Bronze Age Metal Circulation in China

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Abstract

In recent years, several research groups have concluded that traditional 'provenance studies' of metals, in which an object is linearly related to a single source, do not represent the reality of many archaeological assemblages. This paper sets out a new systematic approach to metal chemistry designed to characterize, using trace elements and isotopes in an assemblage of material, the underlying circulation of metal. When applied in China to the use of leaded tin bronze to cast the large and numerous ritual vessels of the Shang (c. 1500-1045 BC) and the Zhou dynasties (c. 1045-771 BC), the methodology reveals the complexity of the copper sources on which the major late Shang capital at Anyang depended for its bronze workshops. This has been recognised by many in the past, but has yet to prompt a full reassessment of the organisation of the Shang bronze industry. Here we point out the possibility of a need to transport copper from distant regions in the south, on the Yangzi, and even from far to the north, in northeast China. Using lead isotope data, presented in a new format, we attempt to enlarge the understanding of this organisation, demonstrating that, while the Zhou took over some of the range of copper available to the middle Anyang period, the lead sources exploited in early and middle Anyang phases differed from those taken up by the Zhou. The methodology enables a further understanding of the network on which the major dynasties depended for supplies of copper, lead and tin, and can thus lead us towards one of the major objectives of the new interpretational system - to give equal weight to archaeological and chemical data.

Key words: Flame Bronze Age China Metal Chemistry Network

This paper presents a new and systematic approach to metal chemistry, alloys, and lead isotopes, which aims to characterise the *circulation* of copper and its alloying metals (Bray *et al.* 2015), rather than linearly link an object to its source. Although this methodology has so far primarily been applied to areas dominated by relatively small-scale social structures, we now wish to extend it to the vast and highly centralized society of ancient China. In the discussion below we are indebted to the extensive work carried out in China, a large part of which is summarised in the work of Chen Jianli, Mei Jianjun, Zhao Chunyan and their colleagues. Although, in all probability, bronze technology was introduced to China from the Steppe (*e.g.*, Linduff and Mei 2014; Mei *et al*. 2015; Li 2005), the bronze-making traditions that emerged were distinct from those in the rest of Eurasia. The many diverse bronze-making groups within China (Figure 1) shared a combination of technical features unique to the area, namely an almost exclusive concentration on complex casting (using decorated ceramic multiple-part piece moulds) rather than a combination of casting, forging, and cold working, as well as the addition of lead to the predominant alloy of tin and copper. However, despite such shared similarities, this overall territory has to be viewed as at least three major and very different regions.

At the heart are the Central Plains, the rich agricultural areas along the Yellow River, which were extended in the late Shang and early Zhou up the Wei River and towards the Yangzi, especially along the Suizao corridor in Hubei province. The Shang centres of power during the Erligang phases (*ca*. 1500-1300 BC) and, later, at Anyang (*ca*. 1300-1045 BC), generated a huge bronze industry, casting large ritual vessels intended to be used in sets for offerings to the ancestors, and also weapons and chariot fittings. These vessel sets are the defining feature of Shang ritual and cultural power and were similarly taken up by the Western Zhou elite (1046-771 BC). The fact that these vessels are also found north and south of the Central Plains highlights extensive networks of contact. This did not, however, involve these other regions in adopting the ritual and culture of the Shang, since they did not generally employ the vessels in standard ritual sets. Instead they used their casting skills to make many different and striking bronze types.

The mountainous topography along the Yangzi created fertile basins in which agricultural production was already well-developed by the Bronze Age. Although no single ritual culture developed across this area, there was significant interaction between the basins. These diverse communities were to a greater or lesser extent participants in the technological system of the

Central Plains. They used complex piece-moulds to cast a wide range of artefacts and shared the preference for leaded alloys with their northern neighbours. The scale of some of these castings, such as the figure and heads from Sanxingdui and the bells in Hunan, Jiangxi and Anhui, suggest that some of these several and completely distinct bronze industries must have had their own large and stable supplies of metal, first suggested by Kane (1974) and Bagley (1977).

To the north of the Central Plains, an area, here defined as 'the Arc', following a proposal made by Tong Enzheng in 1987 (Tong 1987; Rawson 2015), is a distinct region of highland, with varied ecologies, ranging from deserts to very high mountainous plateau, and delimited by the predominance of herding, but with some sedentary agriculture. The boundaries of the Arc are defined qualitatively with reference to a series of overlapping physical and cultural characteristics, principally based upon elevation, precipitation, and dominant regional economy (using modern data). The cultures of this region, part of which is often referred to as the Northern Zone (Lin 1986), had diverse strategies with agriculture as well as pastoralism and shared far more with the societies of the Eurasian steppe, in terms of lifestyle and weaponry (knives, daggers and axes) than with the polities of the Central Plains. As in the south, some vessels were brought into the Arc by exchange or capture, and others were produced as local copies or variants. However, these metallurgical traditions remained relatively small in scale by comparison with those of the Central Plains or the South.

