1

Introduction

In the late summer of 2016, I visited Anyang for the first time. As an archaeology student, Anyang is one of my must-see destinations because of Yinxu (the Ruin of Yin), one of China's largest and most famous archaeological sites. Anyang is widely recognised as the last capital city of the Shang for about two centuries (c. 1250–1046 BCE) (Chang, K. 1980; Li, C. 1977; Tang, J. 2009). While wandering among cases full of ritual vessels and oracle bones in the museum, I finally reached the last gallery, with a gigantic bronze vessel in the centre of the room. This rectangular vessel, known by the inscription on it as the *Simuwu* 司母戊 (or *Houmuwu* 后母戊) *ding* 鼎, is probably the best-known discovery from Anyang (Figure 1.1). The *ding* is a name given to a type of cooking vessel. This *ding* in the Yinxu Museum is actually a replica. The original is now displayed in the National Museum in Beijing, the capital of China (PRC). This arrangement itself tells us something about the importance of the bronze vessel and its symbolic meaning even in modern China. When I stood in front of it, the first thing that shocked me was its sheer size. On a base in the showcase, the vessel was almost as tall as I am, while the record of the National Museum shows that the object is 133 cm high and weighs 833 kg. A vessel of this size was almost certainly not for daily cooking but only for certain ritual ceremonies.

What is equally impressive about this vessel is the enormous resources devoted to making it. Unlike materials such as stone and wood, bronze—what this vessel was made of—does not come directly from nature. In this book, I use "bronze" to refer to any copper alloy with tin (e.g. leaded bronze means copper-tin-lead), while "copper" refers to the pure metal or its alloys without tin (e.g. leaded copper and arsenical copper represent copper-lead and copper-arsenic). Some scholars also use "tin bronze" to refer to copper-tin alloys. The *Simuwu ding* was made of an alloy with 84.8% copper, 11.6% tin, and 2.8% lead as its three primary components (Yang, G. and Ding, J. 1959). Creating this alloy required several steps. The first was to obtain metal-bearing minerals, or ores, by mining. Metal ores were then heated to extract the metal elements (smelting). Extracted metallic copper, lead, and tin were mixed to achieve a particular alloy composition for casting. To cast the *Simuwu ding*, as researchers estimate, around 1.5 to 2 tons of metal was required, while the whole operation may have involved dozens or even hundreds of people working simultaneously (Keightley 2012: 23; Li, W. 2016; Yu, X. 1964).

Putting so much effort into one single object is undoubtedly remarkable, while the quantity of bronze vessels produced by Anyang is also remarkable. In the tomb belonging to Lady Fuhao, consort of King Wuding, there were more than 400 bronze objects, with a total weight over 1600 kg (Zhongguo 1980: 15). In a nearby tomb, which belonged to a military leader, Yachang, there were also more than 260 bronze objects, over 300 kg in total (Zhongguo 2007a: 93). These bronze objects certainly played significant roles in the rituals of the Anyang society. Even across the entire ancient world, this scale of metal use and production was an exceptional case.

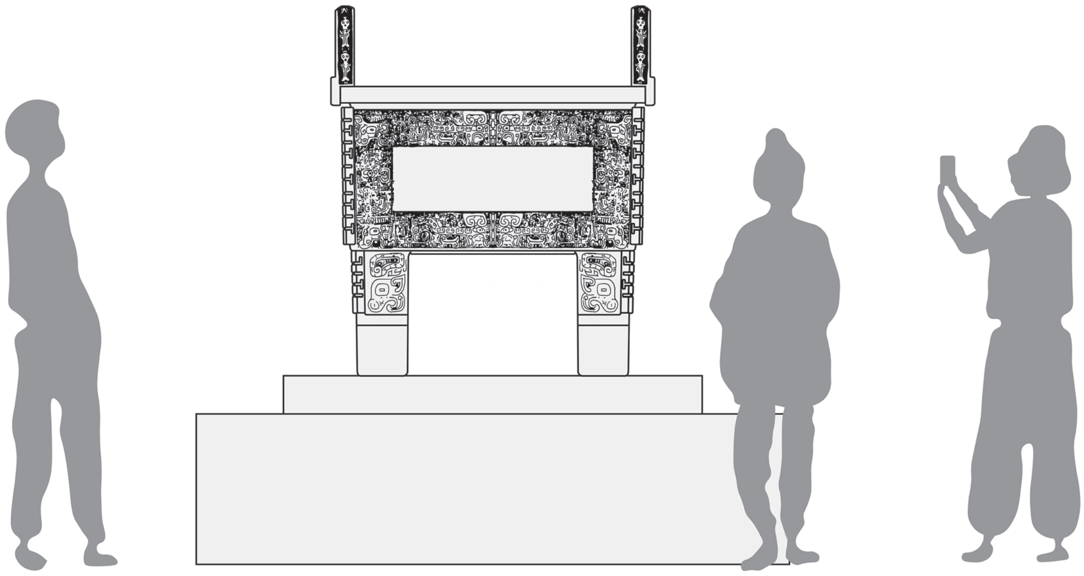

Figure 1.1. ***Simuwi ding*** **vessel, Anyang (object modified from Feng, F. et al. 1981).**

However, bronze metallurgy was not a local technology in China despite its importance and wide use. Before 2000 BCE, or just about 800 years before Anyang, there was almost no metal production in East Asia. Only around 1600 BCE did people start to make some relatively large bronze objects, including ritual vessels (but much smaller than those in Anyang; see Chapter 4). Thus, the development of metal production from this humble beginning to the heyday of Anyang was a surprising trajectory. The other oddity of this development was that the whole industry depended on an uneven distribution of metal resources in East Asia. Anyang and its surroundings happen to be areas with relatively few metal resources. How did people in these metal-poor areas have so many bronze objects? As this study suggests, there were at least three key points. First, people must have procured metal resources from other metal-rich regions. Second, people also needed to use the metal wisely, such as to use different metals for different purposes. Even with both methods, the critical elements of bronze—copper and tin—were still precious. Hence, the third secret of the early metallurgy in China was lead, a common but often neglected metal. Unlike in most other areas where people typically produced bronze without much lead, in early China, leaded bronze, or the alloy of copper, tin, and lead, dominated the bronze industry. By revisiting the development of leaded bronze in different regions and communities of early China, I argue that the additional lead not only increased the whole metal supply but also changed how people perceived metal as a new material, leading China to a different Bronze Age.

1.1. China and its early metals

"China" is not a naturally enclosed geographical area. It is an idea which gradually developed through the ages. People living in the second millennium BCE certainly did not consider themselves a single political or cultural organisation, nor did they hold the concept of China as an identity or a territory or speak Chinese as their common language. Although some communities may have felt that they were living in the centre of the world, as what the Chinese name of China, *Zhongguo*, literally means, there was not a culturally core area accepted by all these early communities whose lands now become parts of modern China. In this book, I use the word "China" as a geographical scope mainly because the areas and sites are mostly on the modern country's territory.

Although there is often no clear physical boundary between where we now call China and where we do not call China, some geological features can distinguish this region from the rest of the Eurasian continent. These features are not just boundaries for the scope of the study but also essential for understanding how objects and ideas about metallurgy were exchanged and circulated. Without limiting ourselves to today's political borders, the area I will illustrate starts from the Pamirs and extends to the continent's eastern coast. The area meets the Altai-Sayan, the Mongolian Plateau and the Greater Khingan on the northern side. On the southern side, it is separated from South Asia and South-east Asia by the highland mountains (Figure 1.2). The whole area is also divided by elevation

