Top: primary tin-bronze production. Bottom: non-primary tin-bronze production.

What I term non-primary tin-bronze production features the low-tin artefacts produced by limited local tin resources (such as Transbaikal) or through recycling tin-bronze from external sources. The Transbaikal, the Cisbaikal, the Minusinsk Basin and Xinjiang are represented by declining curves mainly below 7% tin (Figure 7.22, bottom). Among them, artefacts from the Minusinsk and Xinjiang contain relatively higher tin than those from the Baikal. This result is expected since both the Minusinsk and Xinjiang are immediately adjacent to the tin-rich Altai. Some Xinjiang objects demonstrate enormously abundant tin content (19-22%), which turns out to be bronze mirrors requiring special high-tin manufacture.

Overall, there is a clear pathway of tin-bronze movement from the Altai, through the Minusinsk and Xinjiang, and ultimately to the Cisbaikal. The driving force of such transfer is marked by recycling and mixing as showed by the depleted tin concentrations. However, low-tin bronze in Transbaikal poses a more difficult challenge to understand the flow of tin. It is unclear whether the low-tin bronze in Transbaikal results from local alloying preferences or recycling of foreign tin-bronze objects. It is unlikely to produce such low-tin artefacts if metalworkers in Transbaikal have access to tin. It is more likely that Transbaikal had received tin-bronze metals from outside and recast them into local forms. We can investigate this issue further by observing the tin-bronze in a given copper group. It allows us to check whether tin is derived from metallic tin ingots or comes with copper as finished objects.

If tin-bronze objects in one place are frequently re-melted in another place, we would expect arsenic losses over the assemblage. Figure 7.23 displays the distribution of arsenic content in the CG2 tin-bronze (Sn>1%). It is evident that the Altai bronzes feature a primary source of tin-bronze production with high arsenic levels. Such high arsenic concentrations are depleted along the movement of such metals to the east. This suggests that Altai tin is mainly transported as CG2 copper-tin alloys and they are recycled in the Minusinsk and Baikal.

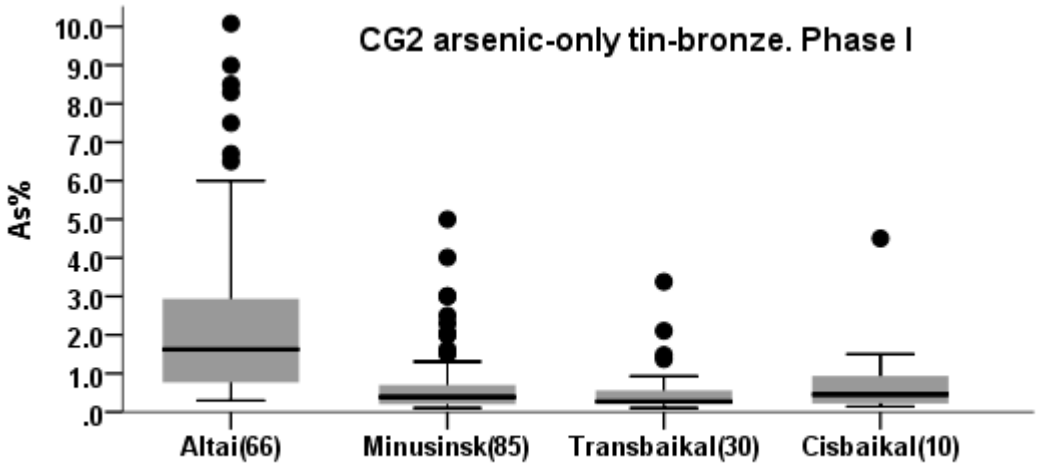


Figure 7.23 Diminishing arsenic content in tin-bronze (tin>1%) from the Altai to Baikal regions.

7.7.2 Phase II: 650 to 300 BC

The Altai lost its dominance over tin-bronze production during Phase II. Multiple metal-producing communities in Kazakhstan, the Upper Ob, the Minusinsk Basin and Tuva had emerged to play a role in the copper-tin alloying (Table 7.4). Spatial

distribution of alloy types indicate a widespread use of tin-bronze in the steppe except for two areas: the Transurals (S. Urals) and western Mongolia (Figure 7.24). As the Urals are located far away from the potential tin sources in the Altai Mountains, it is understandable why this region lacks tin-bronze artefacts. However, it is odd not to identify the primary use of tin-bronze in western Mongolia near the Altai. It is argued that copper smiths there exploited specific copper ore deposits with fairly high arsenic concentrations (see Section 7.8).

Table 7.4 Ubiquity of alloy types across metal-using regions during the Early Iron Age Phase II.

650 to 300 BC	Cu	Cu-Sn	Cu-Sn-Pb	Cu-Pb	Total N
Cisbaikal	**52.4%**	26.6%	15.9%	3.7%	82
Transbaikal	20.2%	**53.6%**	17.9%	8.3%	169
C. Mongolia	**46.2%**	32.7%	17.3%	3.8%	52
Minusinsk	**32.3%**	**49.4%**	16.5%	1.7%	654
Tuva	38.7%	**48.4%**	9.5%	0.0%	31
W. Mongolia	**89.9%**	6.1%	1.1%	2.2%	179
Altai	**56.3%**	25.0%	14.6%	4.2%	48
Upper Ob	**45.0%**	**51.4%**	0.9%	2.8%	109
Xinjiang	**50.0%**	33.3%	16.7%	0.0%	60
N.& C. Kazakh	27.2%	**65.6%**	6.7%	0.0%	195
Transurals	**94.1%**	5.9%	0.0%	0.0%	68
N. Zone	2.1%	7.2%	**89.1%**	1.4%	652
C. China	2.2%	10.1%	**86.4%**	1.3%	674
		Sn>1%	Sn & Pb>1%	Pb>1%	**2973**

The profile of tin illuminates two possible scenarios of copper-tin production: one from the Steppe and the other from central China. Rather than focusing on one particular region, the steppe tin is equally distributed over the vast territory with similar distribution of tin concentrations (Figure 7.25). While objects from Kazakhstan contain slightly higher tin, the difference with other regions are quite small. Compared with Phase I, high-tin bronzes (over 13%) are almost absent during Phase II and overall ubiquity of primary tin (10-13%) is lower (Figure 7.26). This may imply that tin bronzes from Phase I were reused and therefore tin concentrations in Phase II artefacts are relatively low. Furthermore, although Tuva and Xinjiang artefacts demonstrate potential high-tin production, their tin profiles are severely fluctuating due to small

sample sizes, which make it difficult to evaluate the genuine situation of their tin-bronze usages (Figure 7.27).

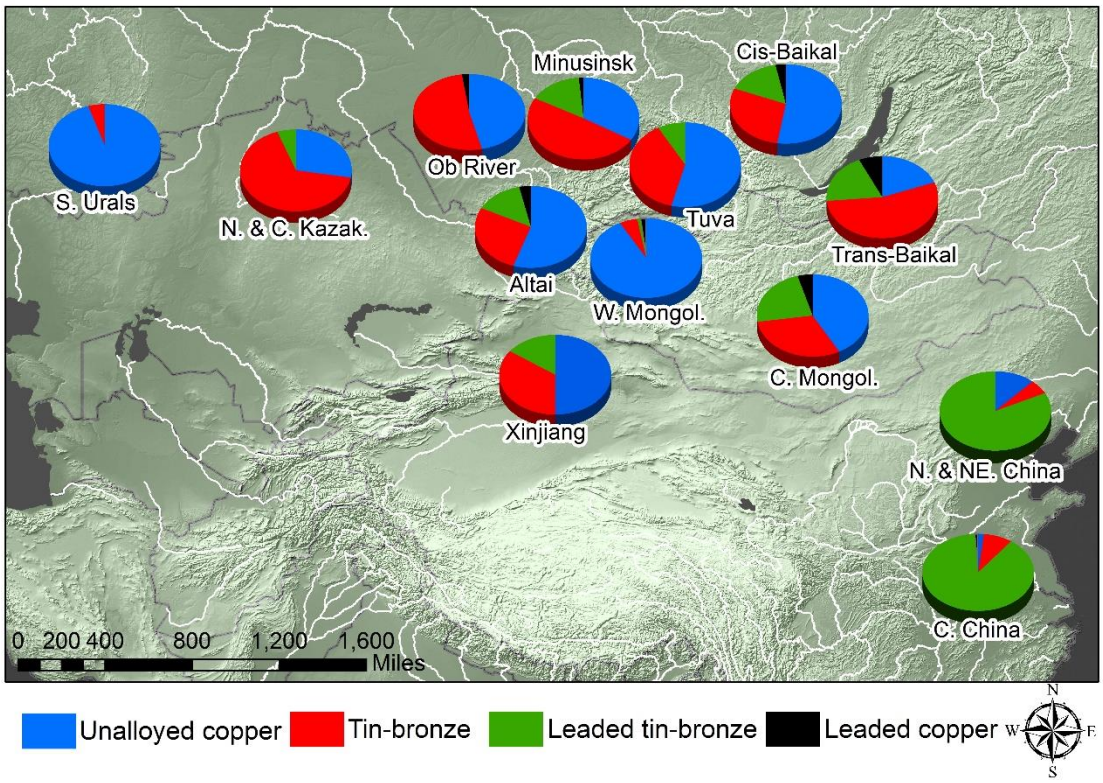


Figure 7.24 Ubiquity of alloy types across eastern Eurasia during the EIA Phase II.

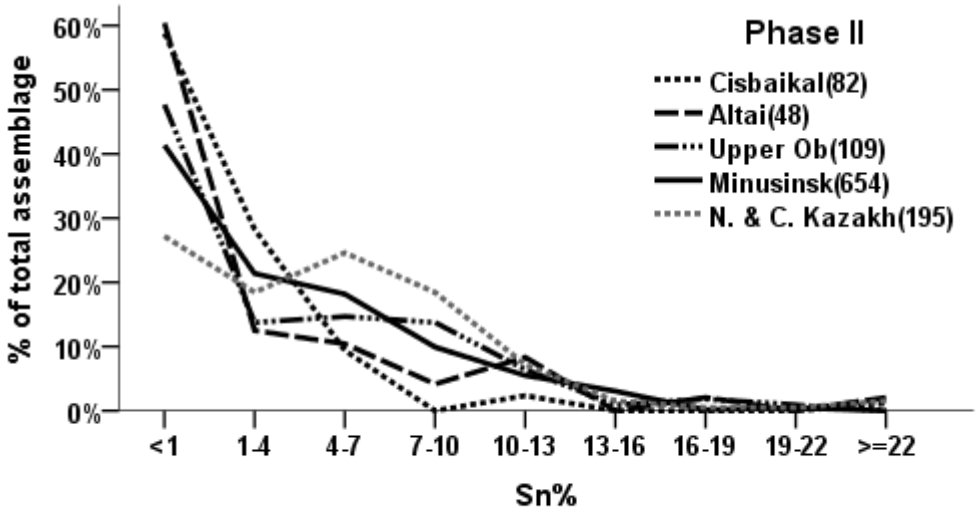


Figure 7.25 Distribution of tin across eastern Eurasian metals during the EIA Phase II.

Apart from the Steppe tin, Chinese tin also plays an important role in the copper-tin alloys from the eastern part of the Eurasian steppe. Figure 7.28 plots the distribution of tin in central China, Northern Zone, central Mongolia and Transbaikal. There is a clear pattern of gradual decrease in tin content when moving from south (China) to north (Transbaikal). As suggested by both copper chemistry and typology, these areas

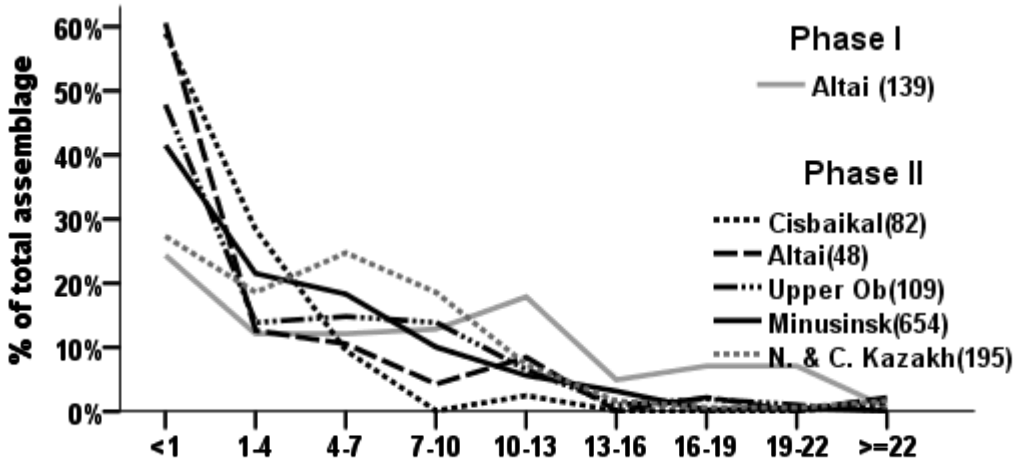


Figure 7.26 Comparison of tin concentrations between Phase I and Phase II tin-bronze.