The widespread presence of Shang- and some early Zhou-type vessels in both the south and the north, where they were not fundamental to the local cultures, demonstrates that peoples of the Central Plains and of these regions were in contact. It would have required a highly organised supply and control network to sustain the metal producing centres of the Central Plains, and this network may have spread the techniques of mould making, metallurgy, and the very concept of cast bronze vessels, across such a large area. Much attention has been paid to possible shifts in the political structures of the Shang in the Erligang and Anyang phases that were responsible for this extraordinary expansion of contacts (Bagley 2014). Campbell (2009: 835) discusses the existence of a network as a political phenomenon, but does not explore the implications for metallurgy. Thus far, therefore, the overall effects of enormous demands placed upon this network by the scale of bronze casting at Anyang have not been fully assessed. Other materials were no doubt also sought, such as ivory and jade

(Hong Kong 1994), but probably did not require quite as comprehensive a network, nor did they absorb labour on the same scale as the bronze industry (IA CASS 2015).

The Shang were probably attracted to the South by the abundance of copper and tin, known today from mines along the southern edge of the Yangzi basin and in Jiangxi province. Interactions with the North may have taken a rather different form. The peoples of the Arc, with good access to the Steppe and its abundant horses, posed a serious military threat to the Shang, particularly in the Anyang period. The vessels that appear at northern sites may in part, therefore, have been used as exchange for horses (Cao 2014: 198-205). In addition to these large scale relationships, some non-Shang groups, including the pre-dynastic Zhou, also imitated the Shang in terms of their ritual practices, including the use of vessel sets. The task before all students of the Chinese Bronze Age is, therefore, to understand how this part of the wider Shang interaction network functioned and changed over time.

Given the scale of Shang bronze production, as seen in such major tombs as that of Fu Hao with her 200 bronze vessels, some in massive size (IA CASS 1980), we assume that many sources of metal were tapped, and that casters would have become aware of copper and tin from different mines (Liu and Chen 2003: 36-56). Lead, likewise, shows variations that suggest a number of distinctive source regions were involved (Jin 2008; Cui and Wu 2008). We also know that some metal was recycled, especially by the Zhou. The looting of Shang tombs in the early Zhou period is well attested, and while we know that some of these vessels were reburied intact (Huang 2013/2014; Ding and Wang, 2016), the potential socio-political significance for the Zhou of reusing and perhaps re-melting such vessels into new forms was so great that it seems unlikely to have been entirely ignored. Major vessels missing from such tombs (Jing 2010; He 2014), and of course those that were kept on royal altars, suggest that large quantities of metal may have been reused over time. Western and Eastern Zhou bronze inscriptions and texts also give clear indications that re-melting of both weapons and vessels took place (Wu 2012)

The Oxford System for interpreting chemical and isotopic data

We interpret the archaeological and textual evidence discussed above as indicating the existence of a complex supply network driven by the demand for vast quantities of raw materials (copper, tin, lead and bronze) in the Central Plains. Current evidence for the scale of contemporary mining operations (Liu and Chen 2003: 38-41; Chen 2014: 44-53) suggests that metal from different mines, and even from different regions, is likely to have been required to satisfy this demand. By the time metal from more than one mining region has been mixed, and we allow for the possibility of the recycling of objects, it becomes difficult if not impossible to provenance the metal in an individual object. The Oxford system, however, is focussed, not specifically on the provenance of individual objects, but is designed to characterize, using trace elements and isotopes in an assemblage of material, the nature of the underlying flow of metal (Bray *et al*. 2015). In a complex supply network, the composition of the metal in circulation at any one time and place is dependent on the balance of inputs from different mining areas, and also on the degree of recycling. If Shang bronzes were looted and recycled by the Zhou, then the composition of the metal used by the Zhou would have been influenced by that of the Shang. This kind of complexity has been recognized by some scholars in other parts of the world (Needham 1998), but here we introduce our system to quantify and visualize these effects for the Chinese Bronze Age.

The system has been described elsewhere (Bray *et al*. 2015; Pollard and Bray 2015). Our aim is, given enough chemical and isotopic evidence, to understand how the patterns within these data vary according to geography, chronology, object typology and archaeological context. We think it is useful to separate conceptually the object from the metal out of which it is made. We then consider the metal in use at any one place and time (either manifested as objects, or raw materials) to be characterizable by three inter-related parameters:

i) A set of 16 ‘Copper Groups’ defined by the simple presence/absence of the four most commonly reported trace elements (As, Sb, Ag and Ni) in archaeological copper artefacts. These ‘Groups’ are not necessarily related to specific mines, but do reflect the chemistry of the parent ores. We use them initially in preference to absolute values of trace elements in the metal because these are subject to change by subsequent human processing, such as dilution, enrichment, or oxidative loss during high-temperature processes (McKerrell and Tylecote 1972). The patterns of presence or absence revealed by Copper Groups can be used as a preliminary characterisation of the copper as it is instantiated in specific sets of objects, and provide a useful tool to enable comparison between different regions, and over time. We make no assumptions at this stage about where the copper might have come from, although subsequent mapping of Copper Groups and detailed analysis of the distributional profiles of trace elements within assemblages may often point towards particular source areas, which can then be verified by mine data, where available.

ii) We take a similar nonparametric initial approach to the definition of alloy types, based on the assumption that not all objects are made from primary designed alloys. We use a presence/absence classification for the presence of the major alloying metals (in ancient China, lead and tin), defining 'present' as being >1%. The levels of these alloying metals will be affected by mixing, but can also be altered by re-alloying to give specific properties – e.g., a copper-tin bronze can have lead added to increase the fluidity when casting. The distribution profiles of tin and lead in groups of objects can be used to distinguish 'primary' (designed or deliberate) alloys from those resulting from mixing. Essentially, assemblages which show an approximately normally distributed profile of lead or tin can be assumed to contain objects of 'designed' alloys. Those assemblages with non-normal distributions of lead or tin are more likely to contain objects that come from different places, or have been made from mixed or recycled alloys.

iii) We use a new approach to the presentation of lead isotope data that is more sensitive to evidence for mixing (Pollard and Bray 2015). Rather than use 'conventional' isotope ratio biplots, we plot 1/Pb against each individual ratio. The advantage is that each diagram not only represents the lead isotope value for each object, but also gives the lead concentration in that object, which allows us to distinguish between objects in which the isotope ratio is dominated by the signal from the lead source (as in a leaded bronze) and those with very low lead, where the lead isotope ratio is probably coming from the copper. Mixing lines can, therefore, potentially show where lead from different sources is being combined, or when copper from one source is mixed with lead from another.