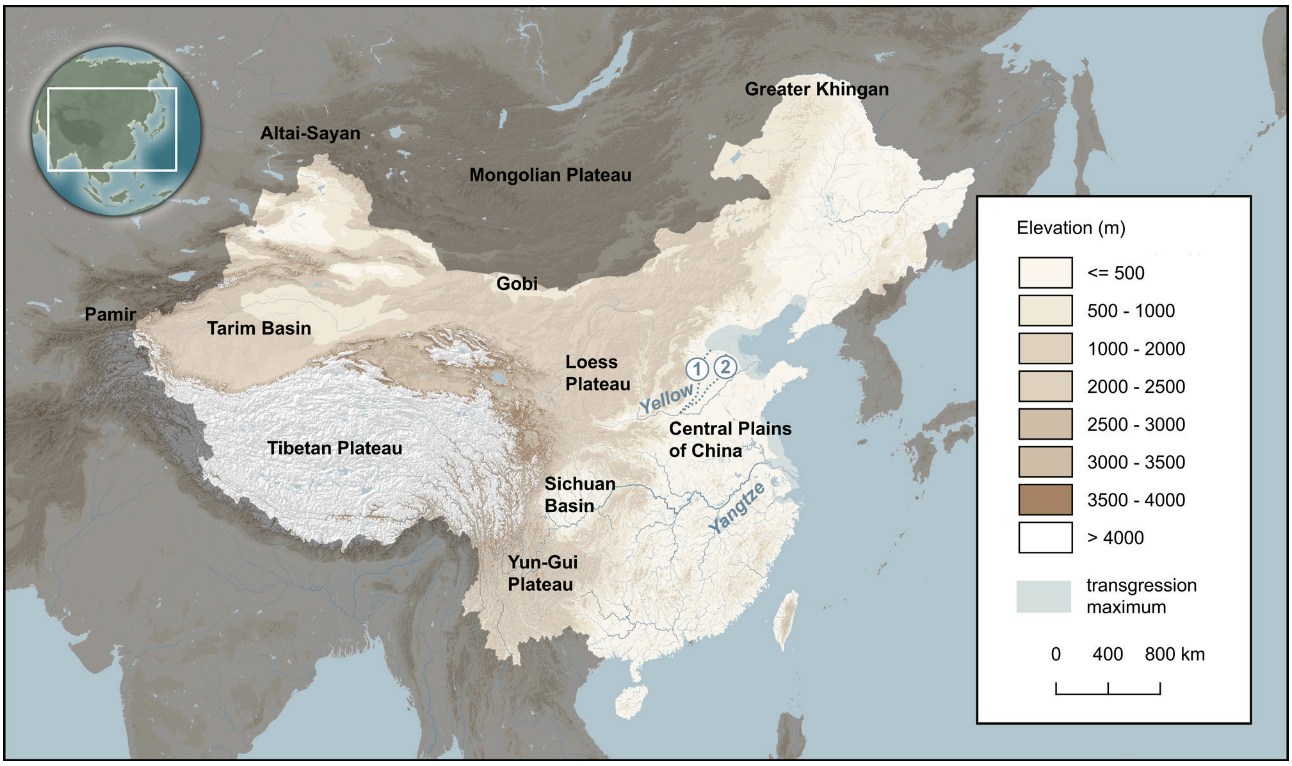

Figure 1.2. Topographic map of China with the extent of the shoreline at the transgression maximum and the late Holocene Yellow River: 1: c. 2278 BCE; 2: c. 602 BCE (modified from Kiddle and Zhuang, Y. 2015; Xue, C. 2009; Zhu, C. 1996).

into two parts. The higher western half includes the Tibetan Plateau, the Yun-Gui Plateau, the Tarim Basin, the Gobi Deserts, part of the Mongolian Plateau, and the Loess Plateau. The elevation of the highlands is above 1000–2000 m, while the Tibetan Plateau is even higher, with an average elevation above 4000 m. The lowland floodplains and the south-eastern hills are the south-eastern lower half, while the Sichuan Basin also belongs to the lowlands. The lowland floodplains and river valleys in eastern China are sometimes called the "Central Plains" since this area was traditionally considered the centre of the Han Chinese culture.

The Yellow River and the Yangtze are two large rivers running across the plains. A river is not just a line but an area constantly flooded. For the Yellow River, in particular, almost the whole northern part of the Central Plains—the North China Plain—is or used to be its floodplain (alluvial plain). Based on paleoenvironmental studies, the river's main stem during the second millennium BCE was further north of its current location (Kidder and Zhuang, Y. 2015). The coastlines were also continuously reshaped by natural and unnatural factors. Around 5000–3000 BCE, the transgression maximum pushed the coastlines to their westmost locations (Guoji 1986; Xue, C. 2009; Zhao, X. 1985; Zhu, C. 1996). In the second millennium BCE, the area between the transgression maximum and the modern coastlines was occupied by a few megadeltals, as illustrated in Kidder and Zhuang (2015). These geoarchaeological features are crucial to our understanding of the environment and the lifestyle of the early communities in the lowland regions. Nevertheless, as this study focuses mainly on metallurgy rather than paleoenvironment, most maps are still drawn based on the modern locations of the geological features. Additional discussion on the eastern coast is included in Chapter 5.

The landforms, together with other geological features such as the monsoon systems, divide East Asia into several zones with different physical environments and regional climates (sometimes described as different "biomes") (Dinerstein et al. 2017) (Figure 1.3). In the east, temperate broad-leaved and mixed forest climates cover most parts of the lowland Yellow River and Yangtze plains. This temperate region was also where the early agricultural societies, such as Anyang, boomed. In the north, temperate grasslands and shrublands occupy the whole of North Asia, forming the Eurasian Steppe (or "the steppes"). These continuous biomes provide what Nicola Di Cosmo (2002) called "the Steppe Highway" or what Evgeny Chernykh (2008a, 2008b) called "the Steppe Belt", as people can move fairly efficiently in almost all directions on the steppes without encountering radical changes of local climate. Through these movements, the Steppe Belt contributed significantly to spreading ideas and objects, including early metallurgy. Between the steppes and the Tibetan Plateau, high-altitude arid areas and deserts are cleft by some of the tallest mountains in the world, especially the Pamir and Tianshan Mountains in the south and the Altai and Sayan Mountains in the north. Although the heterogeneous landforms and drastically changing elevation pose certain problems to travellers,

Figure 1.3. Terrestrial biomes in eastern Eurasia and three suggested routes for interregional interaction. 1: Steppe Belt; 2: Inner Asian Mountain Corridor; 3: Hexi Corridor (biomes: Dinerstein et al. 2017).

the high mountains and deep valleys also provide people with something absent on the open steppes—natural shelters, especially to survive in winter. Historically, it was in this area that the famous Silk Road went through. For the region around the Pamir, Michael Frachetti (2012) proposed a network called the Inner Asian Mountain Corridor (IAMC). The IAMC incorporates various routes along the valleys of the high-altitude mountain ranges. Communities living in these highland areas, as Frachetti argued, were not isolated from each other but connected through the IAMC (Frachetti 2014; Frachetti and Bullion 2018). In the east, the narrow passage between the northern slope of the Tibetan Plateau and the deserts is called the Hexi Corridor. It is also a section of the Silk Road. Like the Eurasian Steppe, the IAMC and the Hexi Corridor present another possible route for early communication across Asia.

On the south of these regions, the Tibetan Plateau is a large area (about one-fifth of mainland East Asia) with a relatively uniform montane biome. Since steep mountain ranges are on all edges of the plateau, climbing onto it from any direction would be difficult. People who do so must overcome both the harsh terrain and altitude sickness. Nevertheless, archaeological discoveries in the recent decade suggest that, no later than 9000 to 6000 BCE, the earliest settlements had already appeared on the eastern and southern edges of the Tibetan Plateau (Aldenderfer 2011; d'Alpoim Guedes and Aldenderfer 2020; Hou, G. et al. 2015; Meyer et al. 2017; Zhang, D. et al. 2016). Archaeobotanical studies also suggest that domesticated crops from both the east and the west—millet from China, wheat and barley from Central and South Asia—were cultivated on the southern edge (the Himalayas) of the Tibetan Plateau between the fourth and the second millennium BCE (d'Alpoim Guedes 2015; Lister et al. 2018; Liu, X. 2019; Stevens et al. 2016). Therefore, other types of early cultural exchange may also have followed this direction.

On the southern and eastern sides of the plateau are the South Asian subcontinent and mainland South-east Asia. These areas all belong to the subtropical or tropical biomes. Like the Tibetan Plateau, archaeologists have also successfully traced the cultural exchange across this (sub)tropical south back to the prehistoric eras (Higham 2021; Ma, M. et al. 2023; Pryce et al. 2022). Regarding early metal objects and metallurgical technologies in South-east Asia, researchers are still divided mainly by the dating of the materials. It is now generally agreed that early metallurgy was introduced from southern China into the region (Ciarla 2022; He, Q. 2022; Higham et al. 2011; 2020; Pigott and Ciarla 2007; Pigott and Pryce 2022; Pryce et al. 2014; 2022; White and Hamilton 2014). In the opposite direction, no archaeological evidence suggests that early metal objects or metallurgical traditions from the South Asian subcontinent and South-east Asia arrived in southern China. For these reasons, this study focuses on the northern routes in discussing early metallurgy while leaving the potential southern contact to be confirmed by future studies (a recent study of southern China during the second half of the second millennium BCE, see Lai, C. 2019).

Regarding the beginning of metallurgy in China, some scholars endorsed an independent, local origin since the bronze vessels are extraordinary and unlike any metal objects produced elsewhere in Eurasia. Recent archaeological discoveries have now convinced most scholars that bronze metallurgy in China was not a local invention but part of a transcontinental phenomenon (Linduff and Mei 2009; Mei et al. 2015). Bronze metallurgy, or more accurately, copper-based metallurgy, refers to a specific group of technologies related to the production of copper and copper alloys, including the methods of obtaining certain metal ores (especially oxide and sulphide ores), extracting various metals from the ores by applying heat (smelting), and shaping and improving the products by techniques such as casting, forging, and annealing. Currently, it is generally agreed that the earliest copper smelting in Eurasia appeared in the region across West Asia and Eastern Europe before the fifth millennium BCE (although there is still a debate whether it was a single or multiple beginnings in this region) (Hauptmann 2020: 9–11; Roberts et al. 2009). From the fifth to the third millennia BCE, several alloying technologies (more in Chapter 2) were developed. These technologies also triggered the intentional production of bronze (copper-tin) objects (Roberts et al. 2009; a discovery of early bronze in Serbia, see Radivojević et al. 2013).