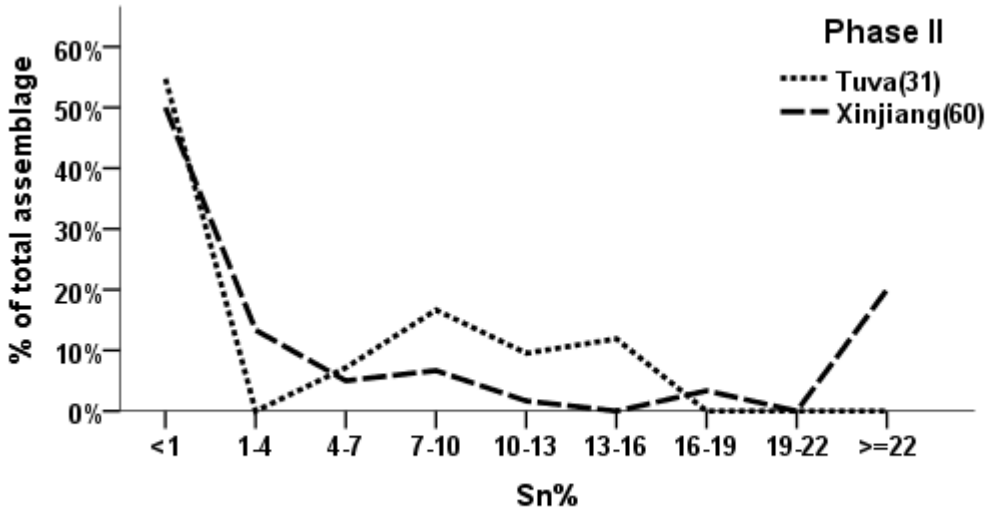


Figure 7.27 Distribution of tin in metal objects from Tuva and Xinjiang. Some artefacts show high concentrations of tin.

are highly interconnected during the Early Iron Age. Interestingly, while metal artefacts from the Northern Zone are stylistically similar to the Eurasian steppe, their manufacture complies with central Chinese traditions with similar ranges of tin concentrations. This characteristic is more remarkable when we look into lead content (see below). As a result, it is proposed here that this communication is channelled by the recycling of Chinese leaded tin-bronze to the north as well as flow of ideas of making steppe-style artefacts to the south.

The transfer of Chinese tin is probably by means of finished products rather than tin ingots as leaded tin-bronze are relatively more abundant in certain regions of the Steppe (namely central Mongolia and the Baikal). It is highly plausible that lead in those steppe artefacts originated from ancient China, where leaded tin-bronze production had been well established since the late-Shang period. Judging from the distribution of lead, the

movement of Chinese leaded tin-bronze possibly adopts two major routes. To the north there is a declining Pb concentrations from C. Mongolia all the way to Lake Baikal regions, the Minusinsk and Altai (Figure 7.29). To the west, leaded tin-bronze occurs in Xinjiang with a median of lead around 5%.

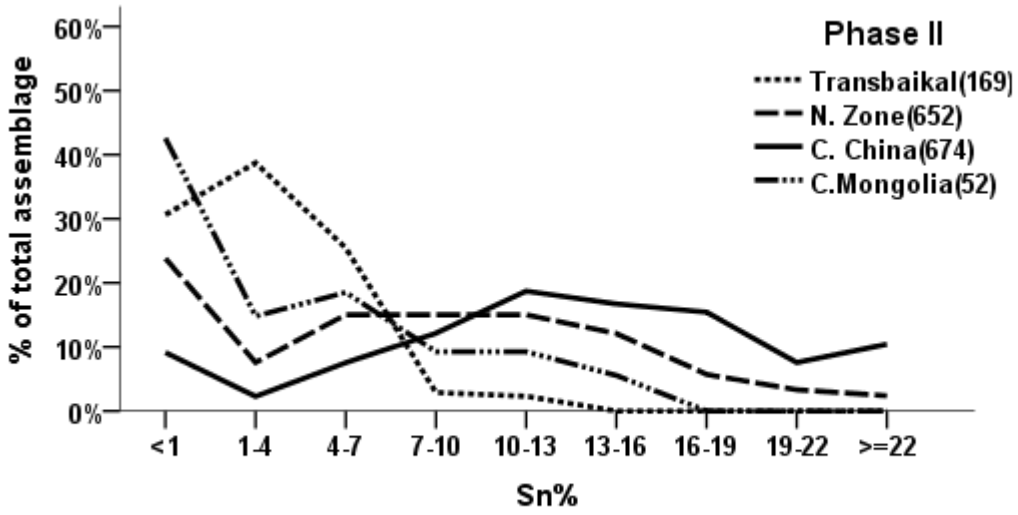


Figure 7.28 Distribution of tin in metal objects between China and the Steppe. It shows deleted tin concentrations from central China to Transbaikal.

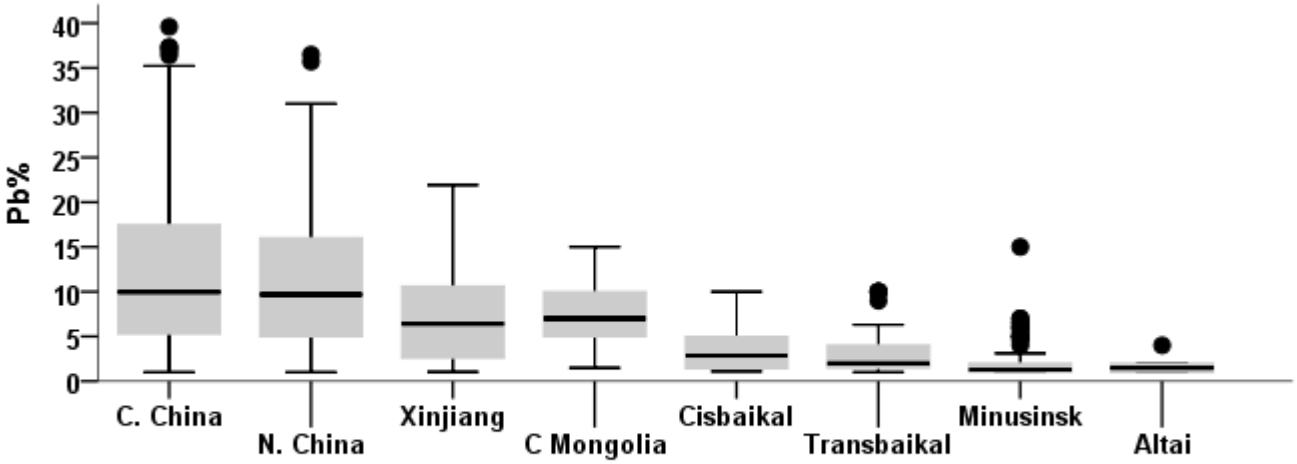


Figure 7.4 Distribution of lead in metal objects between China and the Steppe. It is marked by decreasing lead content from central China to the Steppe.

7.8 Alloying elements in relation to copper groups

Comparison of tin or lead concentrations between different copper groups demonstrates varied ways of metalworking preferences in the Steppe. The Altai, as a primary copper-tin alloy region, consists of two types of tin-bronze production (Figure 7.30, top left). One is based on local copper sources, namely CG2 and CG6, to manufacture high-tin artefacts. The other is the use of pure copper (CG1) for low-tin bronze in which more recycling/mixing takes place. Similarly, Kazakhstan also specialised in producing high-tin bronzes made from CG2 and CG6 sources as opposed to relatively recycled CG1

tin-bronze (Figure 7.30, top right). Pure copper sources may come from the Transurals, where 75% of copper alloys belong to this copper type. This region was renowned for pure copper production during the Late Bronze Age (see Chapter 5).

On the other hand, the Minusinsk Basin, as a tin-free area, shows a diminishing tin level throughout each copper group (Figure 7.30, lower). It implies that once tin flowed into Minusinsk, local artisans, unable to know the subtle trace-element differences in copper, mixed all available copper with imported tin bronzes.

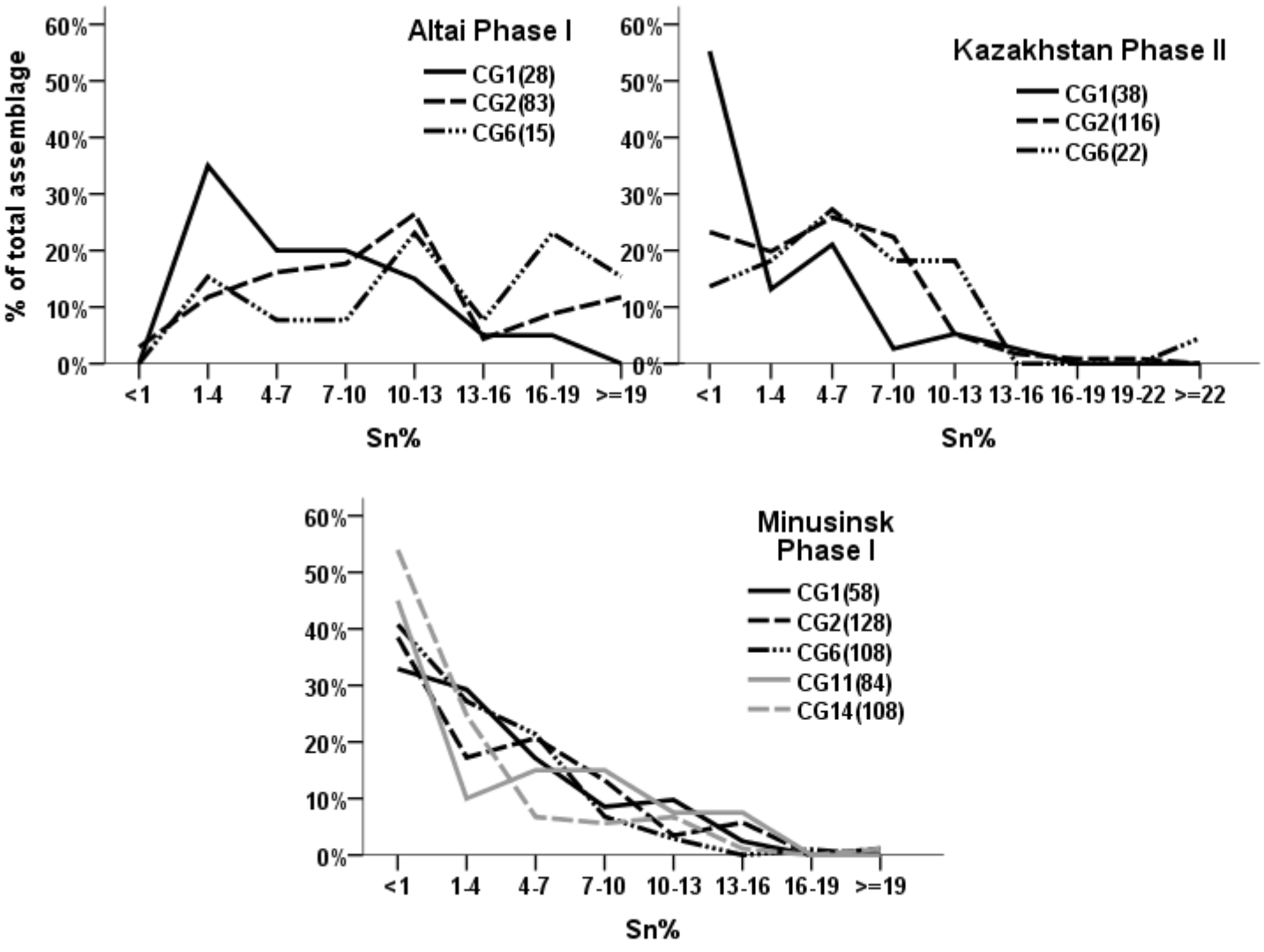


Figure 7.30 Distribution of tin concentrations across different copper groups in a given region. Top left: Altai. Top right: Kazakhstan. Bottom: Minusinsk.