In this paper we consider the use of 'Copper Groups' combined with lead isotope data to throw new light on the circulation of metal in Bronze Age China.

i) Trace elements and 'Copper Groups'

Table 1 shows a summary of the ubiquity of each of the 16 Copper Groups as a percentage of the total number of available analyses for each site, divided into three major periods – Early/Middle Shang (pre-Anyang, *ca.* 1600-1300 BC), Late Shang (Anyang period, *ca.* 1300-1045 BC) and Western Zhou (*ca.* 1045-771 BC). The total numbers of samples are given at the extreme right, and the ubiquities of the Copper Groups are colour coded – red is 30-50% ubiquity, orange is 20-30% and yellow is 10-20%. Figures 2-4 map the copper group profiles for each site by period.

Figure 2 (Early/Middle Shang) shows the two Central Plains sites of Erlitou and Zhengzhou (Erligang), as well as Panlongcheng and the Middle Shang features of Hanzhong. This suggests a marked difference between Erlitou and Zhengzhou, with the former dominated by CGs 4 (Cu + Ag, 31%), 12 (Cu + As, Sb, Ag; 31%) and 9 (Cu + As, Ag; 23%), and the latter by CGs 1 (Cu only; 40%) and 9 (Cu +As, Ag; 24%). We must note, however, that there are only 13 and 25 samples for each site respectively, meaning that any conclusions based on these data must be extremely preliminary. More convincing however, are the comparisons with Panlongcheng and Hanzhong. Panlongcheng is a site associated with the Erligang period, situated to the south of the Central Plains on the Yangzi River, close to an important mining region. Figure 2 shows a strong signal of copper groups containing nickel at Panlongcheng [CG 5 (Cu + Ni) and CG 11 (Cu + As, Ni), together making up 30% of the total assemblage], which is rare among mainstream Erligang and Anyang bronzes. This shows that a significant proportion of the bronzes at Panlongcheng were not made at the major Erligang centre of Zhengzhou (since no nickel-containing objects have yet been reported from there), and also that Panlongcheng had access to copper sources that were not being used at Zhengzhou (Chi-squared test confirms that this is statistically significant difference at 95% confidence). These differences suggest that the connection between the two areas was perhaps not as direct as is sometimes argued (Wang 2014). The Longtou caches of Hanzhong, dated to the Middle Shang, also show the presence of copper containing nickel. Here, CGs 5 and 11 are only represented in 12% of the assemblage, but CG 16 (Cu + As, Sb, Ag, Ni) contributes to a further 12%, meaning that a total of 24% of the assemblage contains nickel. The remainder is dominated by CGs 4 (Cu + Ag; 24%), 9 (Cu + As, Ag; 18%), 2 (Cu + As; 15%) and 1 (Cu only; 12%). Given this evidence, it is tempting to see the presence of nickel as a feature of some of the copper coming from the west or southwest.

Figure 3 shows a comparison of the Copper Groups in the Central Plains (Anyang and Qianzhangda) during the Anyang phase of the Shang Dynasty (*ca.* 1200-1045 BC), with material from Sanxingdui (Ma *et al.* 2012), Hanzhong (Sucunxiaozhong, dated to Late Shang, Chen 2009), and northern Shaanxi (Liu 2015). The most striking observation to be made of this figure is the relative complexity of the metal in use at both Anyang and Qianzhangda compared with that at other sites in the northern and western borderlands. Both these sites have at least four copper groups represented at significant levels, whereas Hanzhong (dominated by CGs 1 [Cu only; 89%] and 9 [Cu+As, Sb; 10%], which is in stark contrast to the earlier Longtou caches), Sanxingdui (CGs 1 [Cu only; 57%] and 2 [Cu+As; 33%]) and northern Shaanxi (CGs 6 [Cu+As, Sb; 59%], 1 [Cu only; 24%] and 3 [Cu + Sb; 18%] have much more restricted variation. This suggests that the Central Plains network is capable of attracting copper from a wide variety of places, whereas the regional centres of Hanzhong, Sanxingdui and northern Shaanxi are using a more restricted range of local resources. This difference also correlates with what has been observed from archaeological evidence in these areas. Although many Shang-type bronzes have been found here, the peoples in these regions certainly had their own lifestyles and their own bronze-casting traditions (Rawson 2015). We also note that the northern Shaanxi data are very different from those at Hanzhong and Sanxingdui in that they are dominated by copper containing As and Sb (CG6, 59%) or just Sb (CG3, 18%), which could be a feature of some of the copper coming from the northwest.

