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Metal Trade and National Integration: bronze technology and metal resources of Yue Style Bronzes from Hunan (8 ~ 5 C. BCE)

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Abstract

A large number of Yue style bronzes with regional cultural characteristics were unearthed in Hunan, which is of great significance for studying the cross-regional circulation of bronze technology and metal resources in the south of the Yangtze River during the Late Bronze Age (8 ~ 5 C. BCE) in China. In this study, 30 Yue style bronzes and 3 Chu style bronzes unearthed from five regions in Hunan Province were analyzed for chemical composition, metallography and lead isotopes. The results show that the alloy materials of Hunan Yue style bronze ware are diverse. The containers are mainly leaded tin bronze, with both tin bronze and copper. The weapons or tools are mostly tin bronze, and the alloy composition is primarily tin. The lead isotope ratio analysis results showed three main ore sources: polymetallic deposits in the Nanling Mountains, the eastern Hubei-northern Jiangxi metallogenic belt and the western Henan Qinling-Dabie metallogenic belt. The extensive source of minerals reflects the frequent trade of metal resources between Yue people and the Chu state, which is not only the economic basis for the close relationship between Hunan Yue people and Chu State but also an important driving force for the southward expansion of the Chu state and national integration in Hunan.

Keywords Hunan, Yue Style Bronzes, Alloy Composition, Lead isotope, Metal Flow

Introduction

Hunan is located in the south of the Yangtze River. During the Shang and Zhou Dynasties, it was outside the direct control area of the States in Central China for a long time. The local population was dominated by the indigenous Yue people (Fig. 1) [1]. Hunan is rich in non-ferrous metal resources such as copper, tin and lead, especially tin resources, which may have supplied the tin-poor Central Plains during the Shang and Zhou Dynasties [2]. Hunan had close contact with the Huaxia ethnic in the north during the Shang and Zhou Dynasties. There are a large number of bronzes of the late Shang and early Western Zhou Period unearthed from Hunan, famous as animal shapes, such as the Four Sheep-shaped Square *Zun*, the Human-face Square *Ding*, the Tiger-shaped *You*, and the Pig-shaped *Zun* [3]. The emergence of bronzes in Hunan is inseparable from the southward advance of the Shang and Zhou dynasties. The research shows that the Shang bronzes in Hunan have high-radiogenic lead (HRL) isotopes generally, which is an important manifestation of the spread of bronze technology in the Shang Dynasty [4–7]. In the early Western Zhou Dynasty, the bronzes of the Gaoshaji site began to use lead ore from the Nanling (南岭) polymetallic deposits of southern Hunan, and the Yue style bronzes began to form a unique local style [8].

China's ancient Yue ethnicity is widely distributed in the southern provinces. It has many branches, which is

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Fig. 1 Archaeological sites and mines mentioned in this research. (1. Yaozilun, Yiyang; 2. Gaoshaji, Wangcheng; 3. Tanheli, Ningxiang; 4. Xiangxiang; 5. Yunhuqiao, Xiangtan; 6. Zhuzhou; 7. Mayang; 8. Tonglushan; 9. Yangxin; 10. Tongling, Ruichang; 11. Tongling; 12. Zhongtiaoshan; 13. Lingbao; 14. Lushi; 15. Luanchuan;16. Songshugang; 17. Limu; 18. Huashan; 19. Tongshanling ; 20. Shuikoushan; 21. Shizhuyuan; 22. Guposhan; 23. Jiuyishan; 24. Xianghualing; 25. Qitianling; 26. Hehuaping; 27. Jiepailing; 28. Zuozhong; 29. Huangtupo; 30. Xiasi; 31. Qiaojiayuan; 32. Xitian; 33. Yichun)

also called 'Baiyue' (百越). The Xiang River and Zi River basins in Hunan are the main settlements of the Yue people, where the Yue people have created an ancient culture with its characteristics. During the Warring States period, with the development of Hunan by the Chu people, the Chu and Yue peoples lived together and their cultures infiltrated into each other, forming a historical phenomenon of integration [9]. The Yue people's tombs found in Hunan are mainly the most typical in the Spring and Autumn period. The tombs are mostly narrow and long vertical earthen pit tombs. The ratio of length to width of tombs varies greatly,

Fig. 2 Bronzes of Yue and Chu Style unearthed in Hunan

reaching 3:1 to 4:1. It is speculated that they are buried in boat coffins. During the Warring States period, with the influence of Chu culture, the tombs gradually widened. The funerary objects are mostly practical utensils, mostly bronzes, and less pottery, jade and stone. The bronze vessels that were buried were mostly tripods (Fig. 2). The weapons were mainly daggers and spears. The tools were axes, scrapers, spades and shovels. They were often buried with pebbles and crystal blocks [10]. A large number of Yue people's tombs have been found in Yiyang, Xiangtan, Xiangxiang, Ningxiang and Zhuzhou (Fig. 1), with the most representative Yue people's tombs in Yaozilun site in Yiyang during the Spring and Autumn Period and the Warring States Period. The funerary objects in the Yaozilun site show that some tombs funerary objects appeared Yue, Chu mixed phenomenon since the late Spring and Autumn period. It is a significant research on the technology and metal source of Yue style bronzes in Hunan. This study systematically conducted the metallography, SEM-EDS and lead isotope analysis on Yue style bronzes from Hunan for the first time. The purpose is to investigate the history of metal resources circulation and ethnic interaction.