Lead is another substance that was commonly added in ancient metals. In the whole eastern Eurasia, China was considered as the only place where their bronzes were

constantly deliberately alloyed with lead. Copper-based artefacts in the Steppe basically contain very little lead except for Mongolia and Baikal. As stressed above, both copper chemistry and alloying practices in these two regions illuminate a possible route of metal exchange with the south. The distribution of lead in Transbaikal copper groups further consolidate this connection (Figure 7.31). Silver-bearing copper (CG12), as a typical chemical signature of Chinese leaded tin-bronze, contains relatively higher lead concentrations than those of other groups. This provides a clue to associate this copper type with a Chinese origin.

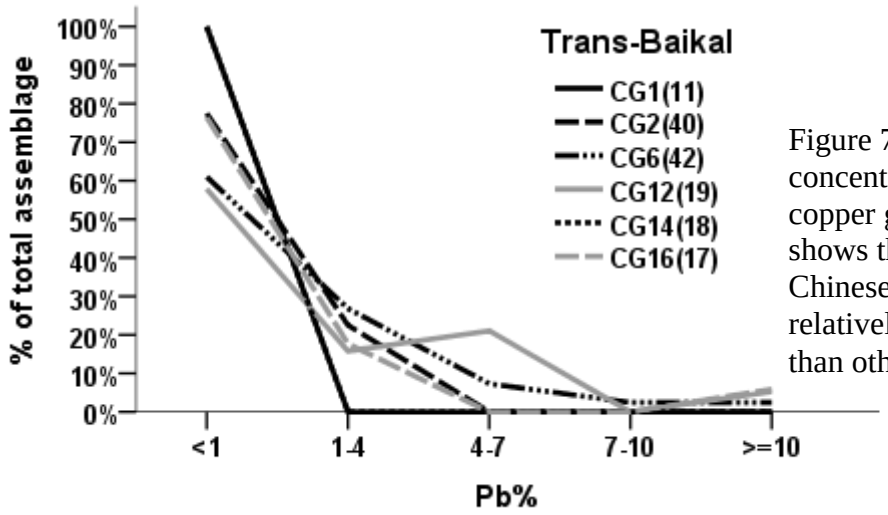


Figure 7.31 Distribution of lead concentrations across different copper groups in Transbaikal. It shows that CG12, a typical Chinese copper group, contains relatively more abundant lead than other groups

7.9 Object typology and chemistry

So far we have discussed the various copper groups and alloy types without taking object typology into account. The main reason is that when dividing the datasets into different artefact categories, we are forced to deal with smaller sample sizes in each object type. This may prevent us from making a firm conclusion regarding chemical pattern. Typology; however, is one of the most important factors to determine the nature of copper alloys representing different metalworking traditions between regions. In this section, I am particularly targeting metal production in the Transbaikal and the Minusinsk as their artefact chemistry demonstrates the most interesting and diverse life histories.

7.9.1 Transbaikal

Figure 7.32 (left) presents the profile of tin across artefact types in Transbaikal. We can immediately notice a similar alloying pattern between single-bladed knives, weapons and tools with tin mainly ranging from 1% to 7%. They are presumably utilitarian items which require certain degree of hardness. On the contrary, over 60% of ornaments

contain less than 1% tin, and only occasionally were decorative items alloyed with low amounts of tin. Another interesting aspect is the relatively higher lead contents in ornaments (Figure 7.32, right). The addition of lead can increase the fluidity of molten metal for casting intricate motifs. However, this is not implying that Transbaikal metalworkers were aware of this advantage because lead in the Transbaikal artefacts was possibly obtained from re-casting of Chinese leaded imports rather than the conscious addition of lead locally.

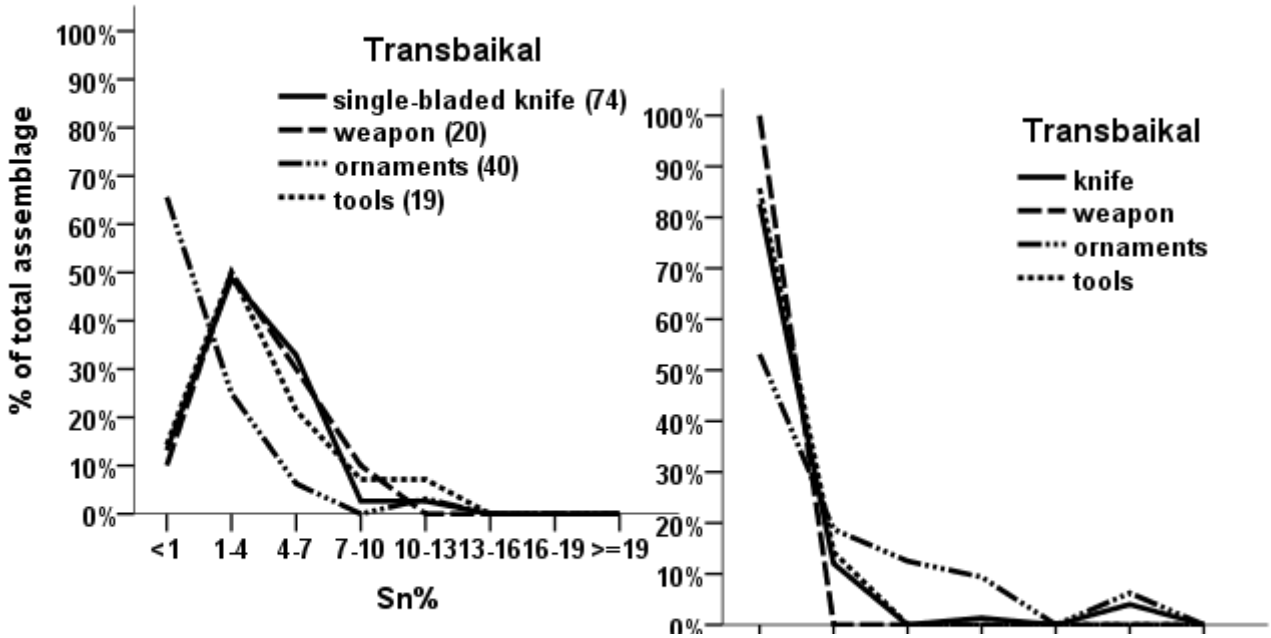


Figure 7.32 Distribution of tin and lead in different artefact types from the Transbaikal. Ornaments tend to contain lower Sn but higher Pb.

In order to identify possible foreign metals in the Transbaikal, one should turn to the underlying copper groups behind object typology. As can be seen in Figure 7.33, single-bladed knives and tools display dominant proportions of CG14 compared with other artefact types. As we have mentioned above, CG14 is a typical copper production in the Minusinsk-Tuva area. As a result, CG14 knives and tools found in the Transbaikal are likely to be imports from those regions. By contrast, ornaments marked by a high ratio of CG12 are likely related to Chinese sources.

7.9.2 Minusinsk Basin

Objects from the Minusinsk Basin form the largest assemblage in the whole dataset. They can be divided into several categories: single-bladed knives, weapons (daggers,

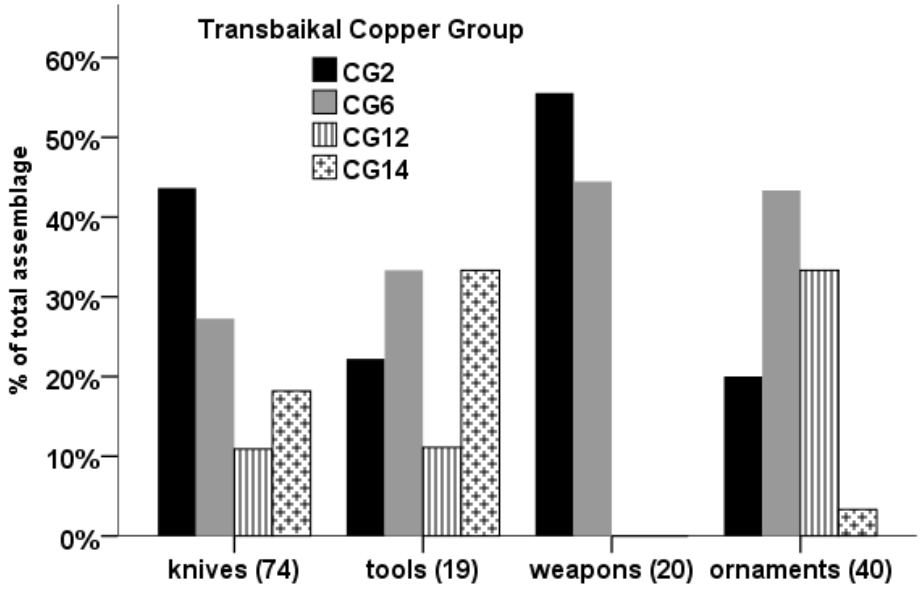


Figure 7.33 Distribution of copper groups in different artefact types from Transbaikal.

pick-axes, arrowheads and spearheads), ornaments, horse harness, tools and vessels (cauldrons). We find it difficult to observe any specification of alloy types across of different classes of artefacts except for vessels and horse bridles which are mostly made unalloyed copper (Figure 7.34). Copper smiths in the Minusinsk possibly applied similar alloying strategies to weapons, single-edged knives and ornaments even if each artefact type serves different purposes in their communities. The tin profile across different artefact types also reflects such indifference between artefact types except for slightly lower tin levels in tools (Figure 7.35).

Thus far, the discussion has considered all types of copper alloy objects together on 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 7.5, these knives mainly consist of CG2 “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 7.36, left). The similar profile of tin (between 1 and 7%) may suggest that some were even transported directly between Minusinsk and the Transbaikal (Figure 7.36, right). Consequently, the circulation of metal in eastern

Eurasia probably involved two stages of exchange. One is represented by the recycling/mixing of Altai CG2 tin-bronze in the Minusinsk Basin and Baikal region as shown by decreasing arsenic and tin contents (see Figure 7.10 & 7.23). The other way of exchange involves direct movement of finished products (e.g. single-bladed knives) across the eastern steppes.

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 (CG2, CG6, CG11 and CG14). 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).

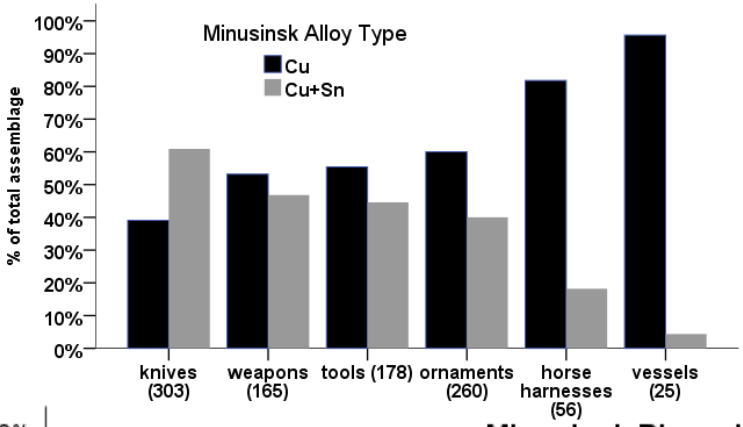


Figure 7.34 Distribution of copper groups in different artefact types from the Minusinsk.