Large-scale metal production emerged in the third millennium BCE in the eastern part of the Eurasian continent (Figure 1.4). On the Iranian Plateau, two alloys, arsenical copper (copper-arsenic alloys) and leaded copper (copper-lead alloys), were produced, while bronze was still rare, if not totally missing (Helwing 2021; Thornton 2014). Around the second half of the third millennium BCE, metal production sites appeared on the north-eastern edge of the Iranian Plateau and the Amur River region, such as Altyndepe (Kirtcho 1988; Masioli et al. 2006; Salvatori et al. 2002), Gonur (Kraus 2016; Sarianidi 2007), and Sapalli (Askarov and Ruzanov 1977; Kaniuth 2007). This emerging cultural group is often called the Bactria-Margiana Archaeological Complex (BMAC). Although arsenical copper and leaded copper continued to be used, the proportion of bronze objects at some sites increased significantly (Kaniuth 2007). Some researchers suggest that access to tin resources in Central Asia facilitated the rise of the BMAC (Lyonnet 2005; Pigott 2018). In the east, the BMAC extended to the western edge of the Pamir. One important site here was Sarazm, founded around 3500 BCE (Isakov 1981, 1994). Rich metal production remains (crucibles, slags, and furnaces) are dated to no later than 2400–2000 BCE (Phase III of the site). The recovered metal objects from Sarazm correspond to those from other BMAC sites, but a few analysed objects were all made of relatively pure copper (Isakov et al. 1987). It is unclear whether other types of copper alloy, such as bronze, were also produced. Around the same time, metal production

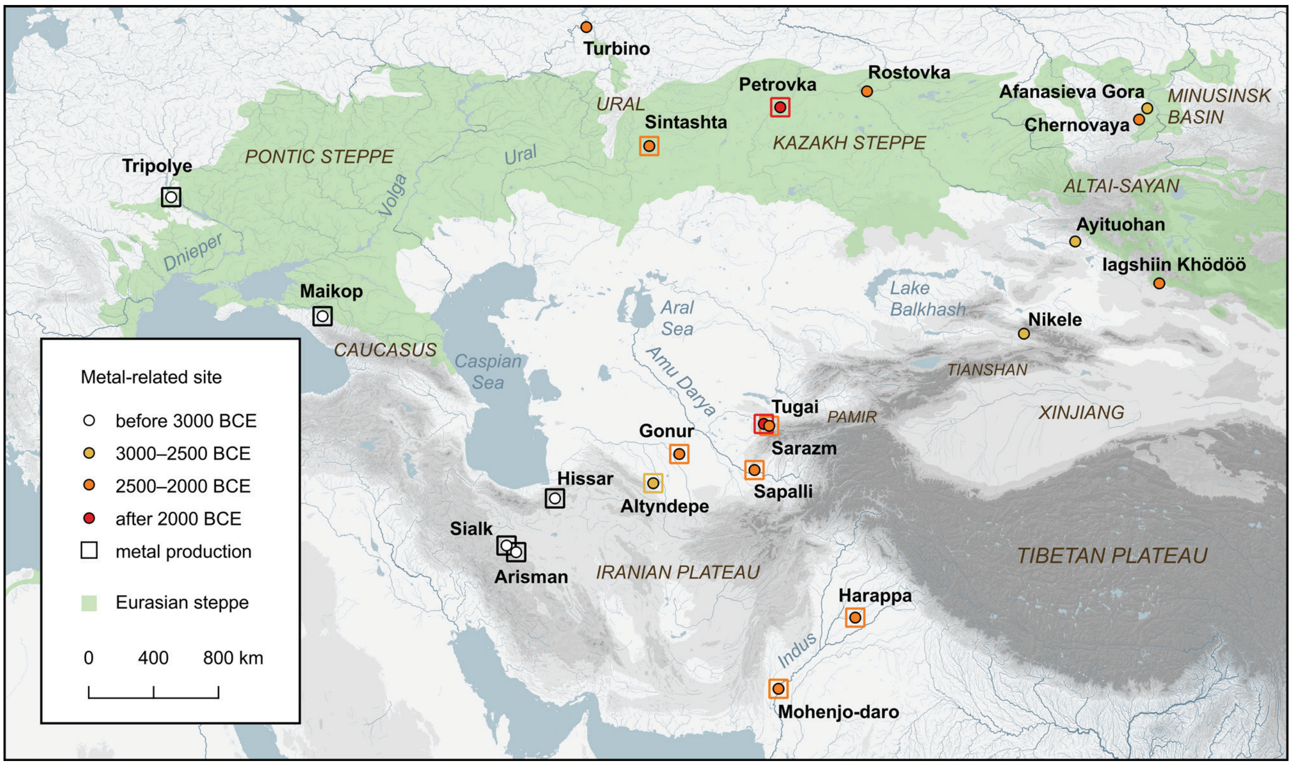

Figure 1.4. Development of early metallurgy across eastern Eurasia with sites mentioned in the text.

started in the Indus Valley, such as at Harappa and Mohenjo-daro (Agrawal 1984; Miller 1994, 2005; Tripathi 2018). However, as previously mentioned, no evidence shows that the metallurgical tradition ever crossed the Himalayas and reached south-western China. Therefore, this direction will not be discussed further.

In the north, copper metallurgy was adopted on the Pontic-Caspian Steppe and in the Caucasus by the end of the fourth millennium BCE at sites such as Tripolye and Maikop (Betancourt 1970; Greeves 1975; Hansen 2014). During the third millennium BCE, communities around the Ural Mountains, such as Sintashta and Petrovka, also witnessed the beginning of metal production. At Sintashta, numerous metallurgical remains (ores, slags, technical ceramics, stone hammers, etc.) appeared in the contexts dating to 2100–1800 BCE. Their presence in almost all houses suggests large-scale but decentralised metal production (Epimakhov and Berseneva 2016; Grigoriev 2015). Most finished products were made of either pure or arsenical copper (Anthony 2007: 391). The Petrovka settlement is dated to 1900–1750 BCE. The comparison of the material culture suggests that Sintashta and Petrovka were two closely related groups (some archaeologists describe them as the Sintashta-Petrovka culture). Metallurgical remains have also been found at Petrovka, but unlike Sintashta, most objects from Petrovka were made of bronze. Cultural exchange certainly connected BMAC to Sintashta-Petrovka (Hiebert 2002). For instance, the Petrovka-type objects have been found at Tugai, a copper-smelting site close to Sarazm (Avanesova 1996; Grigoriev 2002: 78–84), while various cultural elements from the BMAC also appeared at Sintashta (Anthony 2007: 433–35). Both the Ural Mountains and the mountainous area near Sarazm have lavish metal resources. The increasing demand for metal in the late third millennium BCE may have been one of the reasons behind the rise of these societies. Some scholars also suggest that the exchange of metal resources drove the new contact between Central Asia and the steppes. Nonetheless, there is so far no clear proof of this, as a recent study suggests that the two regions relied on relatively separate metal sources (Berger et al. 2023).

Beyond these two regions, metal objects have also been found around the Altai-Sayan Mountains. These objects are attributed to several archaeological cultures. The earliest, the Afanasievo (or Afanasyevo) culture, was about 3200–2800 BCE (Poliakov et al. 2019). Several sites with Afanasievo-type ceramics and burial traditions also appeared in Xinjiang, such as Ayituohan and Nikele. Some small copper-based objects have also been found at these sites (Li, S. 2018; Liu, H. et al. 2018). In the second half of the third millennium BCE, new local cultures gradually replaced the Afanasievo culture, including the Chemurchek (Qiemuerqieke) culture in western Mongolia (e.g. Iagshiin Khödöö) (Kovalev and Erdenebaatar 2014) and the Okunev culture in the Minusinsk Basin (e.g. Chernovaya) (Chernykh 1992: 184; Svyatko et al. 2009). Meanwhile, an interregional cultural phenomenon called Seima-Turbino also emerged. Objects considered typical of the Seima-Turbino phenomenon include the single-edged curved knife with a decorated pommel and the hollow-cast socketed spear head with a side hook. Unlike most Afanasievo metal objects, which were made of pure copper, Seima-Turbino metal objects were made of bronze (Chernykh 1992: 215–34). One of the famous cemeteries on the eastern Kazakh Steppe with Seima-Turbino types of bronze objects was Rostovka. Radiocarbon dates suggest that most burials were around 2200–2000 BCE (Marchenko et al. 2017). Interestingly, the Seima-Turbino bronze spear heads also appeared in northern China (He, D. 2016; Lin, M. 2016; Liu, R. et al. 2015a; Liu, X. 2015; 2021; Liu, X. and Liu, R. 2016). Some scholars date the spear heads to 2100–1800 BCE by typochronology (the relative dating based on the typological change of objects), but this date is not widely accepted (Gao, J. 2015; Lin, M. 2015; 2016; Wang, P. 2023). Other scholars have also pointed out that Seima-Turbino types of objects continued to be used in eastern Eurasia as late as 1500 BCE (Liu, X. 2015; Shao, H. 2021; Shao, H. and Yang, J. 2011; Seima-Turbino in South-east Asia, see White and Hamilton 2014).

These early metallurgical traditions were closely related but also distinguishable regarding the product types, the metal production organisation, and the applied technologies (such as different alloying practices). From the metal production perspective, we may divide these traditions into two categories. One is what I call the "Western and Central Asian tradition". This tradition is represented by sedentary societies that conducted large-scale metal production in a certain region. Specialisation and the division of labour were often remarkable in this production model. For example, at Arisman, Sialk, and Hissar, craftspeople at different locations (the production zones) of the sites focused on producing typologically and chemically different objects (Chegini et al. 2000; Nezafati et al. 2008; Pigott 1989; Rehren et al. 2012; Thornton 2009b).

