Response to comment of Albarède and colleagues

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We would like to thank Francis Albarède and colleagues for engaging with our article (Wood *et al*. 2023) because we have noticed that research published in the geological literature does not always find its way into the archaeological literature in a form that can directly benefit archaeology. Our purpose is to better understand the actions and behaviours of people in the past, often with a focus on ancient economies, and we are willing to use tools from any discipline that allow us to explore these issues. This is why it is so important that the limitations of techniques applied to archaeology are presented as explicitly as their utility.

Albarède and colleagues state that "silver isotopes were never meant to be used for provenance". This is good to know. In previous articles, however, silver isotopic compositions have been referred to as being "used successfully to trace the origin of coinage" (Desaulty *et al*. 2011), as a "powerful tracer" (Albarède *et al*. 2016) and as a "marker of silver extraction and metallurgy in the mining districts" (Albarède *et al*. 2021) etc., which strongly hint that they could be used to provenance silver. Nonetheless, as far as we understand the current state of the field of silver isotopes (especially after the Arribas *et al*. (2020) critique), no systematic Ag isotopic composition appears to characterise a specific type of deposit, geographic location, or mineralisation age - but silver isotopes can be used for what Eshel *et al*. (2022) have described succinctly as "geological classification". We admit that this distinction was blurred when we used the term "provenance" as shorthand in our article. We hope that this correspondence makes the application of silver isotopes to archaeology more overt and that Albarède and colleagues seize the opportunity to write a primer for the archaeology community.

Our tentative explanation for the narrow range of silver isotope values with respect to the standard (that is, ε^{109}Ag) not only for Roman coins but also for Hellenistic, medieval, modern silver coins and hacksilver, which all report ε^{109}Ag values that have narrower ranges than those reported for hypogene and supergene ores, is that they were mixed and recycled. In effect, we tried to pre-emptively answer the call from Albarède and colleagues "to explain the remarkable isotopic homogeneity of all silver sources used for coinage (ε^{109}Ag~ –1 to +1 parts in 10,000) over a time span of 2500 years on several continents". Albarède and colleagues disagree with our suggestion that mixing and recycling could be responsible and highlight that variation should increase with mixing, rather than decrease. We agree that variation should increase (as we have shown) - but the *mean* values can converge with mixing. Basically, we find it difficult to believe (based on archaeological evidence) that silver was extracted from such a homogeneous set of ores over such long period of time in various locations; that is, the reason for the "remarkable homogeneity" of the ε^{109}Ag is perhaps more to do with the fact that nearly all silver isotope research has been conducted solely on coins, which are likely to have been mixed and recycled.

Regarding our application of bismuth - we agree that it is controversial. However, there were large differences in the Bi/Pb ratio found in Roman coins among the regions explored (East, Rome and West), as well as among the different clusters (that is, clusters identified from the independent log-ratio analysis) within the same regions (in some cases, exhibiting bimodality). When we applied this indicator to the full dataset, we observed high values for those coins minted during the Civil War of AD 69 (compatible with being minted in Iberia), and mixed signatures during times of currency reform. We did not hazard an explanation for this in the article (for many of the reasons that Albarède and colleagues have mentioned) but we applied it empirically. However, we speculate here that it may not be possible to relate cupellation research conducted in a laboratory to that of an ancient mint. In other words, mass production of silver for coinage may still allow the refining signature of the lead to be identified from the Bi/Pb ratio. This clearly requires further research, but we considered that it was important to raise awareness of this potentially very useful indicator.

Overall, we would like to point out that our fundamental tenet (which is that the silver used for silver coins often derives from more than one silver supply, and that it is processed with lead from various supplies) remains unchallenged by the comment of Albarède and colleagues, which has significant repercussions for their own research approach. The comment made regarding the addition of copper to coinage affecting the lead isotope signature is not mentioned directly in our article (we were referring to the elemental signature) but we are aware of the work that Albarède and colleagues cite and we agree that this can further complicate the picture. However, it is the mixing of lead and silver from different sources where we focussed our article. In effect, despite having read the comment of Albarède and colleagues, we still consider that mixing, debasement and recycling of silver for coinage will affect elemental and isotopic signatures, making provenance (and geological classification) investigations that are aimed to better understand the actions and behaviours of people in the past, complex, convoluted and, in many cases, intractable.

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