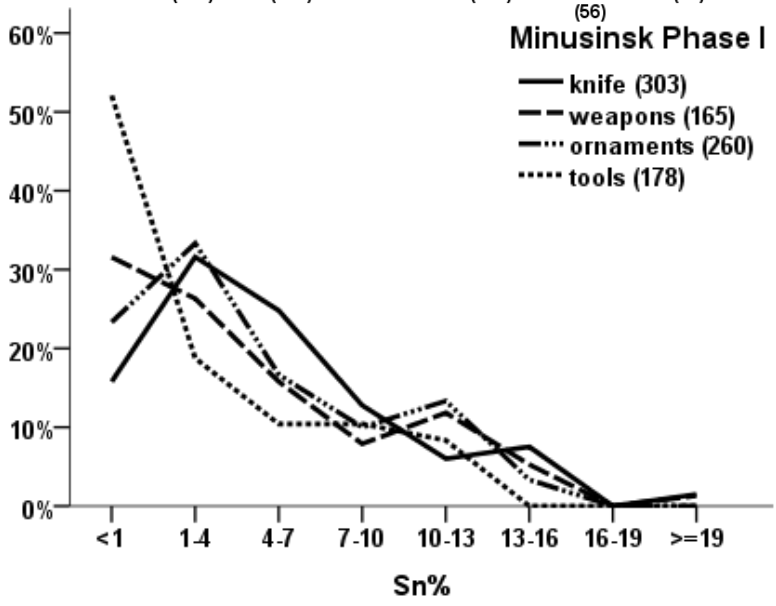


Figure 7.35 Distribution of tin in different artefact types from the Minusinsk.

Table 7.5 Ubiquity of copper groups and alloy types among single-edged knives and cauldrons during the EIA.

Early Iron Age	***Single-bladed knife***			***Cauldron***
Copper Group	**Cisbaikal**	**Transbaikal**	**Minusinsk**	**Minusinsk**
CG1	28.6%	4.0%	8.7%	28.0%
CG2 As	**42.9%**	**32.0%**	**36.5%**	**32.0%**
CG6 AsSb	7.1%	20.0%	22.2%	16.0%
CG9 AsAg	7.1%	5.3%	1.6%	
CG11 AsNi		4.0%	16.7%	
CG12 AsSbAg	7.1%	8.0%	0.8%	
CG14 AsSbNi		13.3%	19.8%	24.0%
CG15 AsAgNi		1.3%		
CG16 AsSbAgNi		10.7%	0.8%	
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		15.8%	12.4%	12.0%
Cu-Pb		1.3%	1.3%	16.0%
Total	16	76	153	25

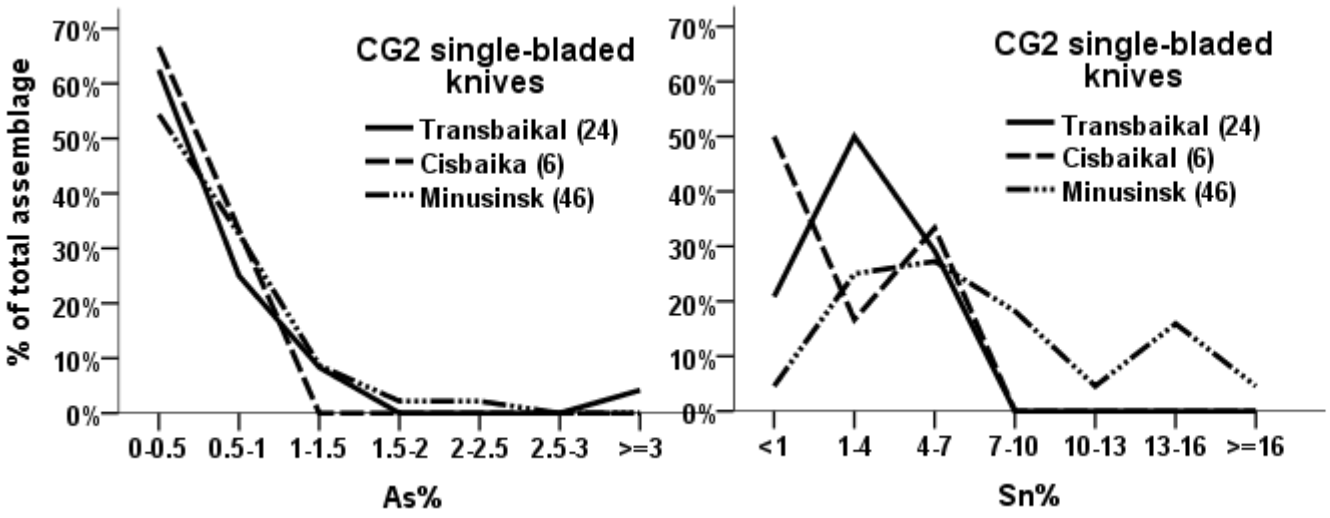


Figure 7.36 Distribution of arsenic and tin in the single-bladed knives from the Minusinsk, the Cisbaikal and the Transbaikal.

7.10 Overall patterns of metal movement during the Early Iron Age

Figure 7.37 & 7.38 recapitulate the potential directional flow of metal under discussion. During the Early Iron Age Phase I, CG2 arsenic-only copper in the Altai was transferred to the Minusinsk Basin and Lake Baikal regions through recycling. Tin-bronze artefacts

from Altai were first re-melted in the Minusinsk Basin and Xinjiang and eventually arrived at the Cisbaikal, bypassing Tuva. Meanwhile, nickel-bearing copper (CG11 and CG14), deeply rooted in the Tuvinian and Minusinsk metalwork, reached as far as Transbaikal. Lastly, the occurrence of CG12 silver-containing copper in Transbaikal suggests a possible long-distance connection with ancient China through the transmission of leaded tin-bronze objects.

When moving onto Phase II, metal production was highly diversified as shown by different levels of copper chemistry and tin-bronze production. While the previous metallurgical centres in Altai, Minusinsk and Tuva remained active, Kazakhstan and the Upper Ob emerged as the important production centres. It is difficult to delineate distribution routes of copper alloys (especially for tin-bronze) at this time due to extremely diverse metal exchange driven by highly mobile horse-riding herding strategies. Nevertheless, western Mongolia is an exception where metalworkers relied heavily on a local copper-arsenic alloying practice without receiving much tin-bronze from outside. Moreover, this period is still marked by powerful nickel-bearing copper production in Tuva and Minusinsk, plus western Mongolia as a new manufacture centre for cupro-nickel alloys. Finally, the metallurgical link between the Steppe and China became increasingly interconnected through central Mongolia in which both Steppe and Chinese metalworking traditions are highly mixed as shown by copper chemistry (CG16) and leaded artefacts.

These patterns of movement suggest a dynamic structure of steppe metallurgy among pastoral communities by means of short-distance contacts. Mobile pastoralists first exploited the indigenous ore resources to make bronze objects and metals were distributed to other pastoral groups along the seasonal migration for herding. Metals, whether they took the forms of finished products or scrap pieces, were exchanged to these new owners who re-cast them into desirable artefacts. The new items would inherit the chemical fingerprints from their original birthplaces. The Altaian copper or tin-bronze may have moved eastwards into the Minusinsk Basin and Lake Baikal regions where metal was reworked into objects with low arsenic and tin. On the other hand, nickel-bearing copper from Tuva and Minusinsk flowed into both the east (Transbaikal) and the west (Altai), suggesting an increasing connectivity in the pastoral world during the first millennium BC. This rapid spread of metals was facilitated by the increasing use of horse-riding practices across the Steppe.

Outside the sphere of the Steppe, ideas of making steppe-style artefacts could travel an enormously long distance into semi-sedentary or agricultural societies. The forms of these objects are strikingly similar to their parallels in the steppe, but their chemical signature could be radically different. For instance, while the Northern Zone bronzes are characterised by their unique steppe animal-style representation, they are often alloyed with lead and tin in contrast with arsenical copper and tin-bronze in the Steppe.

This attempt to hypothesise a metallurgical network through re-interpreting the legacy data is still facing a series of challenges derived from insufficient information regarding geography, chronology, and typology of objects. Firstly, the current research covers little trace-element data from central Mongolia, Xinjiang and the Northern Zone. These regions are indispensable parts for the understanding of the full picture of Trans-Eurasian communication, especially for the interactions between the steppe pastoralists and urban agriculturalists. Secondly, the comprehensive radiocarbon dates are only available in Tuva, the Minusinsk Basin, and central China. The majority of the Early Iron Age societies have ambiguous timeframes, posing a difficult challenge for the synchronous comparison. Finally, it is hoped that future studies can focus more on the correlation between object typology and chemistry. It is through changing forms of artefacts that different communities exchanged their metallurgical ideas and substances.

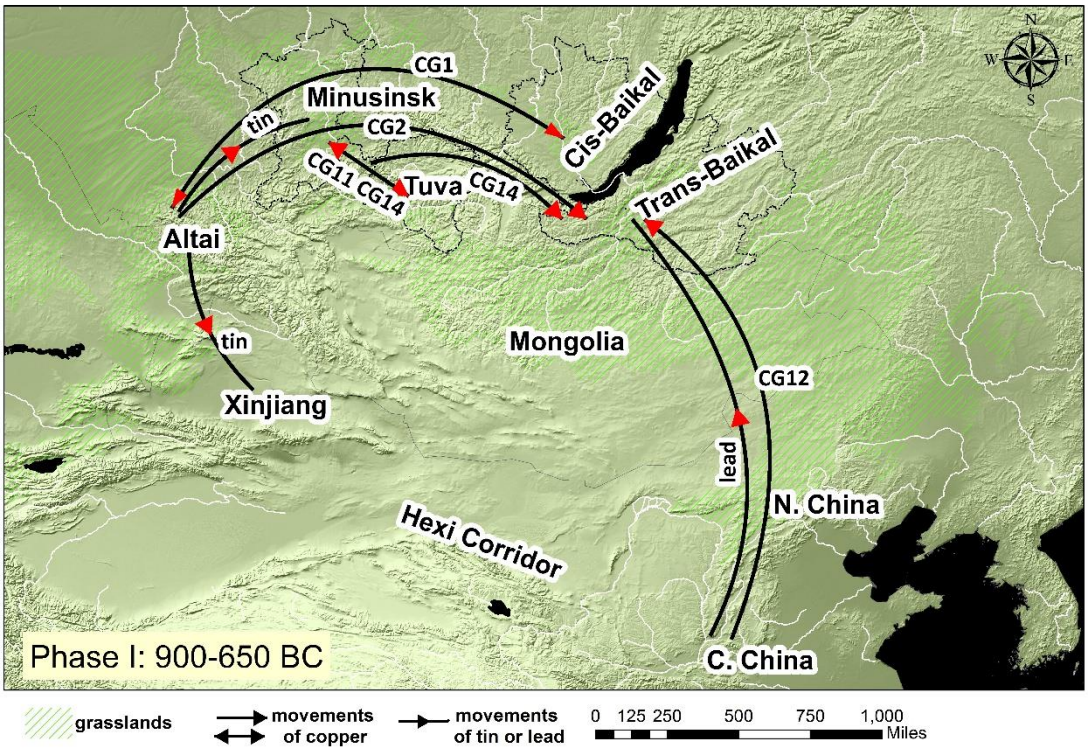


Figure 7.37 Schematic map showing the flows of copper and copper alloys across eastern Eurasia during the EIA Phase I.