Table 1 Chemical composition of Yue and Chu style bronzes from Hunan

No.	Location	Test No.	Name of objects	Alloy composition Wt(%)			Cultural attribute
				Cu	Sn	Pb	
1	Yiyang	ZY-1701	Ding	96.1	—	—	Yue
2		ZY-1702	Ding	92.8	2.9	—	
3		ZY-1704	Li	99.5	—	—	
4		ZY-1705	Ding	54.2	4.9	26.0	
5		ZY-1706	Ding	75.9	19.1	—	
6		ZY-1709	Ding	73.1	16.0	6.2	
7		ZY-1710	Ding	55.8	4.2	26.5	
8		ZY-1711	Ding	69.4	16.1	6.9	
9		ZY-1712	Ding	80.7	16.0	—	
10	Ningxiang	ZY-1602	Sword	√	√	—	
11		ZY-1606	Ding	61.5	8.5	16.5	
12	Xiangtan	ZY-1728	Knife	70.7	23.8	—	
13		ZY-1729	Spear	68.0	13.3	11.0	
14	Xiangxiang	ZY-1731	Ding	73.3	14.9	5.4	
15		ZY-1734	Ding	74.9	20.9	—	
16		ZY-1735	Ge	88.1	7.8	—	
17		ZY-1738	Ding	70.3	12.2	9.1	
18		ZY-1739	Ding	61.4	17.5	9.0	
19	Zhuzhou	ZY-1741	Ding	68.2	14.1	10.0	
20	Yiyang	ZY-1714	Ding	69.3	10.8	13.0	Chu
21		ZY-1716	Fu	63.3	9.7	16.9	

√ indicates that the element is detected, — indicates that the element is not detected; blank is rust sample, not detected.

Historical background

The application of lead isotope method to the study of the source of bronze mineral materials began with Gale's research in the early 1980 s [11]. At the same time, although China 's science and technology and economic strength were very backward at that time, Jin Zhengyao also applied the lead isotope method to the study of the mineral origin of the famous Fuhao tomb bronzes of the Shang Dynasty [12]. Although the production of Chinese bronzes was later than that of the Near East and Europe, the number of Chinese bronzes is huge, mostly containers, and the consumption of copper is huge. Moreover, most of the capitals of the Bronze Age in China were located in the Central Plains, and the resources of copper, tin and lead were scarce. Therefore, the study of the origin of mineral materials is very important for understanding the political and economic model of the Xia, Shang and Zhou dynasties [13–15]. The birth of lead isotope plays an important role in solving this problem [16].

The most important progress and challenge of lead isotope archaeology in China is the origin of highly radioactive lead in Shang Dynasty bronzes [17]. Jin Zhengyao's team has long believed that this copper and lead material came from northeast Yunnan [16, 18]. Sun Weidong et al. proposed that HRL came from Africa [19], which caused a lot of controversy [20–29]. In fact, with the rapid progress of HRL research, Chinese scholars have carried out lead isotope ratio analysis on a large number of bronzes, from the Xia Dynasty to the Han Dynasty [30, 31], from the Yellow River and the Yangtze River Basin [32–34] to the border areas, especially in Xinjiang [35, 36], Gansu [37], Ningxia [38], Guizhou [39] and Yunnan [40]. The research provides a new perspective for us to observe the technology communication, resource circulation and even political relations between different regions of China. Therefore, lead isotope analysis is not critical for in-depth interpretation of Hunan Yue style bronzes and the history of the Yue people.

Materials and methods

Sample information

In this paper, a total of 33 bronze samples were collected and analyzed. 16 pieces of bronzes were sampled from the collection of the Yiyang Museum, 13 of which were Yue style bronzes and 3 of which were Chu bronzes of the Spring and Autumn Period. Another 17 samples of Yue style bronzes were unearthed from Ningxiang, Xiangtan, Zhuzhou, Xiangxiang and other places in the lower reaches of the Xiangjiang River. Among them, 2 samples were unearthed from the

Eastern Zhou tombs at the Tanheli site in Ningxiang, 2 samples were unearthed from the Yunhuqiao site in Xiangtan, 10 samples were collected from Xiangxiang Museum, and 3 samples were unearthed from the Yue people's tombs in Zhuzhou (Tables 1 and 2; Figs. 1 and 2). These are two important distribution areas of Yue people in Hunan, which was also the route for the southward spreading of the Chu culture. The Yue style bronzes represented the Yue people's bronze manufacturing industry in Hunan during the Spring and Autumn and Warring States periods.

