Lead isotope and metal source of Shang bronzes: A response to Sun et al.'s comments

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Abstract:

In this brief response to Sun et al.'s comments on our paper, we would like to emphasize again that archaeological, chemical and isotopic evidence are all relevant to the discussion about the metal source of the Shang period with highly radiogenic lead isotope ratios. The southern African bronzes have much lower lead contents and quite different lead isotopic signatures than the Shang bronzes.

More importantly, there was no metallurgy of any kind in southern Africa before ca. AD 200, so southern Africa cannot possibly be the source of Shang bronze, which date to ca. 1500-1000 BC) .

Key words:
lead isotopes; highly radiogenic lead; Shang bronze; provenance.

Introduction:
In our previous article, we argued that Sun et al.'s (2016) claim that many Shang period bronzes were made with metals from Africa should be rejected for both archaeological and isotopic reasons. In their response to our article, Sun et al. still insist on a southern African source for highly radiogenic Shang bronzes without acknowledging any errors in their original paper. Here we present a brief response to their comments and further clarify a few important points.

Responses to Sun et al. (2018)
The first four paragraphs of Sun et al.'s comments concerning tin bronze and leaded tin bronze in the Shang period are completely irrelevant. We have never claimed that the Shang people had no knowledge of other metals, but stated clearly "*that the source of the highly radiogenic lead in the alloy is indeed a copper ore with variable lead content*" (Liu et al. 2018, 107). As we noted in our paper, Shang artefacts with highly radiogenic lead isotope ratios are known to show a wide range of lead contents, and the scatter plot of $^{206}Pb/^{204}Pb$-Pb reveals no correlation between their lead isotope ratios and lead contents (Liu et al. 2018; Meyers et al. 1987, 555-7; Pollard et al. 2017). This suggests that the copper and lead sources of these bronzes both have similar (and highly radiogenic) lead isotope ratios. (If only the copper source has this lead isotope signature, adding common lead to it would likely result in a bronze with common lead isotope ratios). We therefore concluded that these two metals were most probably from a common source. None of the copper ore deposits in southern Africa satisfy this requirement, and thus there is almost no evidence for leaded bronze in the archaeological record of this region (Molofsky et al. 2014, Killick 2016). Southern Africa is therefore unlikely to be the potential metal source for the Shang bronzes, many of which contain substantial concentrations of lead.

Sun et al.'s understanding of historical records is also faulty. They cite records in *Kao Gong Ji* (Book of Diverse Crafts) in *Zhou Li* and date this book to the 11th century BC. However, the book was in fact compiled during the Eastern Zhou period (8th-3rd century BC) (Hua 1999, 283) and is not therefore acceptable evidence for the uses of metals in the Shang period.

Sun et al. (2018) claim in the fifth paragraph that *"[highly radiogenic lead isotope ratios in] those southern African bronzes…were NOT from tin ore".* This statement is clearly wrong. They have failed to notice: (1) that analyses of archaeological tin metal in southern Africa include samples that contain highly radiogenic lead (Molofsky et al. 2014, Table 1 and Fig. 5); and (2) that the model ages calculated from lead isotope isochrons for the southern African tin samples (2059 ± 36 Ma) and the southern African bronze samples (2083 ± 31 Ma) are both consistent with the known ages (measured by U/Th dating of zircons) for the relevant southern African tin-bearing granite (2057 ± 3 Ma). The only plausible explanation for this, as noted by Molofsky et al. (2014) is that the highly radiogenic southern African bronzes were made by adding tin containing some radiogenic lead to copper that must have had very low lead content. (This is because, as correctly stated by Sun et al., cassiterite contains very little lead). The eleven archaeological tin metal samples analyzed by Molofsky et al. have an average of 195 ppm Pb, with one sample reaching nearly 1200 ppm.). The bronzes resulting from this addition therefore have very low lead levels (Molofsky et al. 2014: Table 2 reports one tin bronze with 357 ppm Pb; the seven other southern African tin bronzes for which lead concentrations were determined have an average of 45 ppm Pb) and are therefore, as we noted in our initial paper, quite unlike the Yin-Shang bronzes.

Sun et al. (2018) state later that *"while there is indeed an offset in $^{208}Pb/^{206}Pb$ for several tin bronze samples that have extremely highly radiogenic lead (i.e., radiogenic Pb isotopes from tin), the majority of the southern African bronzes have similar Pb isotopes to those of the Yin-Shang bronzes"*. They have, however, failed to note that those southern African bronzes and copper which overlap with the Shang bronzes almost all have $^{206}Pb/^{204}Pb<20$ and thus contain common or only mildly radiogenic lead (see Figure 1). Their provenance is not the concern of the present discussion, but it is worth mentioning that many Chinese copper and lead deposits also fall into this range (Jin et al. 2017). On the other hand, it should be noted that at the highly radiogenic end ($^{206}Pb/^{204}Pb>20$), African samples and Shang bronzes are in fact distinct. Both the southern African archaeological tin samples and the southern African bronzes have quite different $^{208}Pb/^{204}Pb$ ratios than the Shang bronzes, invalidating the main argument brought forward by Sun et al. (2016).