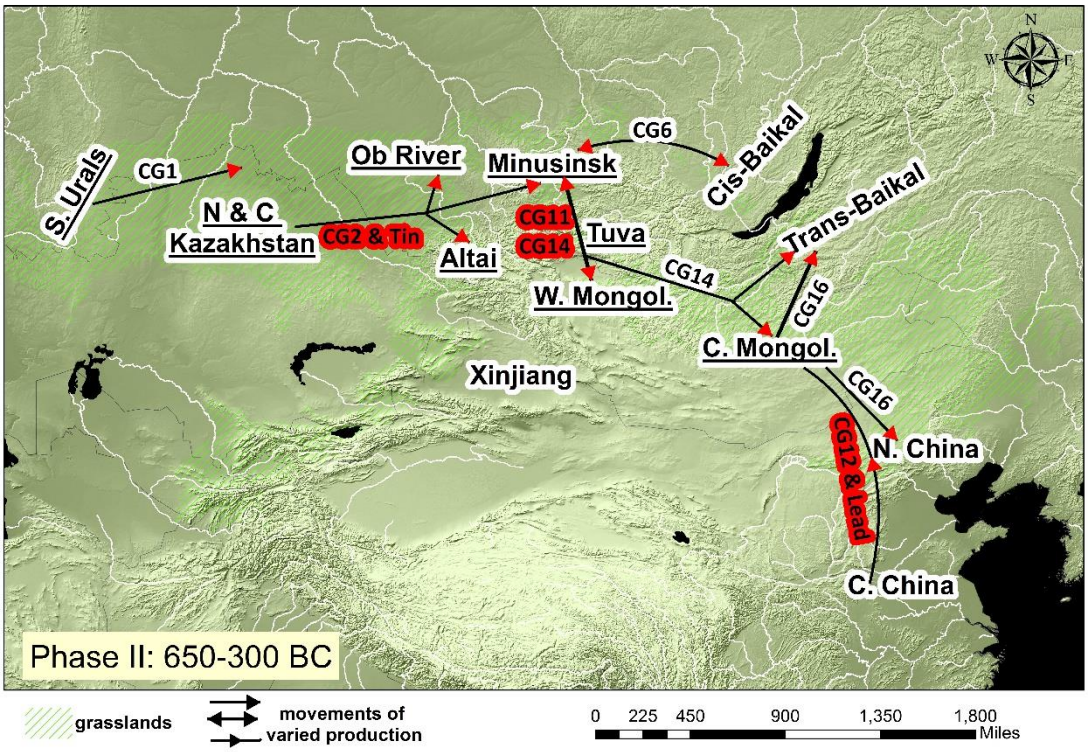


Figure 7.38 Schematic map showing the flows of copper and copper alloys across eastern Eurasia during the EIA Phase II.

7.11 Conclusions

The Early Iron Age (c. 1000 to 300 BC) was a critical phase in Eurasian prehistory and archaeology. Over the course of a few centuries at the beginning of the first millennium BC, material evidence for extensive connectivity, both within the steppe zone and between its pastoral societies and their semi-sedentary and agricultural neighbours, becomes increasingly apparent in the archaeological record. By the middle first millennium BC, strikingly similar forms of material culture and stylistic representation emerged across Eurasia, from the shores of the Black Sea to the grasslands of Manchuria, in societies with broadly similar lifestyles and, perhaps, shared sets of beliefs. It has been suggested by many that the characteristics of both their artefacts and archaeology, which is overwhelmingly dominated by funerary monuments, reflects a dramatic increase in mobility and a more intensive and widespread use of horse-riding in both economic and military activity (Chlenova 1967; Moskova and Rybakov 1992; Davis-Kimball, Bashilov & Yablonsky 1995; Mair 1998; Bokovenko 2006; Koryakova & Epimakhov 2007).

The spread of metallurgy during the Early Iron Age was unprecedented in extent and magnitude, reaching as far as the taiga zone of Siberia and Russian Far East (Matveyeva 1993; Kon'kova 1989). In eastern Eurasia, copper-based artefacts were mainly

represented by three alloying techniques: arsenical copper, tin-bronze and leaded tin-bronze. The first two had been recognised as a steppe tradition since the Middle Bronze Age, and the last one was a typical ancient Chinese recipe. These fundamental alloying preferences highlight the diverse metal production in the steppe as well as its sharp contrast with Chinese metalwork. The Tuva-Minusinsk area features arsenical copper (sometime with nickel or/and antimony as impurities) in contrast with the extensive use of tin-bronze in the Altai-Kazakh tin-bronze. Mixture of these two alloy types seems to very common as some Altai tin-bronze objects contains nickel or/and antimony and Minusinsk arsenical copper with the presence of tin. Further south we encounter the leaded tin-bronze system favoured by people from the Northern Zone and Central China. Chinese leaded tin bronzes were likely to be carried into Mongolia and Transbaikal and be re-melted to make steppe-style items. At Baga Gazaryn Chuluu site in central Mongolia, arrowheads and ornaments bear high amount of lead (≈10%, see Park *et al.* 2011).

The internal variations within steppe communities and the interlocking network between the Steppe, the Northern Zone and central China can be understood as the interplay of social and environmental factors. By the first few centuries of the first millennium BC, the increasing humidity in southern Siberia and Tuva transformed hostile semi-deserts into favourable steppe landscapes for pastoralism (van Geel *et al.* 2004). This climatic improvement, alongside the wider use of horse-riding, encouraged mobile pastoralists to migrate to the new lands, where they established new material cultures such as kurgan funeral complexes in Tuva and Slab-grave tombs in Mongolia and Transbaikal. The sudden rise of cultural groups intensifies metal production in these regions as well as the creation of new forms and designs of metal artefacts. For instance, Arzhan I and II kurgans in Tuva yield an enormous amount of horse trappings and animal-style ornaments made of gold, silver and bronze (Gryaznov 1980; Čugunov 2010). Slab-grave burials contain characteristic personal daggers and helmets (Tsybiktarov 1998). These all testify the wide scale of production in the easternmost of the Eurasian Steppe. Likewise, the Northern Zone had also experienced such boost in metal production characterised by the steppe feature (Shelach 2009:23-33). Though this "steppe" marker, namely animal-style art, already existed before the first millennium BC, the scale, coherence and rapidity of its distribution during the Early Iron Age is unprecedented. Multiple metal-producing communities emerged from northeast to

northwest China, making a very solid cultural frontier between the Steppe and Central China. Therefore, in one way the northerners intrinsically motivated by the steppe traditions in terms of stockbreeding economy, horse riding, and zoomorphic representations of artefacts. In the other way, the central Chinese metalworking tradition, namely leaded tin-bronze, was adopted by northerners to produce steppe-style artefacts with high lead concentrations. These mutual relationships between the Steppe, Northern Zone and central China envision the formation of complex politics and statehood in the subsequent Xiongnu-Han era (Honeychurch 2015).

8. Conclusions

8.1 Not of place, but of path: Chernykh's method compared to the new approach

Since Chapter 4 and 5 are primarily drawing from Chernykh's legacy data, it is necessary to compare his outcomes with the current study's to see what new information can be obtained from engaging with the proposed methodology employed here. Generally speaking, our results are in agreement with Chernykh's conclusions in terms of the broad development of the Eurasian Metallurgical Province (Chernykh & Kuz'minykh 1989a). He has identified that Seima-Turbino tin bronzes during the Middle Bronze Age originated in the Altai Mountains and that the proportions of ST copper-tin alloys gradually declined from the East to West. This pattern is manifested by a ubiquity map (Figure 4.4). In addition, Chernykh's chemical groups for the classification of Abashevo metals are generally consistent with copper groups defined by this thesis, namely clean copper (CG1), arsenic-only copper (CG2) and copper with silver (CG4 & CG9). According to Chernykh & Kuz'minykh 1989a, these copper chemistries are inherited by the Seima-Turbino assemblage, indicating that the same ore deposits were exploited by both ST and Abashevo people.

For the Late Bronze Age, Chernykh has summarised the characteristics of Andronovo and Srubnaya metalwork in terms of using clean copper alloyed with tin (Chernykh 2007). Distribution of such metal artefacts concentrates on the region near the Kargaly copper mine. This tendency is also identifiable from the ubiquity analysis of pure copper (CG1), which shows the presence of hotspot in the Cisurals (Figure 5.7). In a word, Chernykh's research outcomes are valuable to pinpoint the general trajectory of the metalworking history in the Steppe.

However, a fundamental difference between the proposed approach and Chernykh's is the way of explaining chemical variations in metal artefacts. Chernykh views different chemical compositions as the result of using different ore sources, and thus he focuses on a concept of provenance to assign analysed objects to specific mines such as copper sandstone deposits in the Cisurals and Tash-Kazgan (arsenic-rich) and Nikolskoye (silver-rich) copper mines in the Transurals. In order to succeed in metal sourcing, one would require chemical and isotopic analysis of copper ores and slags associated with the context of ancient mining and smelting sites. Such information is often insufficient

in the discussion of the steppe metallurgy. One exception is Grigor'yev research on the analysis of metallurgical debris from the Sintashta sites, whose results actually reject the use of Tash-Kazgan ores for the making of arsenical copper during the Middle Bronze Age (Grigor'yev 2015). Therefore, Chernykh chemical grouping of artefacts may not appropriate to address the question of provenance.

Alternatively, if we regard varied chemical composition as a reflection of object biography, we can not only identify the patterns Chernykh has observed, but provide more insight into the movement of metals. For instance, by comparing tin concentrations between different Seima-Turbino sites, I have been able to demonstrate direct exchange of some ST tin bronzes between the East and West, marked by artefacts made of 4-7% and 10-13% tin (Figure 4.8). I also show a gradual decrease in tin content of different artefact typologies found in the ST sites (Figure 4.23). This suggests that when moving to tin-free regions in the western part of the Ural Mountains, ST communities began to recycle arsenical copper objects from their southern steppe neighbours (Abashevo culture). These aspects of object chemistry reflect a dual metallurgical practice of the ST metals in which tin bronzes from the East are preserved as heirlooms while new items made in the West unintentionally adopt the arsenical copper tradition of western Eurasian steppe through metal recycling.

I also observe some new patterns of the Late Bronze Age metalwork by using the new approach. Contrary to Chernykh's classification of artefacts by cultural groups, I choose the river systems as a proxy to trace the inter-regional communications. This allows me to identify a very clear exchange route of tin-bronze ornaments along the steppe zone from the Transurals to the Don River Basin (Figure 5.24). Tin concentrations of these items remain relatively similar, suggesting a direct trade between the Andronovo and Srubnaya communities. Contrary to the distribution of ornaments, other objects, such as sickles and tools, are subject to the recycling and mixing of metals from different sources. This characteristic is manifested by the re-use of old MBA metal units, particularly copper with silver or nickel. These metals are likely to be mixed with fresh pure copper from the Kargaly mine.

The construction of Chernykh's metallurgical provinces is primarily biased to the western Eurasian steppe. Steppe East Asian Metallurgical Province (SEAMP), as classified by him, is chiefly drawn on the basis of similarities of typology rather than

actual chemical compositions of artefacts. This thesis is the first attempt to focus on the metallurgy of the eastern Eurasian steppe by synthesising the scattered chemical data from a variety of literature, dated to the Final Bronze Age and Early Iron Age. This approach enables us to depict a clear distribution route of metals along Frachetti's proposed Inner Asian Mountain Corridor connecting the Minusinsk Basin with southern Central Asia in the second half of the second millennium BC as well as the increasing north-south communications between steppe mobile pastoralists and the Central Plains of China in the first millennium BC.

As archaeologists have identified multiple strands of communication between many groups across the Eurasian steppe (Chernykh 1992), the steppe metallurgy ought to feature an extremely complex distribution network involving the dynamic flows of multiple metal units in different times and spaces. Changes in artefact chemistry cannot be simply explained as either accessibility of ore deposits or technological superiority. A more practical perspective is to understand different pathways along which metals are distributed and how these transmission and local adaptation of metals and metal artefacts can be placed in a particular social context, such as seasonal migrations in the pastoral societies or ritual systems in ancient China. Overall, these different aspects of human decisions lead to two characteristics of metal flow in the Steppe: localised and grand-scale networks.

8.1.1 "Localised" copper chemistry

By collating legacy datasets in conjunction with the application of new approach (Bray and Pollard 2012), this thesis is able to characterise the nature of copper and copper-alloy production in the prehistoric Eurasian steppe.

The Steppe is marked by diverse chemical signatures of copper chemistry associated with particular geographical locations. The Urals and N. & C. Kazakhstan serve as the most important pure copper sources (a possible candidate for CG1). This is reflected by metal artefacts from the Petrovka (Chapter 4), Andronovo (Chapter 5), Atasu (Chapter 6) and Tasomlia (Chapter 7) communities. Tin-bronze is usually an alloy of choice in these cultures.

Copper with only arsenic as the chief impurity (CG2) is particularly dominant in the regions of the Cisurals, N. Caucasus, Minusinsk, and southern Central Asia. The Balanbash (Chapter 4), North Caucasus (Chapter 4), Karasuk (Chapter 6), Tagar

(Chapter 7) Bactria (Chapter 6) and Namazga VI (Chapter 6) are represented by such arsenic-only copper production.