Methods

Of the 33 samples studied in this paper, 21 contained intact metal bodies, 12 had only corroded powder scraped (in order to protect the integrity of the cultural relics), 33 samples were tested for lead isotope ratios, and 21 samples contained metal bodies were tested for alloy composition and metallographic structure.

A small sample was taken from 21 artifacts, inlaid with epoxy resin, samples with the metal body are ground and polished after preparation. Observe under the metallographic microscope during the polishing process, and spray carbon when it meets the requirements, the microstructure and chemical composition were analysed by SEM-EDS (SSX-550, SHIMADZU), the experimental excitation voltage was 25 kV and the counting time was 1 min. For each sample, 2–3 areas were selected for surface scanning analysis, and the average value was taken as the composition of the sample. The inclusions were analyzed by microanalysis or point analysis to assist in judging the metallographic structure. Then, 21 samples were re-polished and etched with alcoholic ferric chloride. which is observed and photographed under a metallographic microscope (ZEISS Axio Observer A1M), these experiments were done in the USTC Archaeometry Laboratory of the University of Science and Technology of China.

About 50 mg of samples were cut from 33 artifacts for lead isotope analysis, were washed with acetone and ultrapure water first and then dissolved with concentrated nitric acid. The electrolytic deposition method was conducted for the purification and extraction of lead. The lead content in the solution was determined by inductively coupled plasma-mass spectrometry (ICP-MS), and then the lead concentration in the solution was diluted to about 200 ppb. Finally, the isotope ratio was measured by thermal ionization mass spectrometer (TIMS, ISOPROBE-T). The NBS-981 standard solution was interleaved in the test process for correction. The analysis errors of the lead isotope ratio in each group were all less than 0.003.

Results

Alloy composition

The Yue style bronzes unearthed in the Yiyang area have three alloying types (Fig. 3). From the analysis of the chemical composition, 6 of the 11 bronzes from Yiyang are made of leaded tin bronze. The tin content is between 4.2% and 16.1%, and the lead content is between 6.2% and 26.5%, which vary greatly. The average tin content is about 10.3%, and the lead content is about 15.9%. Three samples are tin bronze. The other two ZY-1701 Ding and ZY-1704 Li bronzes are made of copper.

10 Yue style bronzes from the lower Xiangjiang River Valley were analysed for chemical composition. The bronze sword unearthed from the Tomb M6 of Tanheli Site in Ningxiang is analyzed as tin bronze material. The bronze Ding (Fig. 3) unearthed from the Warring States tomb (M11) is leaded tin bronze, containing 16.5% lead and high lead content. The scraper of the Yunhuqiao Site in Xiangtan is high tin bronze, which contains more than 20.0% content of the tin. The bronze spear is lead-tin bronze, containing 13.3% tin and 11.0% lead. The content of tin and lead is relatively high. The three bronze Dings from Xiangxiang are lead-tin bronze, with tin content above 10%, lead content below 10%, and one bronze Ding is high-tin bronze containing 20.9% tin. The bronze Ge is a low tin bronze containing 7.8% tin. The Yue style bronze Ding unearthed from Zhuzhou is made of lead-tin bronze.

It can be seen that the bronze Dings in the Yue style bronzes unearthed in Yiyang and the lower Xiangjiang