The data for Western Zhou (Figure 4) shows a somewhat more complex set of relationships. The metropolitan Zhou state is surrounded by a series of subordinate states or independent centres, most of which show a wide range of Copper Groups, with the most noticeably distinct being northern Shaanxi, which is dominated by CGs 6 (Cu + As, Sb; c. 70%) and 12 (Cu + As, Sb, Ag; 27%). The dominance of CG 12 discovered at the mining site of Dajing (presently dated to the late Western-early Eastern Zhou) suggests that there is a possibility that this Copper Group might have been the major product of this region, although at present there are only 10 objects analysed. Another related mine to the west, Xiquegou, radiocarbon dated to the late Shang and Zhou periods, may, together with Dajing, have contributed to bronzes of the north and north-east and possibly to the metropolitan Zhou foundries (Wang and Fu 2015; Li and Han 1990).

A more remarkable shift affected the south at this time. Evidence of the several large independent bronze industries at Sanxingdui, Hunan and Jiangxi fades away in the early

Western Zhou, although activity in Sichuan continued at Jinsha (Chengdu and Jinsha 2013, 2014). Some Sichuan sites were in contact with the western Wei valley, but the metropolitan centres seem likely to have had more contact with the south by way of areas of present-day Hubei province. The early Zeng state, whose first phases have been recently identified at Yejiashan in the Suizao corridor, seems to have taken over as one of the major southern centres. Unlike the earlier southern centres, the Zeng state followed Central Plains practices in burials for the elite and the use of vessel sets (Hubei and Suizhou 2011). Situated north of the large mining area at Tonglüshan, the Zeng state may have controlled the transport of copper northwards. Some ingots and malachite excavated from tombs at Yejiashan suggests that the Zeng state elite were conscious of their role in the copper network serving the metropolitan Zhou centres.

ii) Lead isotope data

We have introduced a different set of diagrams to present lead isotope data, which plot the inverse of the lead (Pb) concentration against each isotope ratio in turn (Pollard and Bray 2015), which has the advantage that mixtures from two sources show up as linear mixing lines. This is particularly important for understanding Chinese bronzes, which typically contain several percent of lead from at least the Erlitou period onwards. The chemical and isotopic analysis of the Sackler collection provides a useful case study to demonstrate this (Bagley 1987; Rawson 1990), although the unprovenanced nature of most of the items mean that we have to rely on visual identification for the attribution of dates and origin.

Figure 5a shows a plot of (1/Pb) against ^{206}Pb/^{204}Pb, classified by copper group (CG) for the Anyang-period Shang vessels in the Sackler collections, and which are thought to be from the Central Plains. The Sackler Collections, as catalogued in Bagley (1987) and Rawson (1990), provide the only large body of bronze vessels for which good trace element and lead isotopic evidence has so far been published. In these diagrams, objects with the same lead isotope ratio form horizontal lines parallel to the x axis. This diagram therefore shows two isotopically-distinct groups, corresponding to the ‘high’ (^{206}Pb/^{204}Pb ≈ 22) and ‘low’ (^{206}Pb/^{204}Pb ≈ 17.5) lead sources previously identified as ‘radiogenic’ and ‘common’ lead, respectively (Jin 2008). The most significant lead source present in these data is that corresponding to the ‘high’ (‘radiogenic’) source (^{206}Pb/^{204}Pb approximately 22), with most of the objects made from CG’s 1 and 2 copper being combined with lead of this type. Objects made from copper of CG’s 9 and 12 are predominantly alloyed with lead from the ‘low’ source ($^{206}Pb/^{204}Pb$ approximately 17.5), although a number of objects potentially contain lead that is a mixture of these two sources, as shown by those points which fall between these two parallel lines.

Another advantage of this form of presentation is that, unlike the conventional biplots, it shows the lead concentration in the vessels, as well as the lead isotope values. Since the horizontal axis is 1/Pb, a value of 1 on this axis denotes objects with a Pb concentration of 1%. Points to the right of this value have less than 1% Pb, and points to the left have more. Thus, objects plotting around 10 on the 1/Pb axis (where the Pb concentration is 0.1%) have little or no lead added, and therefore the Pb isotope value probably reflects the source of the copper itself, whereas points to the left of 1/Pb = 10 most likely show the isotope value in the added lead. The Anyang-style vessels from the Central Plains, shown in Figure 5, present five vessels made from CG 1 (‘clean’ copper) containing less than 1% Pb (the points to the right of 1 on the horizontal axis). The arrangement of these points would suggest a mixing line between the sources of the copper with that of the added lead. We suggest that this line represents alloying of copper with an isotopic value similar to that in the lower lead source ($^{206}Pb/^{204}Pb \approx 17.5$) with lead from the higher (‘radiogenic’) source ($^{206}Pb/^{204}Pb \approx 22$). If we make the further assumption that copper and lead with similar lead isotope values *could* come from the same geological area, then this might suggest the possibility that copper from the same locality as the isotopically lower (‘common’) lead source is being mixed, not with this lead, but with that from the higher (‘radiogenic’) source. We might, however, point out that the geographical distinction between sources of ‘common’ and ‘radiogenic’ lead, widespread in the Chinese literature, need not necessarily represent two geographically distinct sources. In the southern Yangzi metallogenic zone, for example, modern isotopic data shows that metalliferous deposits within the same geographical region can provide both ‘common’ and ‘radiogenic’ lead , although the latter much more rarely.