CG1 and CG2 metal objects occupy the majority of the Eurasian assemblage. As suggested by either high ubiquity percentages or high arsenic concentrations (for CG2), the metal-producing communities presented above are all possible primary production centres. It is difficult to determine whether objects with CG1 or CG2 signals actually come from the same geological sources without further lead isotope information. Nonetheless, since these cultures are located away from each other, I would prefer to regard their production as an independent development that strongly ties with local resources.

This "localised" attribute of copper chemistry in the Steppe is particularly obvious in terms of nickel-bearing (CG11 & CG14) and silver-containing copper (CG4 & CG9). Arsenical copper with elevated nickel content (sometimes with antimony as well) is restricted to the Sintashta in the Urals (Chapter 4), the Potapovak in the Middle Volga (Chapter 4), the Karasuk and Tagar in the Minusinsk (Chapter 6 & 7), and the Uyuk in Tuva and northwestern Mongolia (Chapter 7). These copper-nickel artefacts may be associated with ores of the ultramafic origin (e.g. the Ishkinino Co-Cu massive sulphide deposit in the Transurals and the Cu-Ni-Co deposit in Tuva). This specific geological condition foresees copper-nickel production in those regions. Likewise, copper-silver artefacts are also confined to certain areas such as the Kama (Chapter 4) and southern Central Asia (Chapter 6). Although Chernykh (1970) argued that silver is enriched in some copper sandstones in the west of the Urals, elevated silver in copper is less explicit in terms of ore mineralisation.

Apart from the primary local copper production regions, the peripheries of these core areas display possible inter-regional networks characterised by metal recycling/mixing. In western Eurasia, objects from the Volga, Don, Oka and Kama regions tend to have decreasing arsenic concentrations, a typical sign of the use of recycled metals (Chapter 4 & 5). This similar trend of diminishing arsenic is also evident in the areas of eastern Eurasia such as the Upper Ob, Semirech'e and the Transbaikal (Chapter 6 & 7). Interestingly, these regions tend to have strong cultural affinities with adjacent archaeological communities featuring powerful metalworking traditions, such as the Andronovo in the Urals, the Atasu in Kazakhstan, and the Karasuk and Tagar in the

Minusinsk. In this regard, the re-use of metals does not necessary correlate to the lack of ore resources. Social backgrounds and preferences play a much more important role in determining the flow of metals.

8.1.2 Dynamic alloying practices in the Steppe

The Steppe features three alloying preferences narrating different histories of metallurgical development, namely arsenical copper, tin-bronze and to the less degree leaded tin-bronze in the Early Iron Age. Arsenical copper, in my opinion, is an alloy of "chance" that heavily depends on the availability of local and regional sources (see Section 8.2.1). Ancient metalworkers may only initially search for copper ores, but accidentally discover some specific arsenic-bearing copper ores that produce metals with desirable colours or hardness.

On the contrary, tin-bronze or leaded tin-bronze is more likely to be an alloy of "choice" that requires the intentional addition of tin and lead. Unlike primary copper production sustained by local raw material, tin-bronze in the Steppe is a highly mobile item that could be potentially transferred over an extremely long distance. The most remarkable example is the spread of the Seima-Turbino tin-bronze weapons into eastern Europe. As shown in Chapter 4, some ST metals found in the West may be directly imported from the East as heirlooms and trade goods. The ST tin-bronze metallurgy also witnessed the emergence of a totally different metallurgical system in eastern Eurasia, independent from the existing tin-bronze network in the Near East. During the Andronovo period, this unique tin-bronze production, presumably based on the tin mines in the Altai or central Asia, became extremely influential in the making of copper alloys not only within the Steppe but East Asia. Tin-bronze personal ornaments are considered as a common cultural marker to connect the steppe communities under a shared ideological belief (such as Srubnaya and Andronovo cultures in Chapter 5). Nonetheless, tin-bronze artefacts are also subject to the recycling during the Early Iron Age, as suggested by recycled Altai tin-bronze in the Minusinsk and Lake Baikal regions (Chapter 7).

Compared with arsenical copper and tin-bronze, leaded tin-bronze in the Steppe appeared relatively late and was only restricted to the easternmost regions of the Eurasian steppe, namely the Transbaikal and central Mongolia (Chapter 7). The injection of lead in the steppe-type artefacts is likely to be a consequence of recycling

of Chinese leaded metals, which has been clearly demonstrated in the Northern Zone metalwork (Chapter 6 & 7)

8.1.3 How was a Bronze Age/Early Iron Age system of the Steppe structured?

Although each period has its own structure of metallurgical network determined by particular social and cultural backgrounds, some aspects are shared by metal-producing/using societies in the Steppe regardless time or space. We fail to apply the world-system approach to the steppe communities since there is not a single identifiable politically superior core area over a technologically undeveloped periphery in the Eurasian steppe. Nor can we say steppe societies are socially or technologically interior to their settled agricultural neighbours as the organisation of pastoral nomadism is extremely complicated in a different manner (Honeychurh 2015), and horse domestication and horse-drawn chariot technology were actually first mastered by the steppe people (Anthony 2007). Instead, what we see in terms of metal production is a complementary character of metalworking framework. On the one hand, some steppe communities serve as the primary production centres based on local copper sources, such as the copper mining in the Ural Mountains, Kazakhstan, the Minusinsk Basin and Tuva, and tin mining in the Altai and southern Central Asia. These regions distribute either raw material, copper or copper alloys to the ore-lacking areas such as the Volga, western Siberia or Baikal. On the other hand, inter-regional exchange takes place via the circulation of commodities, ideas and labour. Regions/societies provide their "expertise" in exchange for things they lack in their own niches. One of the best examples is the Kargaly mining complex in southern Urals where the extraction of copper became a specialised profession. Miners received an enormous number of livestock (mostly cattle) from outside in exchange for their metals (Chernykh 2004a). Other candidates for exchanging steppe metals could be jade, precious stones, timber, fur, imported textile or wheel-made ceramics.

8.2 Copper alloying: technical aspects and archaeological implications

The making of arsenical copper or tin-bronze is one of the most intriguing phenomenon in the study of archaeometallurgy. In order to understand how these two alloying traditions came into existence and the variability of their use in the Eurasian societies, one should scrutinise different ways of alloying production as well as anthropological perspectives on the adoption of copper alloys.

8.2.1 Arsenical copper/bronze

Arsenical copper/bronze was the first copper alloy used in the history of metallurgy. By the mid-fourth millennium BC, arsenic was present in the copper-based objects (whether deliberately-added or not) in ancient Levant, and arsenical copper production became prevalent during most of the 4th and 3rd millennia BC throughout the Old World metallurgy (Roberts *et al.* 2009). Interestingly, the average arsenic level in ancient copper-based objects is around 2%, which offers very little improvement over pure copper (Northover 1989:113). However, this amount of arsenic can facilitate the casting process by reducing the viscosity of the melt (Northover 1997: 327), and subsequent cold working can enhance the hardness and tensile strength of metals (Lechtman 1996).

According to radiocarbon dates, the use of arsenical copper/bronze in the steppe was more and less synchronous with the inception of this alloy in the Near East by the 4th millennium BC. The famous Maikop complex in the northern Caucasus, dated to 4000-3000 cal. BC, has yielded numerous good quality bronze, gold, silver artefacts (Kohl 2009). The Maikop metallurgy marked the initial formation of the Circumpontic Metallurgical Province that featured the copper-arsenic tradition persisting throughout the 3rd millennium BC in the Pontic-Caspian steppe among the Yamnaya and Catacomb communities. Arsenical copper/bronze was also extended to Abashevo-Sintashta societies in the Urals during the first quarter of the 2nd millennium BC.

The technique to produce arsenical metals in the Steppe remains puzzling due to the lack of a full spectrum of metallurgical evidence, especially for ores and slags. Questions such as “which processes are used for making arsenical copper/bronze” or “is this copper alloy meant to be intentional or accidental?” are still open to be debated. Sintastha metallurgy is the only exception allowing for a detailed study of the occurrence of arsenical copper in the Steppe. As discussed in Chapter 2, Grigor'yev (2015) argues that arsenic-rich mineral is added during the copper smelting process because local copper ores contain very little of this substance as opposed to relatively rich arsenic levels in slags and artefacts. Nevertheless, he did not examine other possibilities to manufacture arsenic-rich copper. It is essential to review different ways of making copper-arsenic alloys in order to comment more appropriately on the Sintastha metalwork.

In practice, there are several ways to produce arsenical copper/bronze. The first method involves direct addition of arsenic or arsenic minerals to molten copper (Budd *et al.* 1992:679), but it is difficult to find the archaeological evidence of using native arsenic in antiquity. The second method is the smelting of grey-coloured copper sulphosalts (sulphides with arsenic, antimony or bismuth). According to Ixer & Pattrick (2003), they included two subgroups: (1) the fahlerz, tetrahedrite ($Cu_{12}Sb_4S_{13}$) and tennantite ($Cu_{12}As_4S_{13}$); (2) the enargite series with engargite, luzonite $Cu3AsS_4$ and famatinite (Cu_3SbS_4). Because they are primary copper sulphide ores, roasting (heating in an oxidising condition) is required to eliminate sulphur from ores. Although this practice inevitably leads to the loss of arsenic as volatile arsenic trioxide (Tylecote 1980), a proportion of arsenic could still remain in the smelted copper and final products. The most well-known example is the Early Bronze Age Ross Island mine in Ireland (O'Brien 2004). Ross Island metalworkers smelted tennantite- bearing ores starting with approximately 20% arsenic to obtain raw copper with around 7% arsenic. Eventually, finished products with subsequent casting and hammering contain around 1- 2% arsenic.

The third method is to smelt secondary copper arsenates derived from supergene oxidation of tennantite-tetrahedrite or chalcopyrite-arsenopyrite (Charles 1980; Budd *et al.* 1992; Pigott 1999). These green copper-arsenic ores, likely to be mistaken as copper carbonates, contain minerals such as olivenite ($Cu_2AsO_4(OH)$), clinoclase ($Cu_3(AsO_4)(OH)_3$), cornwallite ($Cu_5(AsO_4)_2(OH)_4.H2O$), cornubite($Cu_5(AsO_4)_2(OH)_4$) and liroconite ($Cu_2Al(AsO_4)(OH)_4.4H_2O$). The smelting is carried out in mildly reducing atmospheres, thus hindering the great loss of arsenic compared with roasting (Budd *et al.* 1992). The resulting arsenical copper usually contain less than 5% arsenic and it could be independent of the arsenic/copper ratio in the ores (Pollard *et al.* 1991).

The fourth pathway to obtain arsenical copper is the co-smelting of copper oxides with arsenic-bearing sulphides. Lechtman and Klein (1999) demonstrate a series of co-smelting experiments on charges of copper oxide minerals with enargite or arsenopyrite at mixtures from 1:1 to 4:1. All cases, except for the 1:1 ratio, successfully produce metals with arsenic from 7 to 26 wt% in either the crucible or furnace. This provides a plausible scenario of making arsenical copper by such approach.

The final approach is the adding of the so-called speiss (an iron arsenide) to molten copper. The speiss is smelted from arsenopyrite and relevant slags are found at Tepe Hissour in north-eastern Iran and at Arisman in central Iran (Thornton *et al.* 2009; Rehren *et al.* 2012). Of course, we needn't rule out the possibility that arsenic is brought by the recycling or mixing of arsenical copper/bronze from somewhere else.

Given such a variety of "choices" to making copper-arsenic alloys, we are able to scrutinise the nature of the Sintastha metals according to these criteria. According to Grigor'yev's research, 90% of analysed copper ores from Sintastha sites are malachite with low arsenic (rarely over 0.03%) and only 10% belong to malachite with high arsenic (>0.1%). Likewise, ore minerals in the slags are mostly malachite with very few covellite and chalcocite grains. Since Sintastha ores are carbonates free from arsenic, we can basically rule out the use of copper sulphosalts or secondary copper arsenates. There is also no proof of using enargite or arsenopyrite for co-smelting or the production of speiss. These strands of evidence deny any possible natural-occurring or deliberately-made copper-arsenic alloys in the Sintashta metallurgy. This leaves us the only option of the recycling or mixing of arsenical copper objects from elsewhere. The most likely candidates, as shown in Chapter 4, are northern Caucasus and Cisurals where artefacts contain relatively high amount of arsenic. These regions may deliberately produce arsenical copper via the methods described above, but current evidence is insufficient to unravel the true character of arsenic-alloying in the Steppe.