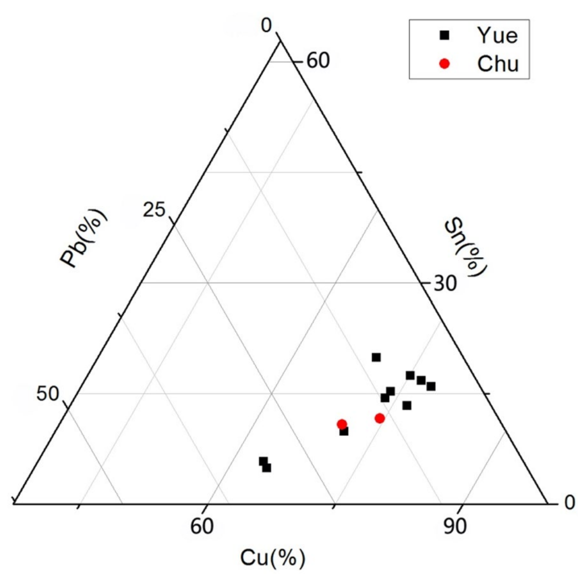

Fig. 3 Ternary diagram of alloy composition

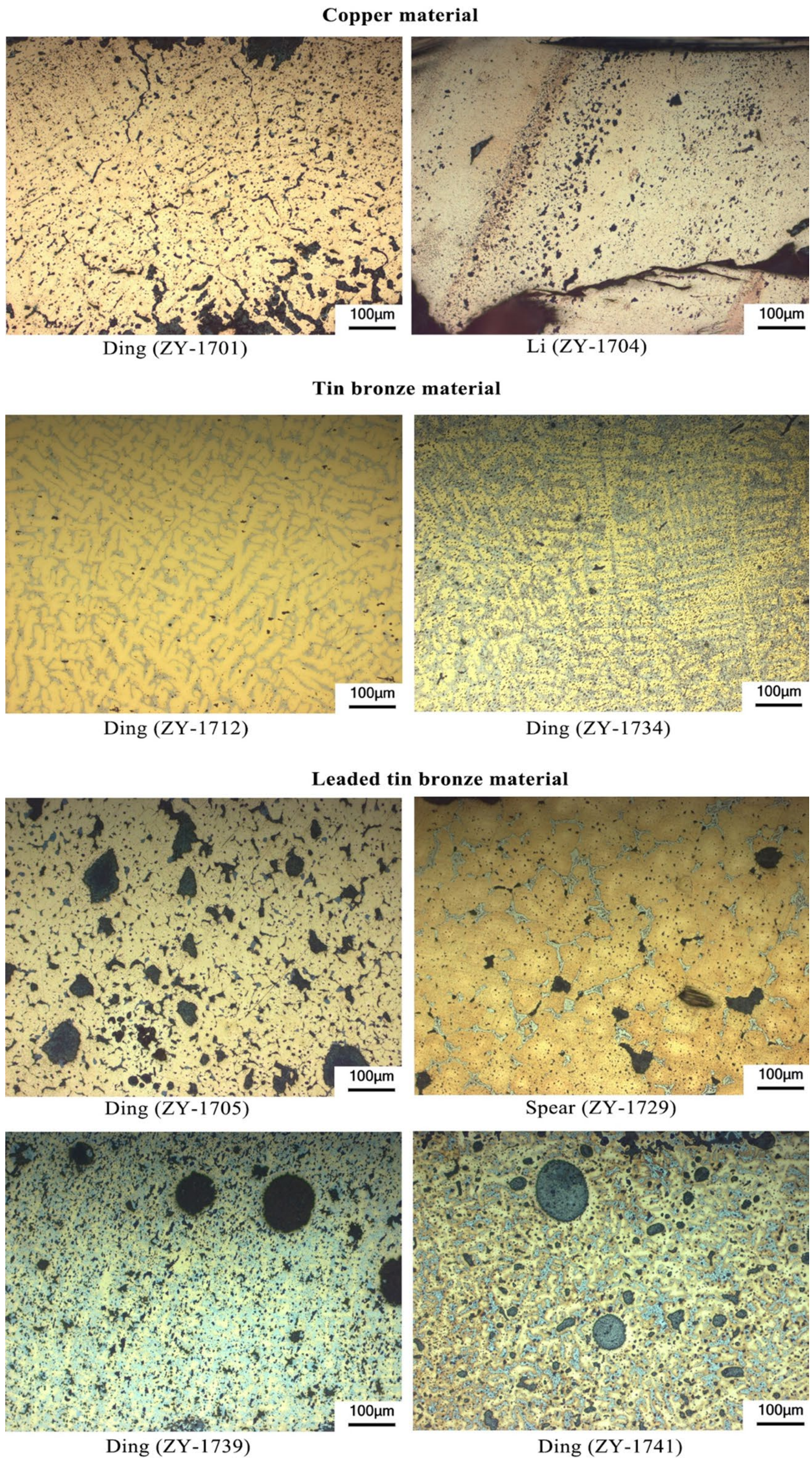

Fig. 4 Metallographic photos (200x) of some Yue style bronzes

River Valley are mainly leaded tin bronze, and the tin content is generally high. The lead content is also higher than that of the late Shang Dynasty bronzes in Hunan, and a few are tin bronze or pure copper. Weapons and tools are substantially tin bronze. On the whole, the alloy materials of Yue style bronzes are diverse, and tin is the main alloying element.

Metallographic analysis

We analyzed the metallographic structure of 21 bronzes. Both the Yue style bronzes and Chu style bronzes were cast (Fig. 4). Most of the bronzes are lead-tin bronze and tin bronze, with obvious crystal segregation, fine dendrites, more $(\alpha+\delta)$ eutectoids distributed at the interdendritic boundary, and lead particles are spherically dispersed (Fig. 4). The metallographic structures of six bronzes were homogenized, indicating that the bronzes were overheated after casting (Fig. 4), which may be related to the cooking or the burning for sacrifice during burial.

Lead isotope analysis (LIA)

The lead isotope ratios of 33 bronzes are all ordinary lead, but the range of variation is large (Table 2). Among them, the lead isotope data of 16 bronzes unearthed in Yiyang are scattered and widely distributed; the lead isotope data