However, this specialised and standardised metal production tradition did not reach East Asia directly. What was really transferred to the east was the metal use and metal production model on the steppes (Jessica Rawson, personal communication), which I call the "steppe-Inner Asian metallurgical tradition". The production was often decentralised and despecialised (e.g. Sintashta). In the east, beyond the Kazakh Steppe, most metal-related sites in the Altai-Sayan and Xinjiang were relatively small. Metal objects were usually found in the graves, while the remains of settlement and craft production were often missing. So far, we do not know whether this is simply due to the limitation of archaeological fieldwork or whether metal production was indeed absent. The large metal production centres in the west likely produced some metal objects circulated on the steppes. Meanwhile, people on the steppes may also have produced some metal objects, but this was on an individual or household level rather than centralised and stratified in the societies. As anthropological studies on modern pastoral communities suggest, some craft production was conducted by professionals, but these people also needed to take care of their herds, and their special abilities usually did not help them accumulate additional wealth (Vreeland: 50–51). Nonetheless, in the Bronze Age, this decentralised metal use and production did not stop some individuals from accumulating large numbers of high-quality metal objects, as we can see in some burials.

In northern China, although some metal objects and metallurgical remains are dated by researchers to as early as 3000 BCE, such findings are scarce and often have no or questionable contexts (Xu, H. 2016a). These findings and dates need to be taken with extreme caution. For the metal-related findings dating around the end of the third millennium BCE, these dates are usually more reliable (for a complete list of the sites used in this study, see Appendix 1). Hence, we can use 2000 BCE as the approximate beginning of our discussion of the early metallurgy in China (Figure 1.5).

Among these early metal-related findings, the object types (tools, weapons, personal ornaments, etc.) and the practices of small-scale metal production both remind us of the "steppe-Inner Asian metallurgical tradition". One pioneering region in this metallurgical turn was the Hexi Corridor. Intensive metallurgical activities started around 2000 BCE. At the best-studied site, Xichengyi, production remains and finished copper-based objects have both been found (Chen, G. et al. 2015a; Li, Y. et al. 2015; Wang, H. et al. 2015; dating: Zhang, X. et al. 2015). The emergence of metallurgy in this area was quite abrupt since, from its very beginning, metal production in the Hexi Corridor had already shown a certain level of complexity, with a variety of product types (knife, awl, mace head, mirror), techniques (casting, forging, cold working), and metal alloys (pure copper, arsenical copper, bronze) (Chen, G. 2017a). The complexity suggests that metallurgy was not invented locally but was introduced by communities that had developed this mature technological tradition.

The other area where early metal objects and metallurgical remains have been found is around the Yellow River's middle to lower reaches (An, Z. 1993). In recent years, with the discovery of a large, stone-fortified site called Shimao, the eastern side of the northern bend of the Yellow River (also known as the Ordos Plateau) has attracted much attention. A few radiocarbon dates suggest that Shimao was occupied around 2300–1800 BCE (Sun, Z. et al. 2020). Copper or bronze knives and stone moulds have been found at the site (Sun, Z. et al. 2017). In the further south, another site with metal objects is Taosi. They appeared in the middle and late phases of the site, or around 2100–1700 BCE (Gao, J. and He, N. 2014). Since the material culture of Taosi had a clear connection with Shimao, it is possible that knowledge and ideas, including the use of metal, were carried by people from the north to the south (Shao, J. 2020). No metal production remains have been found at Taosi, although a crucible fragment found at a nearby site (Dongbaizhong) may belong to the Taosi period (Zhang, K. 1992). At each of these Middle Yellow metal-related sites, the number of metal objects and metallurgical remains was meagre. None of the sites had a systematic practice of metal production. Therefore, by that time, the scale of metal-using and metallurgy in the Yellow River Valleys was still limited. Large-scale metal

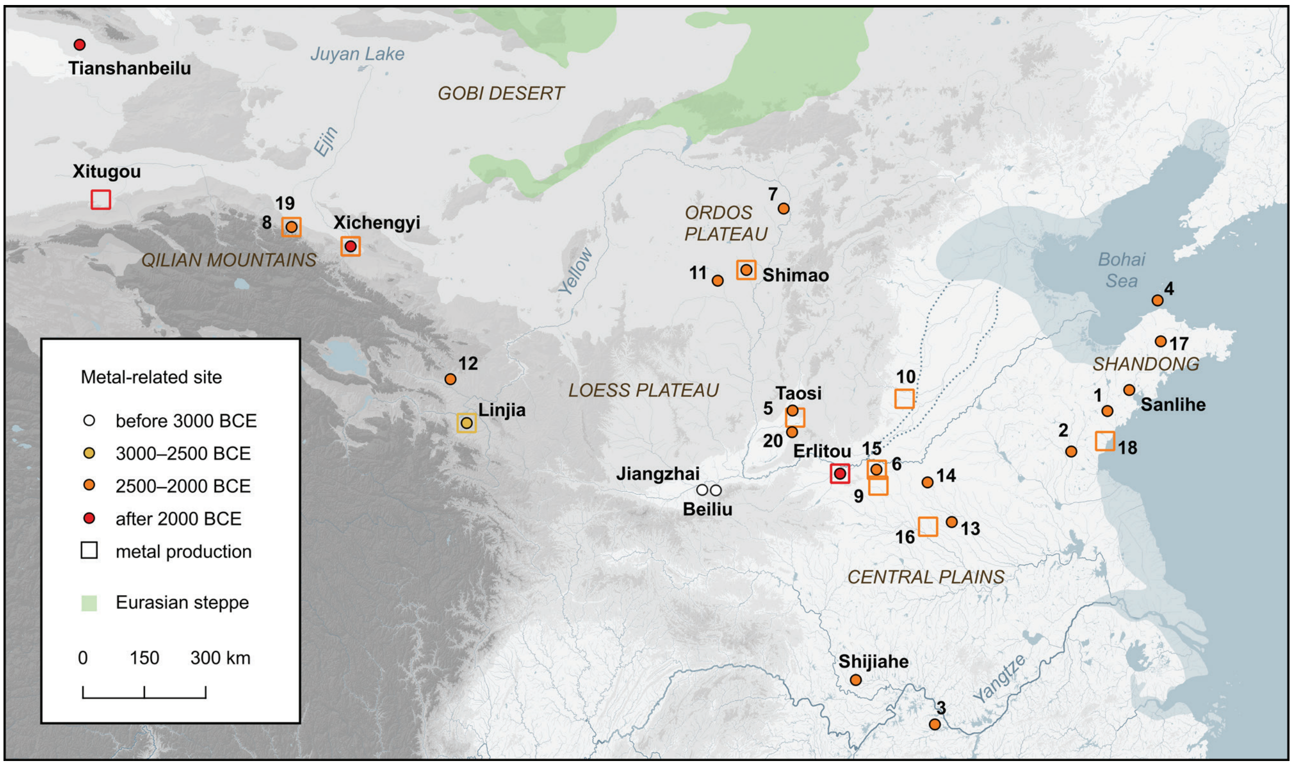

Figure 1.5. Early metal-related sites in East Asia. Sites mentioned in the text are labelled on the map. Other sites: 1: Chengzi; 2: Dafanzhuang; 3: Dalupu; 4: Dianzi; 5: Dongbaizhong; 6: Dongzhai; 7: Erliban; 8: Gaomuxudi; 9: Guchengzhai; 10: Hougang; 11: Huoshiliang; 12: Jiangjiaping; 13: Luantai; 14: Lutaigang; 15: Niuzhai; 16: Pingliangtai; 17: Yangjiaquan; 18: Yaowangcheng; 19: Zhaobitan; 20: Zhoujiazhuang (data: Appendix 1).

production only started in this region around the second quarter of the second millennium BCE (Chapter 4).

For the Hexi Corridor and the Middle Yellow River Valley, the similarity between their metallurgical practices and those on the steppes is undeniable. For this reason, Chernykh has already suggested that China was part of the "East Asian Metallurgical Province" (Chernykh 2008a, 2014), with its metallurgy coming from the west. However, Chernykh did not describe how the cultural contact happened. In recent decades, as the archaeological discoveries of early metallurgy grew in numbers and the dating methods greatly improved, scholars proposed several "Metal Roads", borrowing the idea of the Silk Road. One route was from the Altai-Sayan, through Xinjiang, to the Hexi Corridor (Li, S. 2005; Mei, J. 2003a; 2003b). This hypothesis was proposed before the discovery of Xichengyi. After that, since Xichengyi was earlier than most metal-related sites in eastern Xinjiang or north-western Gansu, such as Tianshanbeilu and Xitugou (Li, Y. et al. 2018; Mei, J. 2000; Qian, W. 2006; Tong, J. 2021), scholars suggest an alternative route along the Ejin River. The river starts in the Qilian Mountains and flows northward into the Gobi Desert, forming a few oases in this relatively drought area (including the historically famous Gashuun Nuur, or Juyan Lake, which is now mostly dried up). As most early metal production sites were located near the river valley, the knowledge of metallurgy may have been transmitted by people moving from the steppes into the Hexi Corridor through this route (Jaang, L. 2015; Janz et al. 2020).