8.2.2 Tin-bronze metallurgy

As discussed in Chapter 4, the enigmatic Seima-Turbino horizon marked the first predominant use of tin-bronze in the Steppe. In this specific archaeological context, tin was alloyed with a wide range of copper artefacts based on "standardised" recipes. This intentional primary alloying practice is signified by a pronounced peak of tin concentration at the high level (Figure 4.5). Two fundamental questions arises: How did the ST metalworkers come to be aware of the tin alloying while there were no precursors in the rest of the Eurasian steppe? Why did the production of ST tin-bronze, at the very beginning stage, appear as a full-blown technology with tin concentrations in favour of sound mechanical properties (≈10%)?

The rise of steppe tin-bronze challenges a long-standing diffusionist view that tin-bronze was initially regularly used in the Near East and then was gradually transmitted

to the rest of the Old World (Figure 8.1), also see Gallay & Lahouze 1976; Sherratt 1993). Indeed, except for ephemeral use of tin-bronze in the Balkan around 4500 BC (Radivojević *et al.* 2013), tin-bronze first appeared in ancient Near East (Anatolia and northern Mesopotamia) at the beginning of the third millennium BC and became more common by the middle of the third millennium BC as the symbols of elite items, such as "Royal" graves of Ur and the hoards of the Troy IIg (Pernicka 1998). Tin-bronze technologies were then spread into the Aegean in the west and Iran the east, followed by the total adoption in Europe during the second millennium BC. According to the diffusion model, such Near Eastern tin-alloying tradition should be first transferred to the Pontic-Caspian steppe via the Caucasus in terms of geographical locations Nonetheless, Caucasian metals were characterised by copper-arsenic or copper-antimony alloys rather than tin-bronze (Pike 2002). This excludes the possibility of transmission of the Near Eastern bronze metallurgy to the western Eurasian steppe through the Caucasus. In fact, the first predominant use of tin-bronze took place in the Seima-Turbino context of the eastern Eurasian steppe rather than its western counterpart. Therefore, one can regard the Seima-Turbino bronze technology as an autonomous invention unrelated to the tin-bronze in West Asia. Such abrupt increase in tin-bronze production also occurred in the British Isles around 2000 BC based on potentially rich Cornish tin (Pare 2000). The early evidence of British tin-bronze rejects the conventional view on the spread of tin-bronze from the Near East to Europe. There might be at least three independent development of bronze technology in Europe, West Asia and the Steppe (Figure 8.2).

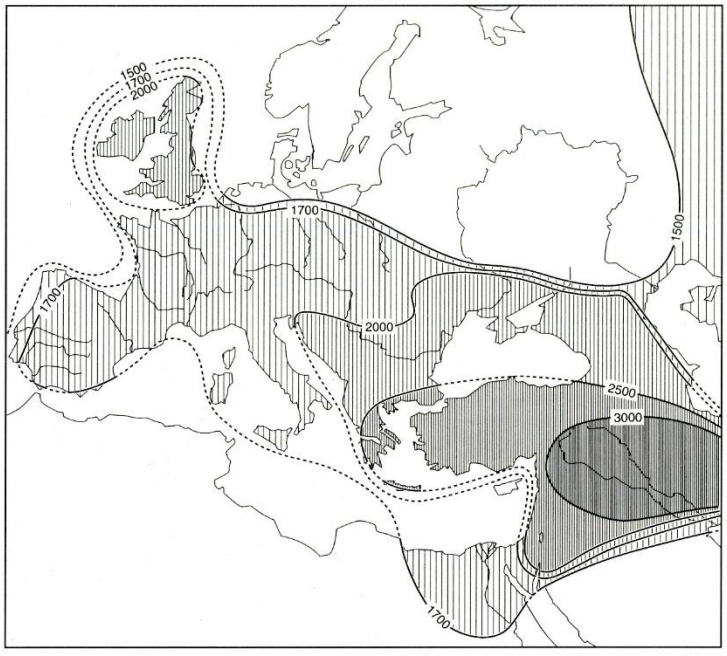


Figure 8.1 Traditional view on the dissemination of tin-bronze metallurgy from the Near East to Europe. From Gallay & Lahouze 1976: 157, fig. 4.



Figure 8.2 Probable dates for the transition to developed tin-bronze metallurgy in the old world (European data from Pare 2000; Near Eastern data from Cuénod 2012; Eurasian steppe and Chinese data from the current thesis).

The European example suggests that tin-bronze metalwork could be an autonomous invention given by specific natural resources and socio-economic conditions. Parallel to Cornish tin in England, the ST metalworkers had potential access to abundant tin deposits in the Altai Mountains, which provide a prerequisite for the development of full bronze metallurgy. In the British Isles, the tin-bronze appeared at the same time when the Ross island mines ceased to be used and many new deposits were exploited by ancient prospectors (Needham *et al.* 1989). This profound change in the metallurgical production may have led to the discovery of tin (Par 2000:22). The emergence of the ST bronze metallurgy also corresponded to a sudden change in socio-political environments reflected by the complexity of "the Sintastha Pattern" that we have visited many times in the thesis. A new form of material culture, marked by fortified settlements, mining and smelting activities, and chariot technologies, may provide an external impetus to the transformation of the pre-Seima-Turbino communities.

Besides the introduction of tin-bronze in the Steppe, it is equally important to address the phenomenon of the predominant use of tin-bronze. Such production is characterised by the application of tin-bronze to the majority of artefacts with a prime signal of tin concentration. The ST metalwork, especially in its eastern group, demonstrates such "controlled" tin-alloying recipe (Figure 8.3, top). This primary patterning is also visible for the introduction of tin-bronze in British Isles where tin content is rarely under 5% (Figure 8.3, middle). On the contrary, ancient Mesopotamia, as the earliest place for tin-bronze production, shows a wide range of tin levels for copper-alloyed artefacts, with a great proportion of unalloyed items (under 1% tin, see Figure 8.3, bottom). Therefore, we can conclude three tin-bronze production centres (Mesopotamian, Seima-Turbino and British Isles) but with two contrasting manufacturing portfolios. This variation, in my opinion, lies in the different socio-economic structures. Ancient Mesopotamia was a hub of trading network in which many metal resources from varied regions were circulated. The fact that tin deposits were scarce and located far away from Mesopotamia made tin as a precious item controlled by the elite class and primarily reserved to produce prestige goods. Mesopotamian societies did not seem to have constant tin supplies. On the other hand, Seima-Turbino and British Isles utilised their respective primary tin resources in a relatively "close" system in which flow of metals often occurred in a single direction (For ST, it was the interaction with southern

steppe communities; for the British Isles, it was the societies living along the Atlantic coasts). The primary signal of tin alloying was shifted towards low-tin levels as more tin-less copper was mixed up along the movement of tin-bronze artefacts (ie. ST bronze in the forest-steppe zone).

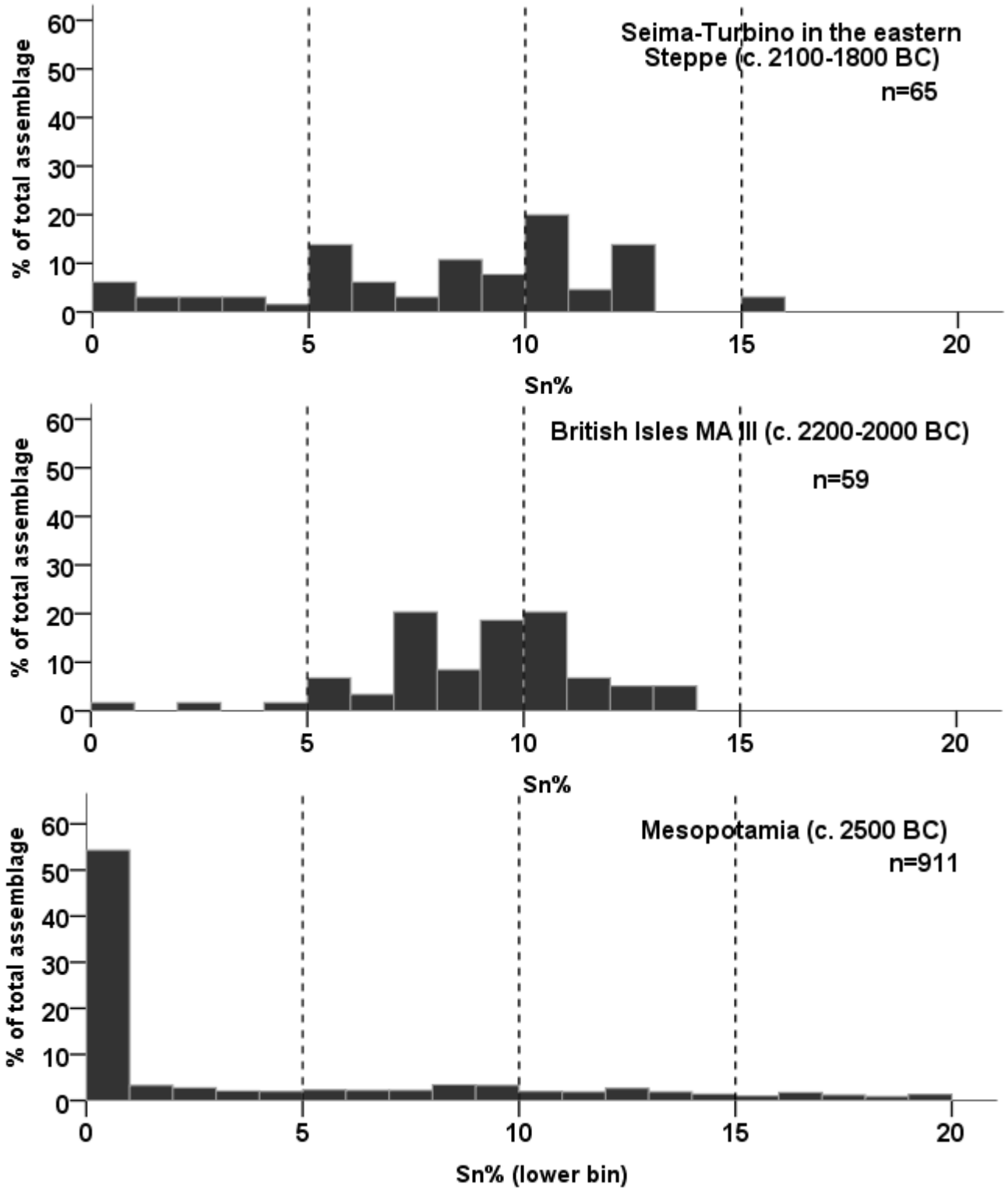


Figure 8.3 Distribution of tin concentration across for copper-based artefacts in the Seima-Turbino, British Isles and Mesopotamia. Data compiled from Chernykh & Kuz'minykh (1989a), Pare (2000) and Hauptmann & Pernicka (2004), respectively.

8.3 Concluding remarks: current challenges and future trajectories

8.3.1 The use of legacy data: strengths and limitations

One of the major tasks in this thesis is to synthesise and reinterpret a plethora of legacy data of ancient Eurasian metals. As explained in Chapter 3, chemical results derived from different analytical methods are generally in agreement with each other, but some seriously deviating measurements may be present (Chase 1974; Northover & Rychner 1998). This is reason why this thesis employs a more "fuzzy" approach, presence or absence of elements, to characterise metal composition in terms of key diagnostic elements. By using ubiquity and the elemental distribution of the assemblage, we are able to more safely delineate possible patterning within analytical data. Bray (2009) has pioneered this kind of research on the metal circulation in the Early Bronze Age of the British Isles; Cuenod (2012) looked into the distribution of tin-bronze between ancient Mesopotamia, Iran and adjacent areas. Liu (in prep.) investigates the Bronze Age network in ancient China. Although these studies embark on distinct archaeological environments, the underlying copper chemistry is universal, which allows us to envision a wider Trans-Eurasian metallurgical network.