Table 2 Lead isotope ratios of Yue and Chu style bronzes from Hunan

No.	Location	Test No.	Name of objects	Lead isotope ratios			Cultural attribute
				$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	
1	Yiyang	ZY-1701	Ding	17.974	15.551	38.178	Yue
2		ZY-1702	Ding	17.946	15.522	38.176	
3		ZY-1704	Li	18.091	15.533	38.199	
4		ZY-1705	Ding	17.955	15.538	38.141	
5		ZY-1706	Ding	18.316	15.643	38.663	
6		ZY-1707	Ding	17.592	15.567	38.321	
7		ZY-1708	Ding	18.225	15.620	38.610	
8		ZY-1709	Ding	17.876	15.571	38.244	
9		ZY-1710	Ding	18.046	15.644	38.341	
10		ZY-1711	Ding	18.592	15.699	38.926	
11		ZY-1712	Ding	17.691	15.519	37.945	
12		ZY-1713	Ding	18.579	15.692	38.867	
13		ZY-1715	Axe	18.377	15.683	38.718	
14	Ningxiang	ZY-1602	Sword	18.473	15.682	38.783	
15		ZY-1606	Ding	18.593	15.701	38.918	
16	Xiangtan	ZY-1728	Knife	18.099	15.585	38.472	
17		ZY-1729	Spear	18.554	15.680	38.835	
18	Xiangxiang	ZY-1731	Ding	18.454	15.663	38.737	
19		ZY-1732	Ding	18.017	15.536	38.215	
20		ZY-1733	Ding	18.278	15.642	38.644	
21		ZY-1734	Ding	18.123	15.577	38.275	
22		ZY-1735	Ge	17.965	15.538	38.191	
23		ZY-1736	Yue	18.107	15.599	38.412	
24		ZY-1737	Ding	18.307	15.593	38.473	
25		ZY-1738	Ding	18.603	15.685	38.876	
26		ZY-1739	Ding	18.264	15.669	38.565	
27		ZY-1740	Spear	18.372	15.598	38.529	
28	Zhuzhou	ZY-1741	Ding	18.611	15.692	38.899	
29		ZY-1742	Ding	18.615	15.694	38.907	
30		ZY-1745	Bo	18.059	15.539	38.237	
31	Yiyang	ZY-1714	Ding	18.226	15.571	38.400	Chu
32		ZY-1716	Fu	17.571	15.417	37.851	
33		ZY-1717	Dui	17.692	15.454	37.984	

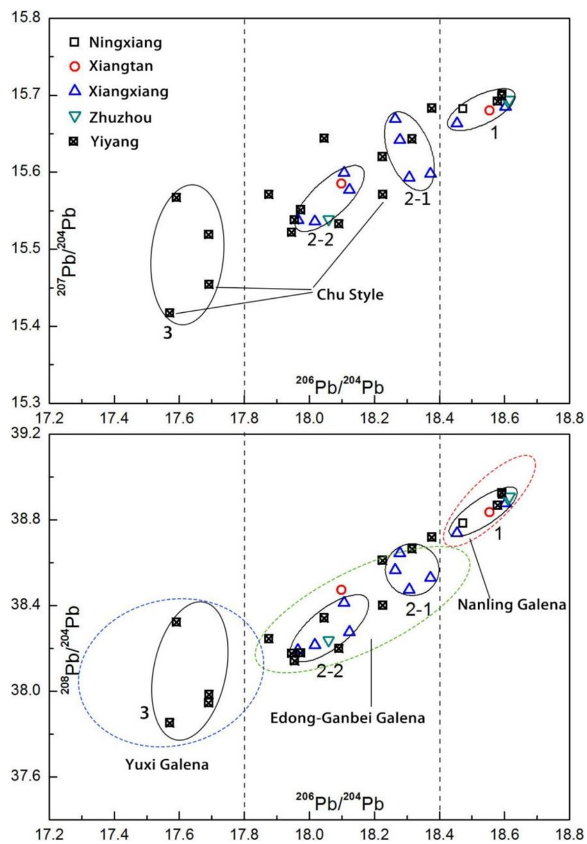

Fig. 5 Lead isotope ratios of Yue and Chu style bronzes unearthed in Hunan

of 17 bronzes unearthed in the lower Xiangjiang River Valley are relatively concentrated (Fig. 5). According to the distribution of bronze lead isotope data and the lead isotope ratio distribution in China's metal mines, they are divided into three fields.

There are 9 bronzes from various areas in field 1, including Dings, swords, spears, etc., most of which are copper-tin-lead ternary alloys with high lead content, indicating that lead is an alloy raw material. The lead isotope ratio mainly indicates the source of lead material.

The largest number of bronzes was found in field 2, with a total of 20 bronzes, of which 19 were Yue style bronzes, accounting for 63.3% of all Yue style bronzes. There are also various types of ware, including various styles of Ding, Li, Bo, axe, scraper, etc., and a Chu style Ding is also in the field. The bronzes in this field have various alloy materials, including copper, tin bronze and lead-tin bronze. The lead isotope ratio reflects the sources of copper and lead.

There are only four bronzes in field 3, all of which were unearthed in Yiyang, including two Chu style Dings (ZY-1711 and ZY-1713) and two Yue style Dings (ZY-1712 and ZY-1707). ZY-1712 Ding is tin bronze with high tin content and ZY-1716 Fu is lead-tin bronze with 16.9% lead content. The lead isotope ratio reflects the source of lead material.