In southern China, the question of the earliest evidence of metallurgy was raised by Guo Jingyun and colleagues (2018; 2019a; 2019b). According to their papers, copper-bearing minerals have been found at several Middle Yangtze Valley sites, such as Shijiahe, dating between the fourth and the third millennia BCE. Some minerals appear to have been heated. Guo suggested that local people developed some metallurgical techniques independently. Among scholars, this argument is not widely accepted. Although the activities described—collecting and heating metal-bearing minerals—may have existed, what scholars really question is whether this can be considered the beginning of metallurgy in the particular academic discussion. As previously discussed, *the* metallurgy in the context of Eurasian archaeometallurgy (the archaeological study of early metallurgy) is a group of specific and interrelated technologies and ideas rather than any human activities associated with metal-bearing minerals (the latter certainly existed in many early communities such as decorating tombs with ochre, a type of iron ore). In this case, we do not know what the Shijiahe people really produced with their experiments. Moreover, Shijiahe and the nearby communities gradually discontinued around 2000 BCE, and so did the metallurgical practices. Metal use and production only reappeared around 1600–1500 BCE. This time, the whole practice derived from the Middle Yellow River Valley rather than from the discontinued local tradition (see Panlongcheng in Chapter 4). Therefore, even if the treatments of the metal minerals did exist at a few sites before 2000 BCE, it is better to describe this as a specific local practice rather than the beginning of metallurgy in early China.

How metallurgy started on the eastern lowlands is also an open question. Some scholars suggest that people with the knowledge of metallurgy moved from the Hexi Corridor to the Ordos Plateau. From the Ordos Plateau, the objects and ideas went south-east along the rivers and mountain corridors and finally reached the lowlands (Chen, K. et al. 2022b; Fitzgerald-Huber 1995, 2003). Nevertheless, if we take Shimao as the earliest evidence for metal-using in the Middle Yellow River Valley, this beginning was almost as early as in the Hexi Corridor. People on the Ordos Plateau likely had direct contact with the steppes. In addition, there may also have been a route (or routes) near the eastern coast, connecting the steppes to North-east China. The emergence of metal-using communities in the first half of the second millennium BCE in the northern Bohai Rim (Chapter 3) may have been a result of this route. On the Shandong Peninsula, some sites also have metal-related findings dating around the second half of the third millennium BCE, such as Sanlihe. These objects suggest that people with the steppe metallurgical tradition may have come along the coast or even across the Bohai Sea to this area. The discoveries of some early wheat samples in Shandong (third millennium BCE) also suggest the connection between the peninsula and the steppes, as wheat is also considered to have been first domesticated in West Asia and was only introduced into East Asia (Crawford et al. 2005; Jin, G. 2007). This coastal route, however, is still not confirmed. In Chapter 3, I use "the steppe frontiers" to refer to all these regions which may have had direct geographical contact with the steppes, such as the Hexi Corridor, the Ordos Plateau, and the northern Bohai Rim.

From this rather late beginning (compared with the western part of the continent), metallurgy grew rapidly in East Asia in the next few centuries. By around 1500 BCE, the scales of metal use and metal production in some areas were already close to those in Central and West Asia. One particular area with large-scale metal production was the Middle Yellow River Valley. In this area, Erlitou emerged as the first regional metal production centre with various metal objects, including some of the earliest metal ritual vessels. Meanwhile, some smaller sites near Erlitou were focusing on the upstream of the industry—mining, smelting, and exporting prepared metal resources (probably as ingots). This level of specialisation was similar to what we have discussed, for instance, on the Iranian Plateau. Around 1500 BCE, large-scale smelting and casting activities also emerged in the Middle Yangtze Valley. The object typology and other evidence suggest that the Yellow and the Yangtze Valleys were closely connected by exchanging people, raw materials, and finished products. In the last quarter of the millennium, Anyang emerged as the largest urban centre and metal production site in the region.

The large-scale metal production model in these early Chinese sites certainly shared some traits with the Western and Central Asian traditions, such as the adoption of specialised production and the division of labour. However, these two metallurgical traditions were not directly associated. What triggered the eastern metallurgical tradition was the mixture of two sources of knowledge. One was the technologies and objects carried by the steppes and Inner Asian people. The other was the knowledge and experience accumulated in other Eastern Asian local craft production (ceramic, stone, bone, etc.). How people in the east used metal objects was also transformed and continuously reshaped by local ideas, rituals, and social structures. In particular, ritual bronzes became a significant symbol of social power. As the *Simuwu ding* from Anyang suggests, these objects were not just crucial to individuals who owned them but also, to some extent, significant to the whole society. Since large metropolitan sites were often (but not always) the centres of the use and production of ritual bronzes, some scholars suggest that the emergence of metal production in early China was a result of the rising urbanism on the Central Plains (Bagley 1999). Campbell et al. (2022) used the term "Central Plains metropolitan bronze tradition" to describe this production model. As Campbell summarised, the traits of this metallurgical tradition include centralised production and distribution, the participation by high-skill, professional individuals, and the focus on specialised product types (see also Campbell 2014). In Chapter 4, I call it the "Central Plains bronze tradition", with more discussion included regarding the use of the term.

The start of metal production on the Central Plains completely changed the material culture and societies in East Asia. As the Central Plains bronze production surged, metal resources and products from the Central Plains poured into its surroundings, while some of the latter had already adopted the metallurgical tradition from the steppes. In this complicated interaction, one particular phenomenon was the use of leaded bronze. Lead was first recognised by craftspeople on the steppe frontiers, while the knowledge may have come from the steppes. However, leaded bronze (especially with as high as 10–20% lead) was first systematically used in the Central Plains bronze tradition around 1600–1500 BCE. In the next half millennium, this alloy also appeared in many other regions around the Central Plains. The spread of leaded bronze indicates how metal objects and metallurgical ideas helped shape societies and cultures and how interregional communication was established and transformed.

1.2. The lead problem in Chinese bronzes

Bronze was a vital part of early Chinese culture. In Chinese archaeology, the word "bronze" and especially its plural, "bronzes", are sometimes reserved for a specific form of bronze object—bronze food and drinking vessels made for ritual purposes. The use of vessels, first in ceramic and later including bronze, has long been part of the ancestral and afterlife rituals. The period from the second to the first millennia BCE was the peak of bronze vessel production, while there were also plenty of replicators and followers of those early vessels during the subsequent dynasties (Wang, T. 2018). For the early bronzes, they were initially buried in tombs or deposited in hoards. In both historical and modern eras, these bronzes were unearthed by serendipity or deliberate treasure hunting. These reappeared objects often attract scholarly interest.

Meanwhile, how the bronzes were made was not well understood before the time of modern archaeology and archaeometry. In ancient China, knowledge of bronze casting was not well recorded and sometimes even kept a secret. An ancient text called *Kaogong Ji* 考工記 (*Artificers' Record*) is the best-known reference to the knowledge of bronze vessel casting. The current version of the text, dated by its style and contents, was probably written between the sixth and the fourth centuries BCE and compiled around 50 BCE (Guo, M. 1947; Jin, J. 1998; Wen, R. 1993: 144–57; Xuan, Z. 1993). In the text, six "mixing ratios" (*liuqi* 六齊) of bronze alloys were listed:

> There are six different bronze alloys. *Jin* 金 and *xi* 錫 with a ratio 6:1 are used for the manufacture of bells and ritual vessels called *ding* 鼎; in the ratio 5:1 for the manufacture of hatchets and axes; in the ratio 4:1 for the manufacture of lances and halberds; in the ratio 3:1 for the manufacture of large knives; in the ratio 5:2 for the manufacture of knives to cut bamboo strips for books and of lethal arrows; and in the ratio 2:1 for the manufacture of plane and concave mirrors (Guan, Z. and Herrmann 2019: 46–47).

The text only mentions two metals: *jin* and *xi*. In ancient Chinese, *jin* means metal in general or copper in particular, while *xi* usually means tin but often includes lead. Therefore, the actual meanings of the two names in *Kaogong Ji* are not clear and result in many interpretations (Lu, D. 1999; Pollard and Liu, R. 2022; Su, R. 1998; Sun, F. 2011; Wu, L. 1986; Yang, H. 2015; Zhang, Z. 1958; Zhou, S. 1978). On the other hand, the presence of lead in early Chinese metallurgy, especially its use in bronze casting, was unknown (examples of early lead and tin objects, see Li, M. 1984; Nie, Z. 2019: 17–25). Only in the early twentieth century, when archaeometry (archaeological science) was developed and used to analyse early Chinese bronze objects, scholars started to realise that the secret of Chinese bronze production depended on not two but three metals: copper, tin, and lead (Liu, R. et al. 2015b). Masumi Chikashige (1918; 1920b, 1920a, 1929) was among the first to analyse some Chinese mirrors, swords, and bells and discovered that the objects contained more than 5% lead. Later, this phenomenon was also noticed by Liang Jin (1925). Liang further compared the chemical compositions to the proposed alloy ratios from *Kaogong Ji*. This comparison led him to argue that *xi* in *Kaogong Ji* refers to both tin and lead. However, he also noticed that the actual levels of tin and lead in the objects do not always agree with what *Kaogong Ji* suggested.