We can also compare the Anyang-style vessels from the Central Plains with those of the Western Zhou (Figure 5b: for both figures we only plot the most significant CG’s, i.e., 1, 2, 6, 9 and 12). In the Western Zhou data, the lead and virtually all the copper have $^{206}Pb/^{204}Pb$ values that are consistent with the relatively small number of late Anyang-style Shang vessels with the isotopically lower lead values ($^{206}Pb/^{204}Pb$ between 17 and 18) relating mainly to vessels containing copper of CG’s 9 and 12, suggesting that the Western Zhou continued to benefit from the supply and practices of the latter part of the Anyang tradition. There is, however, a significant change in alloying practice. The mixing line between low-lead copper (mostly CG's 1 and 2) and the added lead is now horizontal, suggesting that this copper is now being mixed with lead characterised by ‘low’ isotope values ($^{206}Pb/^{204}Pb \approx 18$), in contrast to the mixing of CG 1 with ‘high’ (radiogenic) lead in the Shang. Some lead of the higher value is also present, associated primarily with CG 2, which may represent the reuse of Shang metal, or some continued access to lead of the higher $^{206}Pb/^{204}Pb$ type.

Conclusions

The application of the Oxford system to existing trace element and isotopic analyses of Chinese Bronze Age metalwork reveals some information about the networks of circulation for copper and lead, and the patterns of alloying lead with copper which adds to that already established in previous work (Jin 2008; Chen 2014; Mei *et al*. 2015). We point towards a clearer understanding of the supply network of metal that was drawn into the Central Plains and which brought this area into contact with neighbouring societies north and south. We can present the following conclusions:

1. The similarity in copper groups between the bronzes of the Erligang and Anyang phases, but with a different intensity of use for these groups, indicates some continuity in the lines of communication within the network supplying the Central Plains, but also a somewhat different balance of use of regional sources of metal between these two periods.
2. During the Erligang phase, metal sources used at Panlongcheng appear to have been somewhat different (i.e., to include sources containing nickel) from those used at Zhengzhou, with significant implications for the relationship between these two areas.
3. The strong continuity in copper supply between the Late Shang and the Western Zhou shown in the trace elements indicates that much of the same network supplied both the late Shang and Western Zhou bronze casting workshops, emphasising that the success of the Zhou may have depended on taking over late Shang organisation. When these copper groups are combined with lead isotope data, however, we see the two well-known ‘common’ and ‘radiogenic’ lead sources (referred to here as ‘low’ and ‘high’ $^{206}Pb/^{204}Pb$ values, respectively), but we also obtain much more information about how different sources of copper were alloyed with lead. The Central Plains early and mid Anyang-

period vessels most commonly made use of a different source of lead (high, or 'radiogenic') to that most generally used in the Western Zhou; so there was continuity of copper supply but a change in the dominant source of lead during the latter part of the Anyang period.

4. The role of the southern regions as sources of metal is evident from the development of bronze cultures in the Shang period, most especially that at Sanxingdui. That the south remained significant under the Zhou is evident from the abundance of tombs of the Zeng state. The death of King Zhao (*ca.* 977 BC) on the southern campaign confirms the importance of the south.
5. During the Zhou, there may have been new efforts to obtain copper from the north. The mines in the Dajing area are challenging in their mineralogical complexity and their dating. However, an increase in the numbers of the Central Plains vessels buried in hoards in the north-east, and a growth of production of northern bronze types, such as swords and daggers, as in the Upper Xiajiadian culture region, suggest an increase in metallurgical activity in the north, with supplies of copper and lead unlike those available to their steppe neighbours, where arsenical copper was preferred (Hsu *et al.* 2016).

Our intention here has been to show that by conceptually separating the metals out of which the objects are made from the objects themselves, and by combining trace element, major element and isotopic data within a single systematic framework, we can provide information that can complement existing archaeological knowledge. Moreover, it allows us to ask new questions about the organization of the metal supply in China, and about China's relationships with her neighbours north and south. At present, the number of analysed objects which can contribute to this discussion is far too few to give a comprehensive picture over time and space, but new analyses can easily be fitted into this model.

Acknowledgements

The work presented here has been under development over the last ten years, and has received support from various sources, including a Hastings Senior Scholarship, the Oxford University Press John Fell Fund, Leverhulme Trust Grants (F/08 622/D and F/08 735/G), China Oxford Scholarship Fund, the Santander traveling fund and the Reed Foundation. The current work is supported by European Research Council Advanced Grant 1300505 (FLAME) and an Oxford Clarendon DPhil scholarship.