In summary, there is not much difference in the lead isotope in different categories of Yue style bronzes, whether containers or tools, weapons were made by the same metal source. In addition, lead-tin bronze and tin bronze are not clearly distinguished in lead isotope ratios, indicating that the copper and lead ores don't have different origins and maybe copper and lead ores in the same area.

Discussions

Metal technology and features

Metallographic analysis shows that the Yue style bronzes found in Hunan, whether containers or weapons or tools are cast, with no forging, and no post-casting processing. During archaeological excavations, it was found that the bottom and belly of the Yue style bronze Ding often had a layer of soot, and some had multiple patched scars, indicating that the Yue style Ding was a practical vessel rather than a ritual vessel [10]. The metallographic structure of several Yue style bronze containers analyzed above is heated after casting, which should be caused by cooking and incineration [41]. In addition, the bronze Ge unearthed in the Yunhuqiao Site, Xiangxiang shows that it was overheated, and other weapons analyzed were not overheated. The reason remains to be further studied.

The analysis of alloy composition shows that after the late Western Zhou Dynasty, the alloy materials of container objects are mainly lead-tin bronze and tin bronze, and a few are pure copper. The lead content of lead-tin bronze is generally high, and the alloy technology is significantly different from that of most bronzes in the early and middle Western Zhou Dynasty in Gaoshaji [8] and Tanheli [4] sites. The two early Yue style bronze Dings unearthed from the sites of Tanheli and Gaoshaji are all lead bronzes, and the lead content of the Yue style Dings from the Gaoshaji site is as high as 38%, reflecting the diversification of the alloy technology of Yue style bronze containers, but high content of tin and lead is the main alloy features. As the bronze swords from the Tanheli Site in the Spring and Autumn Period, the metal material of the weapons is mainly tin bronze. The bronze scrapers are the most distinctive Yue style bronze tools, which also with a high tin character [42]. On the whole, during the Spring and Autumn and Warring States periods, more tin and lead materials were added in Yue style bronze casting, and different wares had different alloy recipes.

Compared with the early Yue style bronzes found in Tanheli and Gaoshaji sites, the amount of lead used increased significantly.

Origin of mineral materials

The shapes and structures of the bronzes of the Gaoshaji site (1000 ~ 800 BC) showed local characteristics and were considered to be the relics of the early Yue People, although the bronzes were influenced by Shang Culture. The main raw metal materials used for the Gaoshaji bronzes are not only from Central China by interaction with the Shang and Zhou Dynasty, but also from Local Hunan exploited by early Yue People. It is an important clue to the origin of the Yue style bronzes of the Eastern Zhou Period. The comparison of these bronzes can explore the early and late relationship of Yue style bronzes.

The lead isotope composition shows that the bronzes in Yue style field 1 of the Eastern Zhou Dynasty in Hunan are highly coincident with the Gaoshaji bronzes (Field a) (Fig. 6), and should be the same mineral materials used. The lead isotope ratios of the field 2 and 3 of the Yue style bronzes in the Eastern Zhou Dynasty are similar to those of the bronzes in fields b and c of Gaoshaji bronzes, but most of them do not coincide, indicating that their metal sources are not the same.

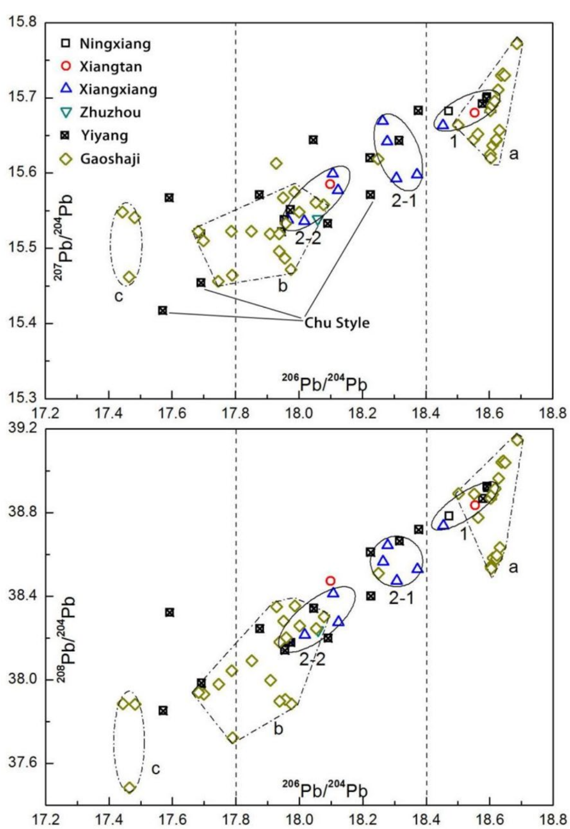

Fig. 6 Comparison of lead isotope ratios of bronzes from the Gaoshaji Site

In addition to using the same mineral materials as the Western Zhou Dynasty, the bronzes of the Gaoshaji site use the copper-tin-lead polymetallic ore in southern Hunan, which was first used by the Tomb M5 in the middle of the Western Zhou Dynasty [8]. The lead isotope composition of the bronze wares in the East Zhou Dynasty Yue style bronzes field 1 and Gaoshaji field a are highly consistent with the lead isotope ratio of copper and lead ores from Xianghualing tin-copper-lead polymetallic deposit [43], Tongshanling lead-zinc-copper polymetallic deposit [44], Yejiwei, Hengshanling, Pojinshan galena [45] and other mines in southern Hunan (Fig. 5).