In the 1930s, more analyses were done by William Collins (1931) and Tsurumatsu Dono (1932, 1933, 1934). All these pioneering studies confirmed the surprisingly high lead contents which are common in Chinese bronze objects. As Dono (1932: 352) wrote:

> As for lead which is contained often in considerable quantities in the samples, it is hardly possible to think that it came from copper ores and it must rather be considered that this metallic element was artificially added to increase the fluidity of molten copper and to make the casting more easy.

In the following decades, more analyses and studies were published, improving the academic understating of lead in early Chinese bronzes. In particular, Noel Barnard (1961: 169–98; 1975; Barnard and Satō 1975) collected most chemical data on Chinese bronzes until his time and pointed out that lead levels in the objects vary with time and object type. Also, in the 1960s, John Pope and Rutherford Gettens published their studies on the Chinese bronze objects from the Freer Gallery in Washington, D.C (Pope et al. 1967). The analyses done by Gettens show that the bronze vessels are generally more leaded than other types of bronze objects. Only 12 of the 68 analysed vessels contain less than 1% lead. Contrastingly, lead contents in weapons are relatively lower but sometimes still exceed 2% (Gettens 1967: 33–56). Based on these and other studies in the following decades (Bunker et al. 1997; Caley et al. 1979; Chase and Ziebold 1978; Chen, M. 1954; Cheng, T. 1974; Wang, J. and Yang, G. 1959), three general views on leaded bronze became widely recognised by scholars. First, leaded bronze was the most popular copper-based alloy in early China, while this alloy (especially high-leaded bronze) was not commonly used by other early societies around the world. Second, the use of leaded bronze in China can be traced back to at least the Shang period (c. 1600–1046 BCE), although we now know that leaded bronze was used before the Shang (Chapter 4). Third, leaded bronze was commonly used for casting ritual vessels. In other objects, this material was not as common as in the vessels.

At the same time, findings from new archaeological excavations also attracted the interests of both metallurgists and archaeologists. The excavation of Anyang was one of them. The first excavation season started in 1928. In 1931, H. C. H. Carpenter (1978) was commissioned to analyse four metal samples from Anyang and published his results. An obvious advantage of working on newly excavated objects is that researchers usually know more about the archaeological backgrounds of the objects. By contrast, those in museums and private collections often have questionable dating, provenance and even authenticity. Unlike the previous discoveries, the objects Carpenter analysed (four fragments) were all made of unleaded bronze (copper: 80–85%; tin: 15–20%).

This first attempted collaboration between archaeometallurgists and field archaeologists did not attract much attention. One obvious problem was that the samples Carpenter analysed, certainly offered by the excavators, were all highly corroded specimens from unknown objects. Even though they were from Anyang, the results did not provide enough archaeologically meaningful information. Nevertheless, this interdisciplinary collaboration still pointed out new directions for future research, as scholars from both archaeology and science realised that they need to understand the methods and practices of the other side. Many new methods currently used in the field archaeology are reflections of this mutual understanding. For example, metallurgical remains such as smelting wastes—previously unfamiliar to excavators and were often neglected—are now better identified, recorded, and preserved.

Ground-breaking work was conducted by the former Beijing University of Iron and Steel Technology (BUIST), the predecessor of the University of Science and Technology Beijing, especially by Sun Shuyun and Han Rubin from the 1970s. In this project, the researchers analysed hundreds of newly excavated objects across China. The results were published in a pioneering paper in 1981 (Sun, S. and Han, R. 1981). Publications by Sun and Han and their colleagues contributed to a monograph series, starting from 1986, and several books (Beijing 1978; 1986; Han, R. 2014; Han, R. and Ke, J. 2007; Sun, S. 2015; Sun, S. and Li, Y. 2003). In the 2000s, archaeometallurgy was included in the state-sponsored "Searching for the Origins of Chinese Civilisation" project, led by Mei Jianjun and joined by three Chinese institutes. Many new research results have been published since the start of the project (Linduff and Mei, J. 2009; Mei, J. 2009; 2011; Mei, J. and Zhou, Y. 2016; Mei, J. et al. 2015).

Besides these approaches to directly analyse and study metal objects and metallurgical remains, new research projects have also been conducted to review the published datasets of early metal objects. One of the projects was the "FLAME" (FLow of Ancient Metals across Eurasia) by Mark Pollard from the University of Oxford. This project aimed to understand the circulation (the "flow") of metal objects and resources across Eurasia. One of the results presented by the project shows that copper-based objects with more than 1% lead were relatively rare in other parts of Eurasia. This is very different from the phenomenon in East Asia, where more than half of the analysed metal objects contain more than 1% lead (Pollard 2018: 130). In addition, by re-examining the published chemical compositional and lead isotope studies, Pollard and colleagues (especially Liu Ruiliang and Hsu Yiu-Kang) also demonstrated that, through the circulation of metal objects and resources, leaded bronze had a profound impact not just on the early Chinese metal-using communities, but also on their neighbours in East Asia and the steppes (Hsu, Y. 2016; Hsu, Y. et al. 2016; Liu, R. 2016; Liu, R. et al. 2019; 2020; Pollard and Liu, R. 2022; Pollard et al. 2017a).

Until 2023, around 2000 copper-based metal objects dating to the second millennium BCE have been analysed, and the results have been published. These objects are from over 100 sites (Appendix 2). This chemical database provides an overall picture of different alloying practices in early China. The data shows that most objects before 1600 BCE were made of pure copper or unleaded bronze (copper-tin), while leaded copper alloys (leaded copper and leaded bronze) became the majority after about 1500 BCE. The proportion of the leaded alloys continued to grow till the end of the millennium (Figure 1.6). A more detailed

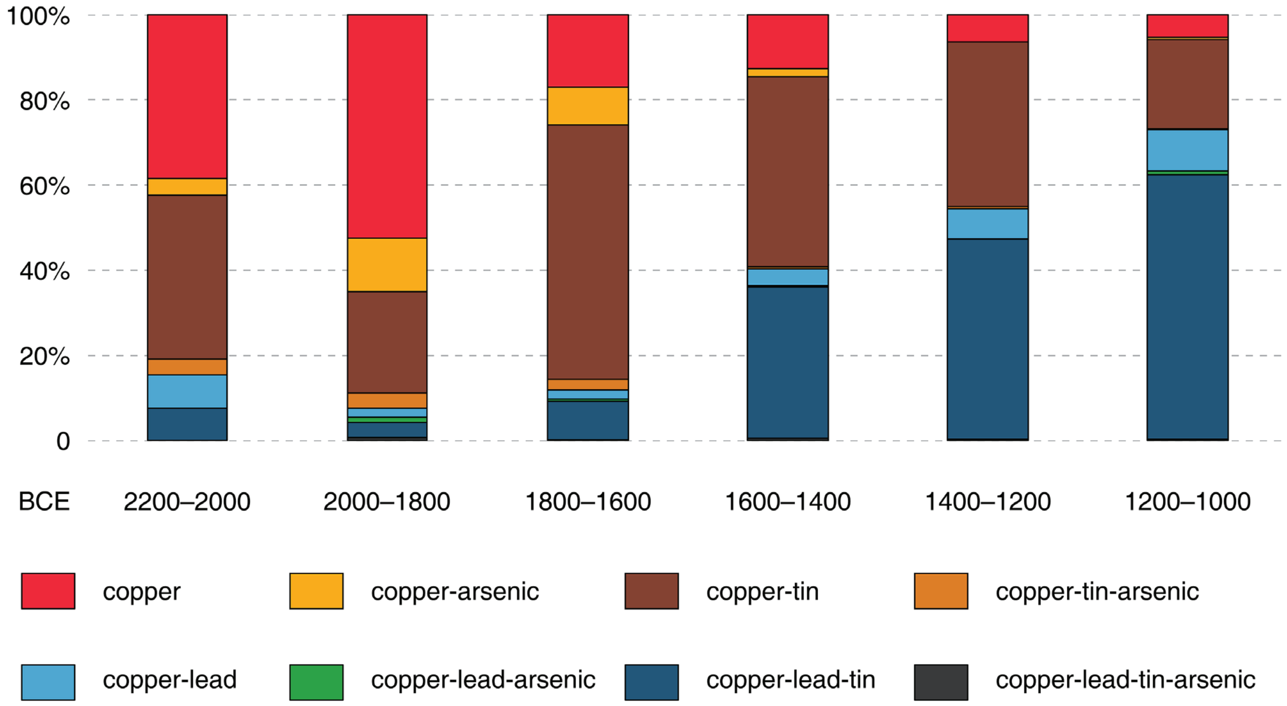

Figure 1.6. Changing ratio of alloy types in early China during the second millennium BCE (data: Appendix 2).

comparison with geospatial data of the sites suggests that the adoption of leaded bronze in the second millennium BCE was not a uniform phenomenon (Figure 1.7). The Central Plains was the core area where most objects were made of leaded bronze. In the second half of the second millennium BCE, the leaded bronze core area expanded as some communities around the Central Plains also adopted this alloy in reshaping their material culture. There were also areas, such as Xinjiang and the Hexi Corridor, where leaded bronze was still unpopular. Beyond the modern territory of China, leaded bronze was not very common. Studies show that, only from the first millennium BCE, leaded bronze objects started to appear on the Mongolian Plateau and the steppes. As Hsu Yiu-Kang suggested, this was probably due to the use of metal resources from China (Hsu, Y. 2016: 228–30; Hsu, Y. et al. 2016; Park et al. 2011). A further comparison of the lead and the tin levels in all the samples (Figure 1.8) suggests that the average lead level was relatively low before 1600 BCE. After that, the average lead level continued to increase over the second half of the millennium. Meanwhile, the average tin level increased in the first three quarters but dropped in the last quarter. A possible reason for this is that, due to the geographical limitation of tin deposits (Chapter 2), the total amount of tin available to the early metal

