



# Copper-base metal supply during the northern Vietnamese Bronze and Iron Ages: metallographic, elemental, and lead isotope data from Dai Trach, Thành Dên, Gò Mun, and Xuân Lập

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## Abstract

We present the results of metallographic, elemental, and lead isotope analyses of one slag and 27 copper-base artefacts from northern Vietnam. These artefacts come from four sites: Dai Trach, Thành Dên, Gò Mun, Xuân Lập and are attributed to the Đông Đậu (ca. 1300–1000 BC), Gò Mun (ca. 1000–700 BC), and Đông Sơn (ca. 700 BC–100 AD) cultures, the two former being Bronze Age (18 samples) and the latter Iron Age (10 samples). Twenty-two of the samples have as-cast microstructures, with one having been quenched, three evidencing working and annealing, and one too corroded to tell. Despite variable corrosion levels, all metal samples are identified as bronzes, rather than copper, though seven are leaded bronzes. All the leaded alloys are Iron Age, which is typical for the region. Lead isotope results were notable, in that none of the study samples is consistent with the known prehistoric Southeast Asian copper production signatures, an unusual occurrence in recent regional provenance research. There is some compatibility with Thai Bronze Age copper-base artefacts, but generally it seems there was only weak overlap in exchange systems between northern Vietnam and southern Mainland Southeast Asia, with northern Laos as a possible frontier zone. Further archaeometallurgical prospection and characterisation in northern Vietnam are needed to identify primary production loci, but sources in the southern Chinese provinces of Yunnan, Guangxi, and Guangdong are also probable.

**Keywords** Vietnam · Bronze Age · Southeast Asia · Copper-base metal · Microstructure · Elemental composition · Lead isotopes

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## Introduction

### Northern Vietnam and the origins of the Mainland Southeast Asian Bronze Age

The ‘origin’, or more likely origins, of the Mainland Southeast Asian (MSEA) Bronze Age has been a topic provoking significant global interest for over half a century (e.g. Higham et al. 2019; Pryce et al. 2018a). This was largely due to unexpected dates published in the 1960s and 1970s for 4th millennium BC copper metallurgy at the northeastern Thai sites of Non Nok Tha (Solheim 1968) and Ban Chiang (Gorman and Charoenwongsa 1976), during the very early days of regional scientific archaeology and associated dating techniques (radiocarbon and thermoluminescence). These dates were then among the earliest in the world, implying MSEA might have been an independent centre of invention for metallurgy (critiqued in Higham 1996: 34). Doubts about the likelihood of this revelation were expressed at the time

(Higham 1975; Muhly 1981) and the errant chronology has now been completely overturned in the academic literature (Higham and Higham 2009; Higham et al. 2019, 2015, 2020; Pryce et al. 2018b, in preparation; White 1986)—though it persists in some museum displays and travel guides. Based on the solid Thai and Myanma chronological data cited above, some MSEA social groups transitioned from the Neolithic to the Bronze Age in the final centuries of the 2nd millennium BC, though there was likely a great deal of regional variation, with some essentially hunter-gatherer groups remaining to the present day. Radiocarbon dates from central Laos (Cadet et al. 2019; Pryce et al. 2011a) are compatible, though the northern Lao chronology remains uncertain (Pryce and Cadet 2018; Shewan et al. 2021). Cambodian Bronze Age sites are few, with Samrong Sen lacking radiometric dates as it was excavated in the 19th century (Mansuy 1902) but Koh Ta Meas, in the Western Baray at Angkor, provided a single ca. 1000 BC date (Pottier 2006). Notably, the Bronze Age dates for Yunnan have recently been brought into alignment with those of MSEA (Yao et al. 2020), and those for Guangxi and Guangdong are likewise placed in the range 1200–1000 BC, albeit with less secure radiometric dating (e.g. Allard 2018; Ciarla 2007). Given all regional specialists concur on there being no evidence for MSEA interaction with South Asia's 2nd millennium BC 'Copper Hoard Culture' (e.g. Agrawal 1971; Pryce 2014; Yule 1997), there is general agreement on a proximal Chinese source or sources for MSEA copper metallurgy, in the southern provinces of Yunnan, Guangxi, and/or Guangdong (Higham 1996; Higham et al. 2011b, 2019; Pigott and Ciarla 2007; Pryce et al. 2010; White 1988; White and Hamilton 2009). What is not yet well understood, and what this paper hopes to contribute to, is the range of routings and/or timings for these technological transmissions (Pryce 2018; Pryce et al. 2014). A brief glance at a regional map (Figs. 1 and 2) demonstrates that northern Vietnam might be an important area for cultural transmissions between East and Southeast Asia, lying simultaneously on the present-day political (though not ecological) frontier, as well as the terminus of the Red River running ca. 900 km NW up to its source in the mountains south of Lake Erhai (Dali). There are of course other potential riverine routes from Yunnan into MSEA, most notably the Mekong into Laos, Thailand, Cambodia, and southern Vietnam, the Salween into eastern Myanmar and Thailand, and the Irrawaddy into northern Myanmar, there being hints of the latter already detected (see Pryce et al. 2018a). Likewise, there might have been a complete maritime bypass of northern Vietnam, with Guangxi and/or Guangdong copper-base metal products, metallurgical knowledge, and possibly practitioners crossing central Vietnam into central Laos and northeast and/or peninsular Thailand (see Pryce 2018). Nevertheless, we should give some thought to technological