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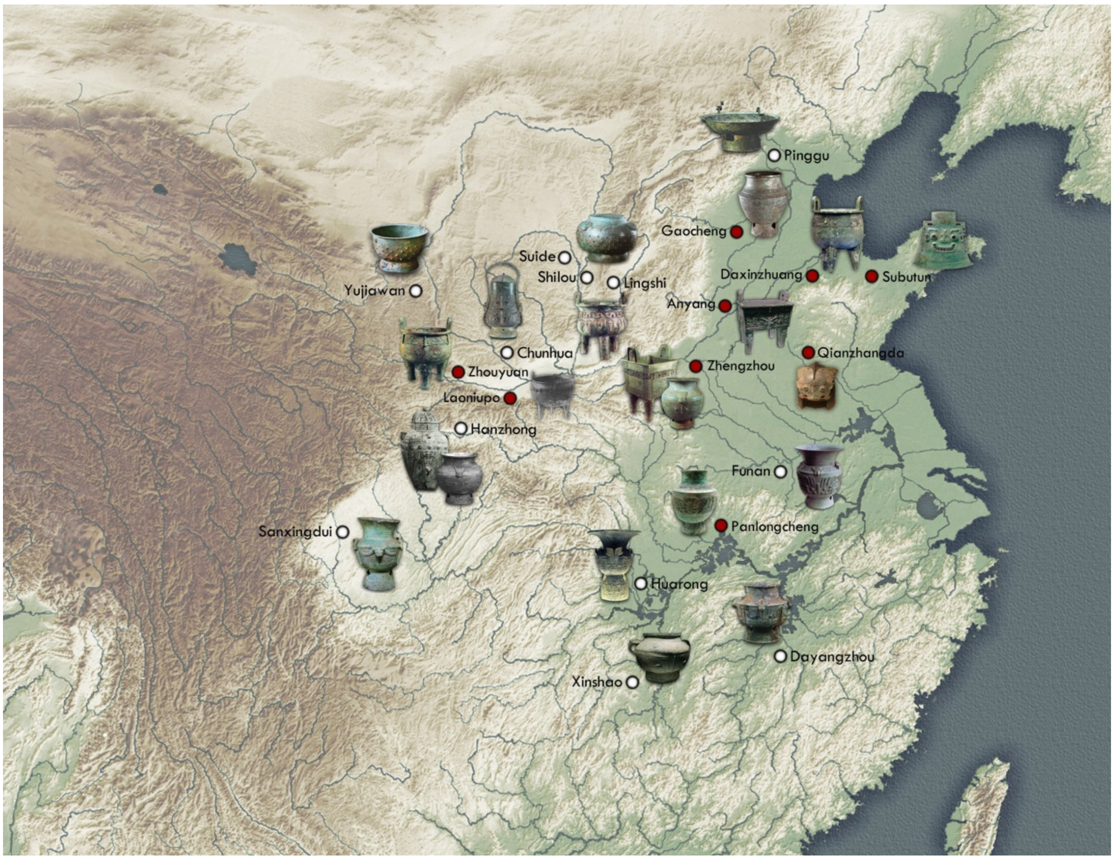

Figure 1 Diversity of bronze-making groups within China

Early/Middle Shang	CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8	CG9	CG10	CG11	CG12	CG13	CG14	CG15	CG16	Total No. Analysis	Data source
Erlitou	0	7.69	0	30.77	0	0	0	0	23.08	0	0	30.77	0	7.69	0	0	13	Jin 2008
Erligang (Zhengzhou)	40.00	16.00	0	12.00	4.00	0	0	0	24.00	0	4.00	0	0	0	0	0	25	Tian 2013
Panlongcheng	34.00	18.00	0	8.00	12.00	0	0	0	6.00	0	18.00	4.00	0	0	0	0	50	Chen et al. 2001
Hanzhong Longtou caches	12.12	15.15	0	24.24	3.03	0	0	0	18.18	0	9.09	3.03	0	3.03	0	12.12	33	Chen 2009
Later Shang	**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**	**CG7**	**CG8**	**CG9**	**CG10**	**CG11**	**CG12**	**CG13**	**CG14**	**CG15**	**CG16**	**Total No. Analysis**	**Data source**
Anyang	50.59	21.18	0	1.18	0	2.35	0	0	10.59	0	1.18	8.24	0	0	0	4.71	85	Bagley 1987
Qianzhangda	12.45	27.90	0.86	2.15	0	6.44	0.43	0.43	17.60	0	0.86	29.61	0	0	1.29	0	233	Zhao 2005
Sanxingdui	56.67	33.33	0	0	0	6.67	0	0	0	0	3.33	0	0	0	0	0	30	Ma et al. 2012
Hanzhong (Sucunxiaozhong)	89.25	0	0	0	0	1.08	0	0	9.68	0	0	0	0	0	0	0	93	Chen 2009
Northern Shaanxi	23.53	0	17.65	0	0	58.82	0	0	0	0	0	0	0	0	0	0	17	Liu 2015
Western Zhou	**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**	**CG7**	**CG8**	**CG9**	**CG10**	**CG11**	**CG12**	**CG13**	**CG14**	**CG15**	**CG16**	**Total No. Analysis**	**Data source**
Metropolitan Western Zhou	11.54	34.62	1.28	1.28	0	8.33	0	0	17.95	0	0	25.00	0	0	0	0	156	Rawson 1990
Yejiashan	31.91	12.77	14.89	0	0	40.43	0	0	0	0	0	0	0	0	0	0	94	Yu 2015
Jinsha	14.29	22.86	0	20.00	0	0	0	2.86	28.57	0	2.86	5.71	0	0	2.86	0	35	Unpublished Data
Jin state	60.00	6.67	0	26.67	0	0	0	0	6.67	0	0	0	0	0	0	0	15	Wang 2002
Hengshui	7.14	57.14	0	0	0	0	0	0	35.71	0	0	0	0	0	0	0	14	Song and Nan 2012
North Shaanxi	0	0	0	0	0	72.73	0	0	0	0	0	27.27	0	0	0	0	11	Liu 2015
Dajing (Eastern Zhou)	0	10.00	0	0	0	0	0	0	0	0	0	70.00	0	0	0	20.00	10	Wei et al. 2006