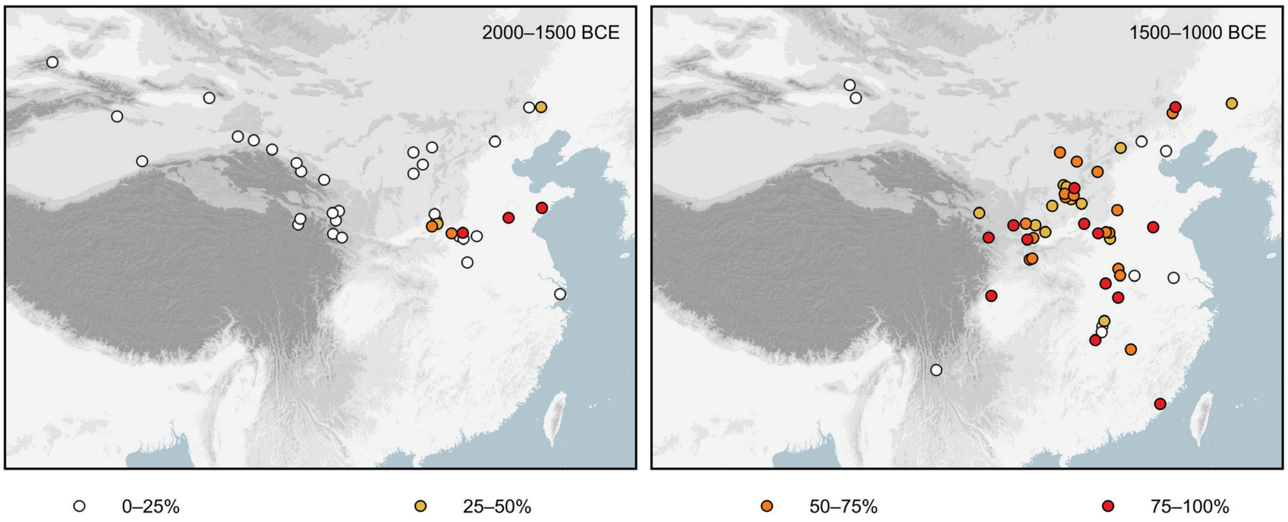

Figure 1.7. Proportions of leaded bronze (over 2%) objects in the metal assemblages, second millennium BCE (data: Appendix 2).

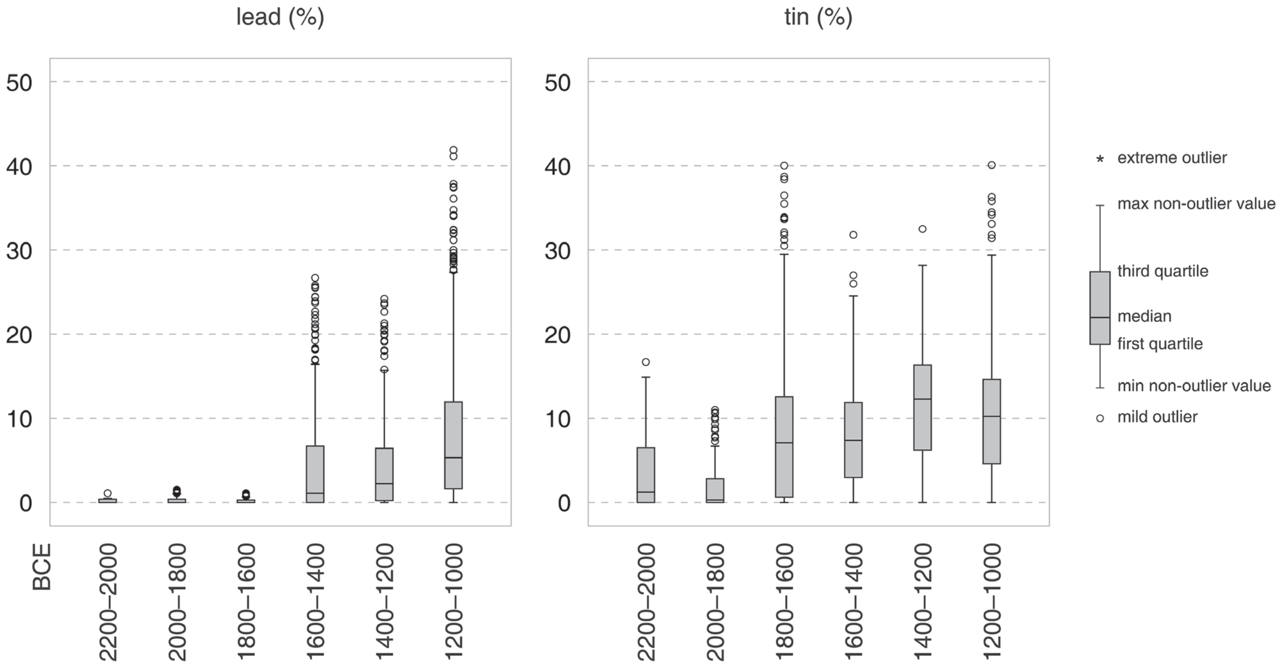

Figure 1.8. Lead and tin levels in analysed copper-based objects from early China (data: Appendix 2).

industry did not increase as fast as the total metal production. In other words, as the two main elements in the bronze alloys, lead was more available than tin. We will revisit this several times in the following case studies.

In terms of the reason for using leaded bronze, a commonly held argument (As Dono also suggested in the previous citation) is that adding lead can facilitate the casting to achieve a better result (Chase 1983, 1994; Chase and Ziebold 1978; Gettens 1967: 42; Yetts 1931). This view echoes suggestions made by scholars studying early leaded bronze used in other regions (Craddock 1979; Hyman 1923; Northover and Staniaszek 1982; Staniaszek 1982). As Katheryn Linduff (1977: 13–15) summarised:

> Although it is still not known exactly how the lead was introduced into the alloy, it is certain that the melting point of the mix was lowered by such addition, that it produced a cleaner cast, and that it made for easier finishing operations, such as removal of ridges and flaws, and for simpler final burnishing. Lead causes this in any mixture. Since the molten material could flow more easily and shrink less rapidly, the addition of lead allowed for the use of more complicated and intricate designs. And even though the exact proportions of the metal were not apparently standardized … Lead was consciously added in a relatively consistent proportion in Shang and would be included often in higher proportion during the Chou Dynasty, though regional preferences must be considered.

An alternative view, supported by some other scholars, argues that adding lead had no functional reason. Instead, lead was added for economic concerns since lead was often more available than tin (Zhu, F. 2009: 698–99). The bronze objects from Anyang are often used to support this argument, as the lead levels of tomb objects are related to the social status of the tomb owners (Li, M. 1982; Liu, Y. 2019: 325–27; Zhao, C. 2004). A more comprehensive review of this case is in Chapter 5. Some studies based on museum collections also suggest this non-functional approach of adding lead (e.g. Yang, H. 2017). However, objects from other archaeological sites have not been thoroughly reviewed to test this economic explanation. In a recent study, Zhang Zhiyan and Cui Jianfeng (2022) also tried to explain the lead use by statistics. Based on the published data of the Shang (1250–1046 BCE) and the Western Zhou (1046–776 BCE) bronze objects, the authors noticed that the tin levels in many objects are relatively stable, while the copper and lead levels are negatively correlated. According to the authors, this correlation suggests that lead may have been used as a substitute for copper due to the shortage of the latter.

Besides these two interpretations, scholars working on early metallurgy in other regions also suggest that the use of leaded bronze or other copper alloys may have been associated with the sensory properties of the material, such as colour, touch, taste, and sound (Baker 2013; Busatta 2014; Chapman 2007; Hosler 1994, 1995; Jones 2004; Keates 2002; Mödlinger et al. 2017; Radivojević et al. 2018). These studies may point to a new direction for the future archaeometallurgy of early China. Nevertheless, before such studies become available, we cannot simply use other case studies to explain ours, as neither the functional nor the sensory interpretations are universally applicable in all cases. Only through the study of the particular archaeological scenarios can we determine why leaded bronze was used. In the case of early China, at least three particular situations need to be considered regarding early metallurgy.

First, the geographical background and the regional variety of the metal deposits are fundamental to our understanding of early metallurgy. As a critical issue, the imbalance of the metal distribution in China means that those who wanted metal products (such as ritual bronzes) the most did not have the most convenient access to the metal resources. Notably, the lack of tin in China, especially on the Central Plains, pushed people to look for other possibilities, including lead. What we also need to consider is the types of the raw material. Some communities may have obtained metals through mining and smelting, while others may have depended on prepared metal resources (such as ingots) or used recycled ("secondary") metals to make new objects. Choosing these different raw materials also led to different compositions in the final products.