The bronzes from Lower Xiangjiang River Valley coincide with the Yiyang bronzes in field 1 and the Gaoshaji bronzes (field a). The metal resources similar to lead isotope composition are located in the Nanling polymetallic metallogenic belt in southern Hunan [46]. They have been exploited sporadically in the early Western Zhou Dynasty and have been exploited on a large scale in the middle and late Western Zhou Dynasty [8]. udging from the fact that several Yue style bronzes and bronze Dings from the Tanheli(炭河里) site of the Spring and Autumn Period fell into this group [4], it shows that from the early Western Zhou Dynasty to the Spring and Autumn Period, the metal resources of Nanling Mine have been mined and utilized, and should be occupied and utilized by Yue people. Therefore, some of the Yue style bronzes of the Eastern Zhou Period unearthed in Hunan continued the metal materials of the early period. It is rich in copper, tin and lead in the Nanling Polymetallic Belt [47], which provides important raw materials for the production of bronzes for the Yue people.

But most of the ores of the Eastern Zhou Yue style bronzes still came from outside Hunan. The lead isotope data in field 2 is consistent with that of copper and lead ores in the eastern Hubei-northern Jiangxi area in the middle reaches of the Yangtze River [15] (Fig. 5). The middle and lower reaches of the Yangtze River are the largest copper belt in China, and it is also rich in lead ore [48]. There is a long history in these areas of copper and lead mining. The Tongling(铜岭) copper mine, Ruichang, Jiangxi, was mined in the middle of the Shang Dynasty [49]. Yangxin(阳新) discovered the lead smelting site dating to the Shang and Zhou Dynasties [50]. The mining of the Tonglushan copper mine reached its peak during the Eastern Zhou Dynasty. The remaining copper smelting slag is more than 400,000 tons, covering an area of about 140,000 square meters. It is estimated that the cumulative copper production is not less than 80,000-120,000 tons

[51]. Therefore, although Yue people in Hunan can obtain copper, tin and lead resources in the Nanling area, it still mainly uses a large number of copper and lead mineral resources from the middle reaches of the Yangtze River.

In addition to the mineral resources of the Nanling and the middle and lower reaches of the Yangtze River, there is a small amount of Hunan Yue style bronzes $^{206}Pb/^{204}Pb$ between 17.4 and 17.8 (field 3). This type of lead ore is more common in North China, especially in the Xiaoqinling area of western Henan [15]. Two Chu style bronzes are distributed in area 3, and they are likely to be products produced by the Chu state and then traded into Hunan.

Chu-Yue relationship and resource circulation

From the late Spring and Autumn period, Chu state began to expand into Hunan. During the Warring States period, especially in the middle of the King Dao of Chu (楚悼王)(401 ~ 381BCE), General Wu Qi(吴起) annexed the Yue group to the south and occupied Hunan. Chu's territory continued to expand southward, thus accelerating the integration of Chu and Yue cultures, forming a phenomenon of coexistence of Chu and Yue cultures [52]. Yiyang is located in the south of the capital of State Chu at that time, which is one of the important routes for Chu culture to enter Hunan. From a large number of tombs of the Spring and Autumn and Warring States period excavated in Yiyang, there are more and more factors of Chu culture, which gradually occupy the dominant position. Of course, Chu tombs in Yiyang are often buried with Yue style artefacts, and Chu tombs in the Jianghan area are also buried with Yue style bronzes, showing the cultural features of Chu and Yue integration and exchange. This paper mainly compares the lead isotope ratios of the Spring and Autumn Period bronzes unearthed in Huangtupo(黄土坡) cemetery, Qiaojiayuan(乔家院) cemetery and Jingzhou. Some of the bronzes are from Chu tombs at Xiasi(下寺), Xichuan and Zuozhong(左冢), Jingmen [53].

Chu style bronzes, whether in the Spring and Autumn period or the Warring States period, a considerable part of them fell into the scope of Hunan Yue style bronzes field 1 (Fig. 7). The metal resources of this group of bronzes are largely from polymetallic deposits in southern Hunan. It can be seen that the metal resources in southern Hunan are not only used by the Yue people but also circulated to the Chu state. These Chu style bronzes are mostly dated to the middle and late Spring and Autumn period, and the bronzes of Jingmen Zuozhong were dated to the middle of the Warring States period. At least in the middle of the Warring States period, this raw material was still supplying Chu state.