Table 1 Summary of dataset for each site

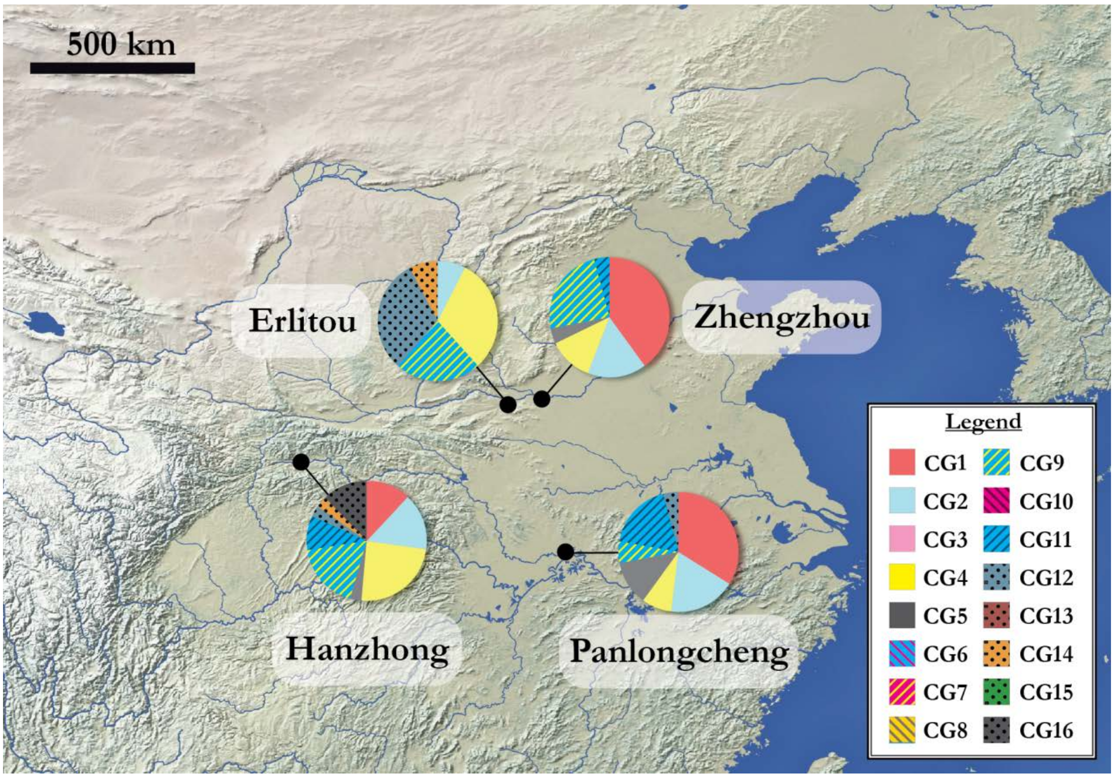

Fig. 2 Spatial variation of copper groups in Pre/Middle Shang

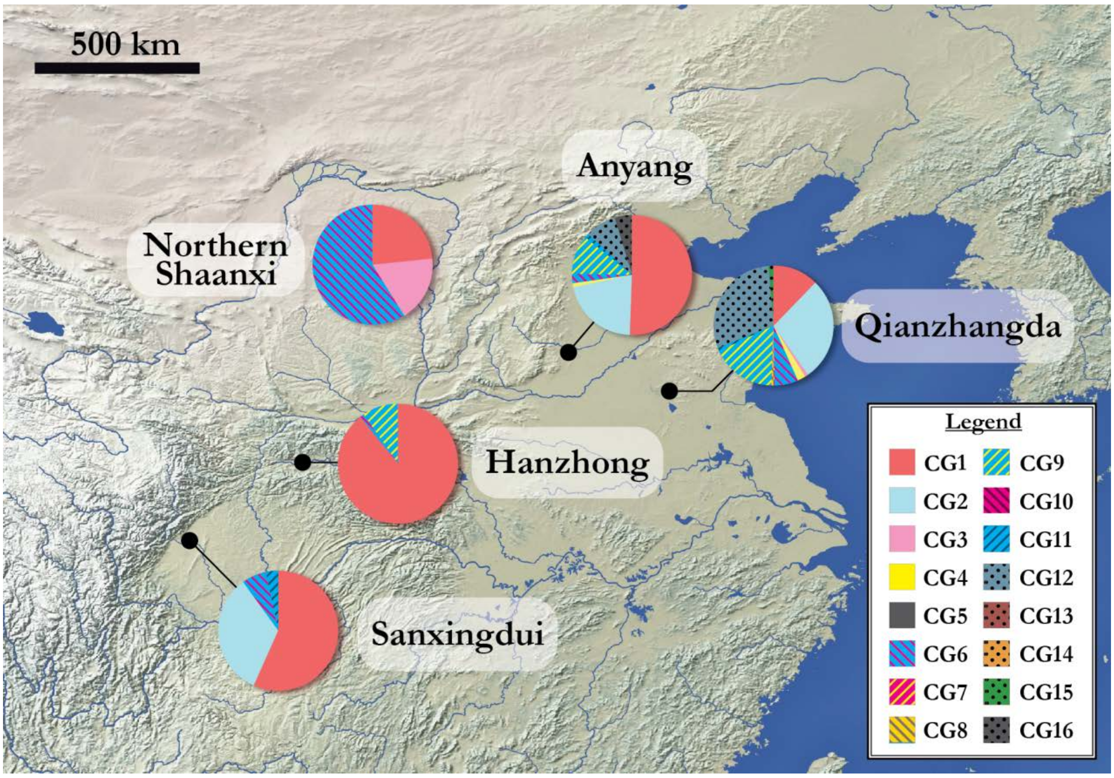

Fig 3. Spatial variation of copper groups in late Shang

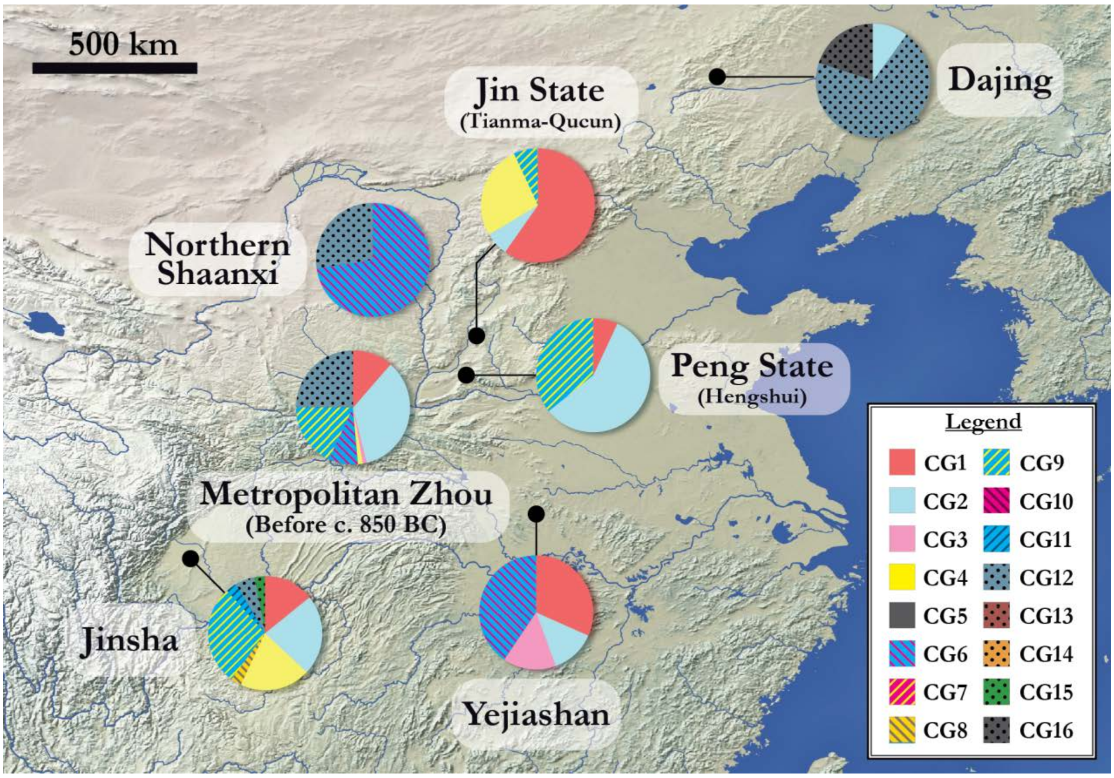