Second, when discussing alloying practices, most previous studies used definitions from modern material science, such as 1 or 2%, to decide alloy types. That is to say, any bronze alloy with more than 1 or 2% lead is identified as leaded bronze. This is the foundation for the data interpretation and visualisation, such as to compare the regional and chronological patterns of different alloying practices (Figures 1.6 and 1.7 are also based on such criteria). A benefit of this approach is that datasets in large size can be compared objectively. Nevertheless, a potential problem is that the comparison neglects how people really thought of the materials and how the materials were really used as objects. For example, using a knife made of leaded bronze with 2% lead is certainly a different case from using a ritual vessel made of bronze with 20% lead, although both objects are identified as made of leaded bronze. These details can only be revealed if we examine each case in its particular context. In other words, we need to understand how people decided to use leaded bronze in each case and the consequences of these choices. This does not mean that interregional and intercultural comparisons cannot be done. As the case studies in the following chapters show, people from different regional and cultural backgrounds certainly shared some common knowledge and practices regarding their relationships with leaded bronze. The similarities of particular objects or alloying patterns may help reveal some connections, but only by particular case studies can we answer why the similarities existed.

Another problem regarding studies relying purely on statistical data is that the mathematical rules of statistics are often overlooked or misused. This means that the patterns and correlations which seem to be "obvious" in the datasets or on the plots and diagrams are often deceptive (one example is the "unit-sum problem" in multivariant analysis; see Pollard and Liu 2023). In particular, a higher resolution (e.g. 5% lead vs 5.023% lead) does not always mean higher explanatory power, nor does a bigger dataset (e.g. 100 compositional values by causal pXRF analyses). After all, data can only help reveal the information of the objects. What we ultimately study are the objects in archaeological questions (and we first need to know how to ask meaningful questions), not data in spreadsheets.

Finally, the production and use of metal objects were related to not only regional but also cultural and social reasons. No object or practice can be adopted in all cultures or by everyone in a given society. For leaded bronze, it was often used by certain people in a community for certain object types while rejected by others and for other object types. Most previous research focused on bronze ritual vessels in large Central Plains urban centres, such as Anyang. These objects and their users, who were a small group of "elite members" in the society, are often over-represented. On the other hand, people from non-elite or non-urban backgrounds and their engagements with metal objects are often less studied. These people and bronze objects from varied cultural and social contexts certainly deserve more attention (examples of using ritual bronzes in different cultural contexts, see Allard 1995; Cao, D. 2014).

However, we also need to admit the limitations of archaeology (or the limitations of all scientific disciplines), especially the resolution archaeological materials can provide. Sometimes, we may have very clear pictures of single individuals but not of the whole community. Sometimes, we may only have vague pictures of patterns from, for instance, ceramic typology or burial patterns, without understanding how these traits were related to the particularity of individuals. This often makes our aim of interpreting the cultural, social, and individual reasons difficult, if not impossible, especially in a study (such as this one) depending mainly on published materials. The only way to improve this, in the discipline of archaeology, is to generate first-hand materials and data with new methods and perspectives in self-participated fieldwork, which, unfortunately, this study cannot offer due to various limits (such as the pandemic). This should be a direction for future studies.

1.3. How this study unfolds

This book has three main parts. Chapter 2 provides the geographical and scientific backgrounds of the metals at the centre of this study—copper, tin, and lead. For the geographical matters of the metals, two key issues are discussed. One is the unbalanced regional distribution of copper, lead, and tin; the other is the availability of polymetallic ores in many areas. Both issues were closely related to leaded copper alloys (leaded copper or leaded bronze). Another important issue discussed in this chapter is the technology of alloying. Several scenarios are listed to show that leaded bronze can be produced by many different methods. This also means that chemically similar objects may not be produced by the same technological choices. The following part of the chapter investigates the properties of leaded bronze. With the discussion, I also suggest how the properties may have affected the adoption of this material in different scenarios.

Chapters 3 to 5 present case studies of people with (or without) leaded bronze (Figure 1.9). These cases are further divided into three parts. Chapter 3 covers early metal-using and metalworking communities that adopted the ideas and technologies directly from the steppes. In these regions, including the northern Bohai Rim in north-eastern China, the Hexi Corridor in north-western China, and the Ordos Plateau in northern China, the use of lead was quite limited. At the same time, leaded bronze was generally avoided rather than embraced. This metallurgical tradition was later introduced onto the Central Plains but was also remarkably changed in this new context. Chapter 4 focuses on the development of the Central Plains metallurgical tradition from the Middle Yellow River Valley to the Yangtze Valley in southern China. As the chapter argues, one characteristic of this new tradition was the use of leaded bronze for socio-economic reasons. Chapter 5 demonstrates how the leaded bronze users on the Central Plains engaged with their neighbours who previously did not use this material. By comparing the case studies, I argue that people did not simply adopt leaded bronze and add it to their material culture. Instead, different responses can be seen in different communities.

In Chapter 6, the issues in the case studies are drawn together to support my main argument of this study, which is a new explanation for the emergence of leaded bronze use in early China. In this explanation, the production of ritual bronzes on the Central Plains, probably driven by socio-economic factors, led to the popularity of leaded

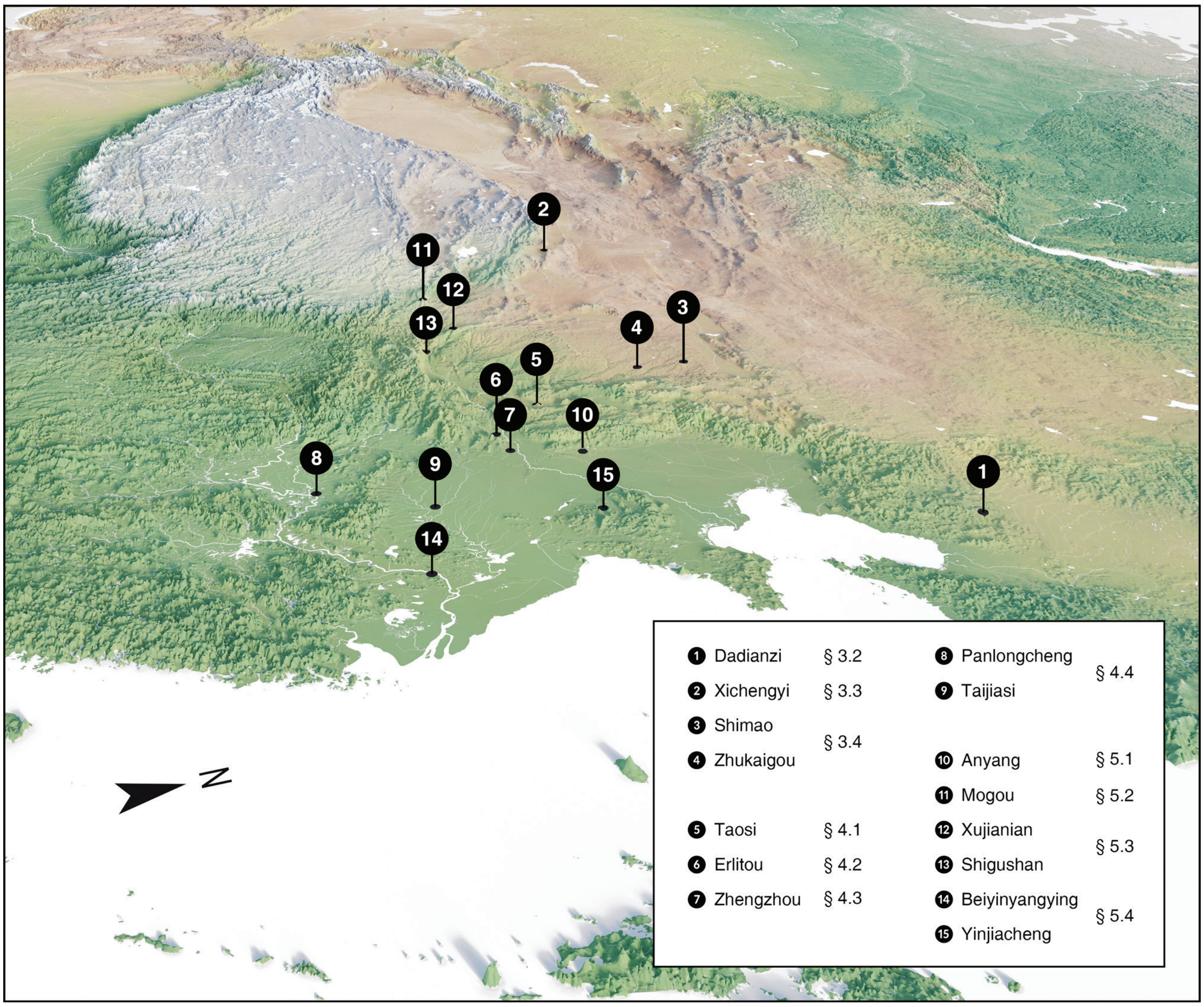

Figure 1.9. **Case studies of metal-using communities in early China during the second millennium BCE.**

bronze in the region and its surroundings. The particular properties of leaded bronze—its castability, mechanical strength, and colour—also contributed to the acceptance or rejection of this material. With this enriched picture, the use of leaded bronze can be seen as a notable example for us to recognise and appreciate the complexity and diversity of technology and material culture in China's Bronze Age.