However, many unsolved questions arise when it comes to the old datasets. Ironically, the biggest problem of using legacy data does not come from their analytical accuracy or precision, but from the artefact chronology. As stated in Chapter 3, many publications still rely heavily on the ambiguous typological dating (either ceramics or metals). Even though recent radiocarbon-dating projects have re-defined the chronological sequences of the Bronze Age and Early Iron Age Eurasia (Chernykh 2008; Zaitseva 2007; Svyatko *et al.* 2009), these dates do not necessarily correspond to the sites in which metal artefacts came from. This leaves us a rather coarse chronological sequence of metal analyses that could potentially undermine the solidity of our interpretations concerning the metal flow in antiquity. Therefore, it is hoped that future archaeometallurgical project should be combined with well-organised excavation strategies and the selection of samples for radiocarbon dating. In this way, we may match metal analyses with accompanying artefacts, burial practices and settlement structures in a particular stratigraphic layer to better understand the role of metal in constituting human societies. Such applications have been exemplified by the Samara Bronze Age Metals Project in the Middle Volga (Peterson *et al.* 2006; 2014)

and Bronze Age Sintashta complex in the southern Ural Mountains (Hanks & Doonan 2009).

Another limitation of using the legacy data is due to the disproportion of available chemical results. Until now, the vast majority of data originate from the western Eurasian steppe in contrast with relatively few analyses in certain regions of the eastern steppe (Figure 8.4). In the east, except for the Minusinsk Basin, many areas lack sufficient chemical analyses to complete the overall picture of metal flow. Altai and Kazakhstan, in particular, having been recognised as the most important copper and tin suppliers for the eastern steppe remain unclear about their role in the formation of metallurgy in the east. Areas in Xinjiang, Mongolia and Northern Zone also hold the key to understand inception and development of metallurgy in ancient China. The legacy data indeed informs us of broad and tentative trends of ancient metal network in the steppe, but much more high-quality analyses are needed to unambiguously confirm or modify the frameworks of metal flow proposed in this thesis.

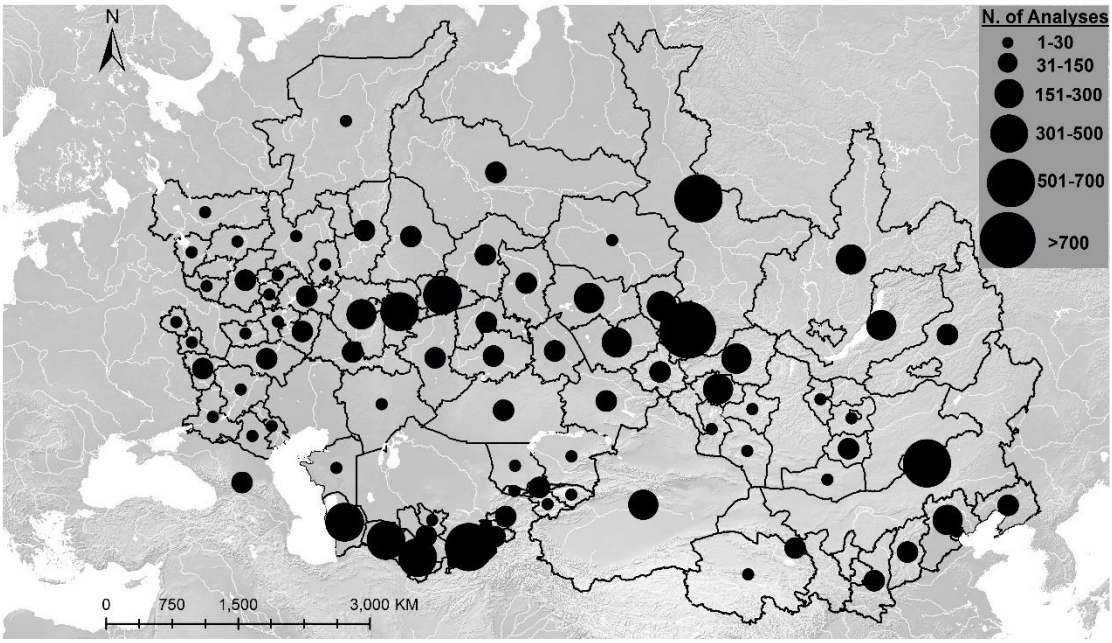


Figure 8.4 Chemical data collected by the author based on modern administrative units (see the supplementary material for raw entries and references).

8.3.2 Thermodynamic modelling and experiments

Unlike other methods relying on statistical grouping of chemical data, the current approach employed in this thesis takes advantage of the thermodynamic knowledge for archaeological copper-based metals and experimental results (Sabatini 2016). This new mindset that artefact chemistry is a dynamic one helps us to identify meaningful

patterns of ancient metal recycling, mixing, reuse and direct exchange. However, it is realised that the present method is based on elemental behaviours in binary and ternary copper-alloy systems. Since the properties of individual elements may change in relation to one another in multi-component system, it is important to establish a more complex model to predict some specific ancient copper alloys with more than three elements such as leaded gunmetals in both Roman and Chinese coinage (Pollard *et al.* 2015; Wang *et al.* 2005) and Cu-Sn-Pb-As alloys in the Northern Zone (Yang 2015).

Another equally important research is the melting experiments that simulate ancient casting in certain furnace technologies, atmosphere, initial charges and composition. According to Sabatini (2016), as thermodynamic modelling (the activity diagram) indicates the likelihood of loss of elements, it is extremely vital to design well-controlled experiments to observe the actual changes in the pyrometallurgical process. Unfortunately, most experimental works on archaeological metals focus on the behaviour of individual elements in the copper binary system, which cannot reflect the chemical reactions and element interactions in higher systems. Thanks to Sabatini's research, we now have thermodynamic data for binary and ternary system. It is hoped that future experimental results on multi-component systems will corroborate the theoretical modelling, which can in turn provide insight into why specific combinations of metal composition existed in antiquity.

8.3.3 The usefulness of provenance studies

Although this thesis highlights the circulation of ancient steppe metals through recycling and mixing, it does not mean that we should abandon provenance studies in tracing possible mineral deposits. On the contrary, I argue that it is extremely helpful to investigate possible raw material used as the starting composition of artefacts. From these starting points, we are able to trace the flow of metals in a complete biographic cycle. For instance, the discovery of tin deposits in the Altai and central Asia has led to fruitful results of tin usage in the Steppe. To what extent did the "steppe" tin supply the urban regions in ancient Near East and China still remain an open question. This puzzle cannot be solved without locating more plausible tin mines in the Eurasian continent. Recently, Pernicka and his colleagues applied tin isotopy to provenancing sources of the Bronze Age tin in the old world (Professor Pernicka's European Research Council Project 2013-2018). Although this new method still encounters the mixing/recycling problem and cannot trace bronze artefacts to their original tin deposits, their research

will be able to generate more trace-element and isotopic data for the better understanding of the metal flow.

8.3.4 Contributions of this work and future trajectories

This study pioneers the first large-scale survey on the published chemical data of ancient copper-based objects in the eastern part of the Eurasian steppe. The principal outcome is the construction of a comprehensive database that can be used to provide fresh interpretations for the connectivity of metallurgy between steppe communities. This work also shows a new way to employ the elemental pattern to characterise metal production in each steppe region, to discuss the possibility of metal recycling and direct trade, and to link the diversity of artefact chemistry with specific artefact typology or socio-political backgrounds.

This research also highlights the first large-scale investigation into the metallurgical interaction between herding societies in the north and farming communities in the south. One important place is the Northern Zone of China which has recently received tremendous attention due to its transmitting role between prehistoric Siberia and ancient China. I have shown that the making of single-bladed knives in the late second millennium BC was prevalent across the eastern steppes, however, steppe-style knives from the Northern Zone were in favour of leaded tin-bronze, which is radically different from knives from Mongolia and Southern Siberia featuring either tin-bronze or arsenical copper. As the leaded tradition came from the Central Plains of China, the Northern Zone metalwork was conditioned by the technology from the south, which draws a distinct boundary of metallurgical practice between the Steppe and ancient China. Another equally important frontier of metallurgy may reside in the regions along the Syr Darya and Amu Darya, or present-day Uzbekistan and Tajikistan. These areas have been considered as the transitional zone for both herders from Kazakhstan and farmers from central Asia during the Late Bronze Age (Kuz'mina 2008). This study has demonstrated the possibility of metal exchange as tin bronzes from Kazakhstan moved to the south.

Although this study provides a general picture how metal may flow between prehistoric steppe societies, it is still far from the complete picture due to the lack of chemical data and detailed survey on ancient mining and smelting evidence. For the entire eastern Eurasian steppe, only the Minusinsk Basin and Northeastern China have undergone

dedicated investigations of primary production sites (Sunchugahev 1969, 1975; Dong 2012). Without knowing the compositions of metallic ores and slags, it is difficult to reconstruct how ancient metallurgy was organised. It is hoped that the future fieldwork can concentrate more on geophysical survey to identify possible primary smelting sites. The priority should be given to the Minusinsk Basin and Kazakhstan. These two areas not only possess rich mineral resources but also have the most metal artefacts that have been chemically analysed. It is promising to explore the whole operational sequences and also talk about more interaction between them.

Another important area is Mongolia which has become a flourishing subject of archaeological research in recent years (Houle 2009; Honeychurch 2015). Scholars have recognised that steppe people in Mongolia, very much like the Northern Zone of China, play an important role in the exchange of idea and technology with northern herders and southern Chinese farmers. However, we currently have very few chemical analyses of metal artefacts and practically no smelting or mining remains in this large territory. This fact seriously challenges the assumption of interaction between steppe and ancient China due to lack of the concrete metallurgical evidence. Similar to Mongolia, Xinjiang and the Hexi Corridor in West China have claimed to be the link for the steppe-China relation (Mei 2003, 2004), yet the archaeometallurgical studies still remain rudimentary, which focusses on the identification of alloy types. As suggested by this study, it is critically important to produce good-quality trace element data to explore dynamic flows of metal rather than static classification of metal.

Lead isotope studies have also proven useful for both provenance and mixing of metal from different sources (see Chapter 7), however, this sort of work is almost absent in Russian publications. Because we often encounter a situation when different metal assemblage contains similar trace element patterns, we need lead isotope data in order to give a better resolution of metallurgical production in each region.

Of course, to make the best use of chemical data, one should undertake in-depth analysis of regional variations in the development of metalwork. Nowadays, many Eurasian archaeometallurgists have paid attention to regional and local case studies in the various parts of the Steppe (e.g. Doonan & Hanks 2015 for the Transurals, Peterson *et al.* 2015 for the Middle Volga; Mei 2004 & 2009 for northwestern China and Xinjiang). Their research highlighted detailed examination on the production sites and

metallurgical remains such as copper ores, slags, casting moulds, and furnaces. Through systematic survey of local catchment zones, they are able to demonstrate how early mining communities were constructed by using micro-regional resources in a localised scale. Although there is a tendency to advocate an indigenous development in different parts of the Steppe, it does not discredit the importance of long-distance exchange. In fact, as more and more regional data becomes available, we are able to sketch a better picture of metallurgical network by connecting individual case studies. For instance, both Hanks and Peterson are investigating contemporary steppe communities in the adjacent locations (the Urals and Volga). It is promising to synthesise their results to shed some light on inter-regional trade as I have briefly discussed in Chapter 4.

Last but not least, Killick (2014) has provided some specific guidelines for future trajectories of archaeometallurgical research in terms of the project design. He calls for teams of collaborating specialists to contribute their expertise on "economic geology; the archaeology of mines and metallurgical sites, the interpretation of ores, slags, refractories, and metals; experimental replication of smelting processes in field and laboratory; and in inferring the geological provenance of ores and metals by chemical and isotopic techniques." (Ibid. 42). Indeed, future research should embrace this interdisciplinary approach by including not only metallurgists, but also ore geologists, field archaeologists, ceramic specialists, experimental archaeologists and lab technicians. This partnership can potentially establish a paradigm for the detailed examination of metallurgical evidence ranging from extractive and smelting remains to finished products (known as a holistic methodology, see Shimada 2007). Ultimately, all analytical results have to be interpreted through the lens of thermodynamic modelling as well as socio-cultural backgrounds of given archaeological complexes.

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