Fig 4 Spatial variation of copper groups in Western Zhou

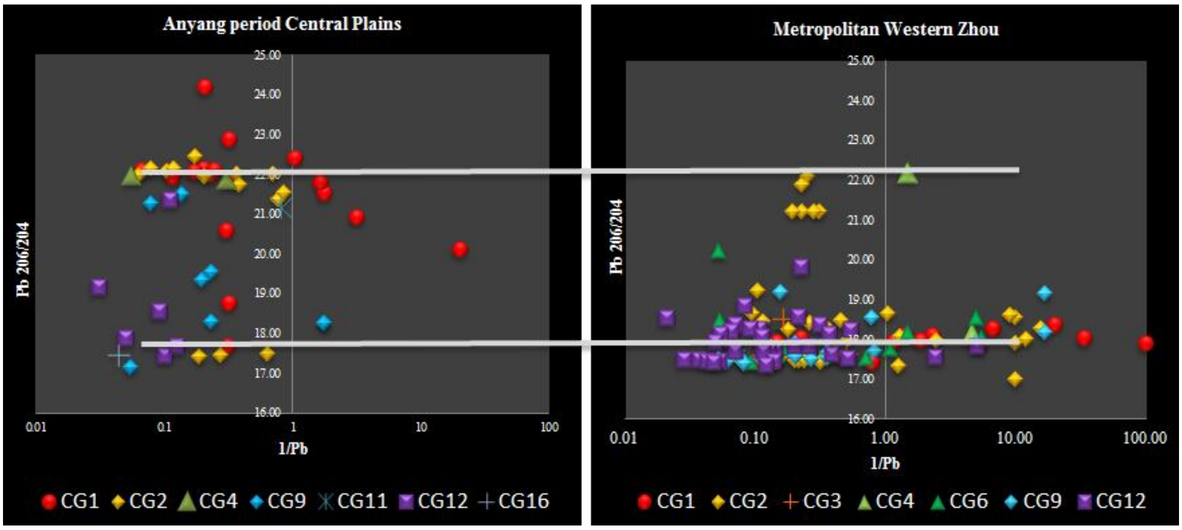

Fig 5a and b: 1/Pb against $^{206}Pb/^{204}Pb$: Anyang-period Central Plains and Metropolitan Western Zhou

Online supplementary

Data Source Online supplementary

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