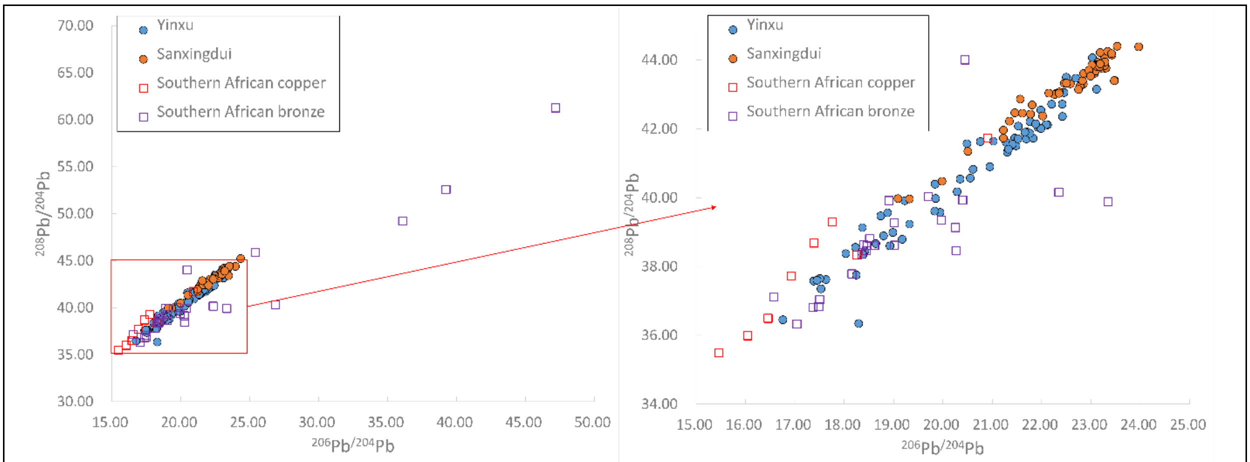

Figure 1 A plot of $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagram for Shang bronze, southern African copper and bronze. Note that those southern African copper and bronze samples which match the isotopic ratios of Shang bronze samples are not highly radiogenic ($^{206}Pb/^{204}Pb<20$). The southern African copper and bronze samples which are highly radiogenic ($^{206}Pb/^{204}Pb>20$) do *not* match the Shang bronzes (data from Jin, 1987; Molofsky et al. 2014; Sun et al. 2016; Liu et al. 2018).

In their sixth paragraph, Sun et al. (2018) claim that we separated the Sanxingdui bronzes from the Yin-Shang bronzes and did not plot the Panlongcheng bronzes to support our argument. However, we just plotted exactly the same set of data in the same way as Sun et al. (2016) to avoid confusion. Moreover, the statement that regards the Panlongcheng bronzes as "*another location of highly radiogenic bronzes in the Yin-Shang period*" is simply wrong, since Panlongcheng is a site of the early Shang period rather than the Yin-Shang period.

The seventh paragraph in Sun et al.'s comments continues to mislead readers in the following statement: "*The only difference is that we proposed Yin-Shang bronzes may come from Africa, whereas three out of the four papers cited by Liu et al., (2018) proposed an origin based on the Eurasian Steppe*". It is really alarming to see that Sun and his collaborators know so little about Chinese prehistory that they failed to realize that these metallurgies are of quite different ages. What we discussed in our paper is the origin of early copper and bronze metallurgy - dated to the early second millennium BC - that has shown a strong connection with the Eurasian Steppe, while the focus of Sun et al. is the Yin-Shang bronzes dated to the late second millennium BC. We know well that they "*did not propose that the bronze technique was developed independently in China*", but they did suggest that *"the majority of archaeologists in China strongly insist…[that] bronze technology was developed independently in China"*. This is a clearly incorrect and a misleading statement, revealing that they lack a basic understanding of the most recent archaeological research on early metallurgy in China.

Furthermore, as we noted in our earlier critique, there was no metallurgy at all in southern Africa before about AD 200, and no bronze before about AD 1200 (Killick 2016). Sun et al. appear to assume that archaeological evidence for earlier bronze metallurgy in southern Africa has been overlooked, but this is highly unlikely. The archaeology of southern Africa has been studied for over a century and is well understood. When the Yin-Shang bronzes were made, the only inhabitants of southern Africa were hunter-gatherers using stone tools. Nor is there any indication of trade goods from beyond the African continent in southern Africa before the eighth century AD (Wilmsen 2017). The only region on the African continent where bronze metallurgy was in use at the time of Yin-Shang was in New Kingdom Egypt and in Nubia, but the lead isotope ratios of bronzes from ancient Egypt and adjacent regions which are roughly contemporary with the Shang period show no highly radiogenic lead isotope ratios.

We also have to disagree with Sun et al.'s claim that Pb isotope compositions provide a direct means of assessing provenance. Metal artefacts are not geological ore specimens. They were created via a series of anthropogenic activities, and subjected to trading, recycling and alloying with other metals from varied sources. Therefore, it is not always possible to provenance an artefact to its geological origin using only its lead isotope data. This data need to be interpreted within archaeological contexts and used to answer appropriate archaeological questions. We do agree that lead isotope data is highly relevant, but the isotopic data cannot be evaluated in isolation. Where conclusions based solely upon isotopic data are contradicted by established archaeological data, one should suspect that there is some other explanation for the isotopic patterns.

Concluding Remarks

We would like to highlight three main points: 1) the source of highly radiogenic lead in Shang bronzes should contain both copper and lead; 2) the African hypothesis for the metal source of Ying-Shang bronzes is fundamentally flawed and without any archaeological and isotopic basis; 3) the source(s) of the metals used to make Yin-Shang bronzes are still unknown, and collaborative interdisciplinary research which takes into account *both* archaeological and geological evidence is necessary for solving this problem.

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