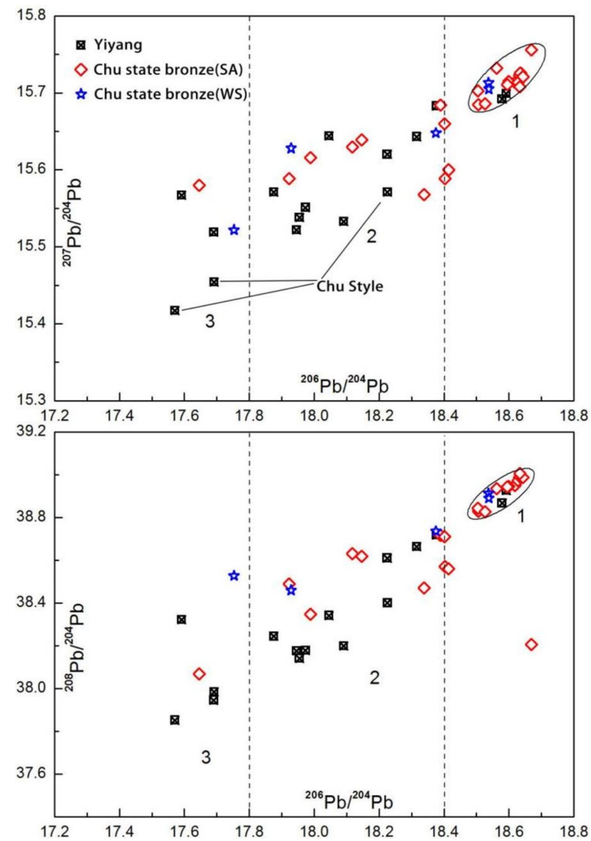

Fig. 7 Comparison of lead isotope ratios with Chu style bronzes

Since the copper resources such as Tonglushan in eastern Hubei are mainly developed and utilized by the Chu state, many Chu state bronzes have lead isotopic compositions of copper and lead ores in the middle reaches of the Yangtze River. Therefore, there is a strong consistency between Yue style bronzes and Chu bronzes in field 2. Yue people's forces are far from sufficient to directly develop copper and lead mineral resources from the middle reaches of the Yangtze River. The metal resources used in Yue style bronzes in the middle reaches of the Yangtze River were mainly exchanged from the Chu state. The products used by the Yue people for exchange are likely to be tin ore or tin materials. As one of the largest vassal states during the Spring and Autumn and Warring States periods, Chu state has a large number of bronzes, and the demand for tin is naturally enormous. Although the copper and lead resources in the middle and lower reaches of the Yangtze River are very rich, there is a lack of tin resources. The Nanling area in southern Hunan is one of the largest tin ore belts in China. Nanling was not included in the territory of Chu state in the Spring and Autumn Period, and the tin mine here was controlled by the indigenous Yue people. The reason why the bronze tools of the Yue people are generally high in the tin is related to the adjacent rich tin resources [42]. Previous lead isotope analysis of tin wares in Chu and Huaihe River Basin showed that tin materials were likely to come from tin deposits in southern Hunan [54]. Accordingly, we can speculate that the Yue people traded with Chu through tin ore or tin materials in exchange for various products, including bronzes and copper materials.

Nanyang Basin in western Henan is also the scope of Chu state, and some bronzes of Chu state also used lead materials from the Qinling-Dabie lead ore belt in western Henan [55] (Fig. 7). Copper and lead minerals in the middle and lower reaches of the Yangtze River and western Henan entered Hunan with the trade between the Chu state and Yue people. It is because of this trade that Hunan Yue style bronzes use minerals from many regions, and lead isotope ratios are more dispersed.

Conclusion

The scientific and technological analysis of Yue style bronzes unearthed in Hunan shows that the bronzes are all casting, and the metallographic structure of some Yue style bronzes shows the phenomenon of heating after casting, which is related to the practicality of Yue style bronzes. The metal materials of bronzes are mostly leaded tin bronzes, with a small number of tin bronzes and coppers. The alloying element is more tin, which continues the alloy characteristics of bronzes from the late Shang to the early Western Zhou Period in Hunan, while the lead content is higher.

The lead isotope data of Yue style bronzes in Hunan are scattered, and at least three ore sources are used. Some of the raw materials are from local polymetallic deposits in southern Hunan, and copper and lead minerals in the middle reaches of the Yangtze River are also used. The metal materials of Hunan Yue style bronzes are in strong consistency with those of Chu state bronzes. There is a lack of tin ore in Chu state, while tin ore is abundant in the Nanling area of Hunan. Tin trade may be an important factor in the sharing of bronze materials between the Yue people and the Chu state.

Abbreviations

HRL	high-radiogenic lead
SEM-EDS	scanning electron microscopy-X-ray energy dispersive spectroscopy
ICP-MS	inductively coupled plasma-mass spectrometry
TIMS	thermal ionization mass spectrometer
LIA	lead isotope analysis

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Author contributions
JB M and XS Y performed the data analysis. JB M and XT W were major contributors to writing the manuscript. JB M and XT W designed the method. All authors read and approved the final manuscript.

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Availability of data and materials
The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Competing interests
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.

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