transmissions from China to MSEA via northern Vietnamese territories and/or populations.

This potential for northern Vietnamese archaeometallurgical research is heightened by the fact that late prehistoric excavations in the area tend to yield incomparably more copper-base artefacts than broadly contemporary sites in the rest of MSEA—the sheer difference in the mass of metal consumed, or at least surviving in the archaeological record, cannot be overlooked (Higham 1996, 2014; Murowchick 1988; Trinh 1990, 1979). This aspect must be tempered by the current reality that the northern Vietnamese Bronze Age is not as precisely dated radiometrically as central and northeastern Thailand and north-central Myanmar (Higham et al. 2015, 2020; Pryce et al. 2018b, in preparation), mainly due to most of the pertinent excavations having taken place in the 1950s and 1960s (Higham 2014: 167, 1996). That said, a broad consensus exists on the lower Red River cultural sequence and their approximate dates, with the Phùng Nguyên culture possibly straddling the Neolithic and Early Bronze Age during ca. 1800–1300 BC, followed by the Đông Đậu culture from ca. 1300–1000 BC, the Gò Mun culture from ca. 1000–700 BC, which then led to the 'Iron Age' Đông Sơn culture spanning ca. 700 BC–100 AD, and overlapping with the Han conquest of northern Vietnam, Bắc thuộc, in 111 BC (Dung 2015; Huyền 1996; Liêm 2013; Phung 1993; Trinh 1990). The Phùng Nguyên culture's status as part-Bronze Age rather than entirely Neolithic period is somewhat disputed, and in any event we were unable to access samples from Phùng Nguyên sites. We do though have a selection of 28 samples from four sites spanning the Đông Đậu (14), Gò Mun (4), and Đông Sơn (10) cultures (see also Le Meur et al. 2021; Pryce et al. 2014 for Iron Age northern Vietnamese metallurgical data). There is an extensive and growing database for MSEA Iron Age (ca. 400 BC to AD 500, depending on the area) metallurgy but that for Bronze Age material is far smaller, reflecting the fewer sites discovered and the lesser quantities of metal they tend to yield (Pryce et al. 2014 and subsequent site-focused papers). Our 18 northern Vietnamese Bronze Age samples thus offer an essential insight into MSEA metallurgy at a critical chronological and geographical juncture.

## Study sites

### Dai Trach

Situated near the southern bank of the Duong River at 106.044083°E, 21.056258°N, Đại Trạch (Bắc Ninh Province) is a Đông Đậu culture site. The Đông Đậu sequence was 5–6 m deep and 3 ha in area, exposed over 550 m<sup>2</sup> in four seasons in 1960s. The basal level is of the Phùng Nguyên period, with subsequent Đông Đậu and Đông Sơn phases (Higham 2014: 151; Masanari 2005).



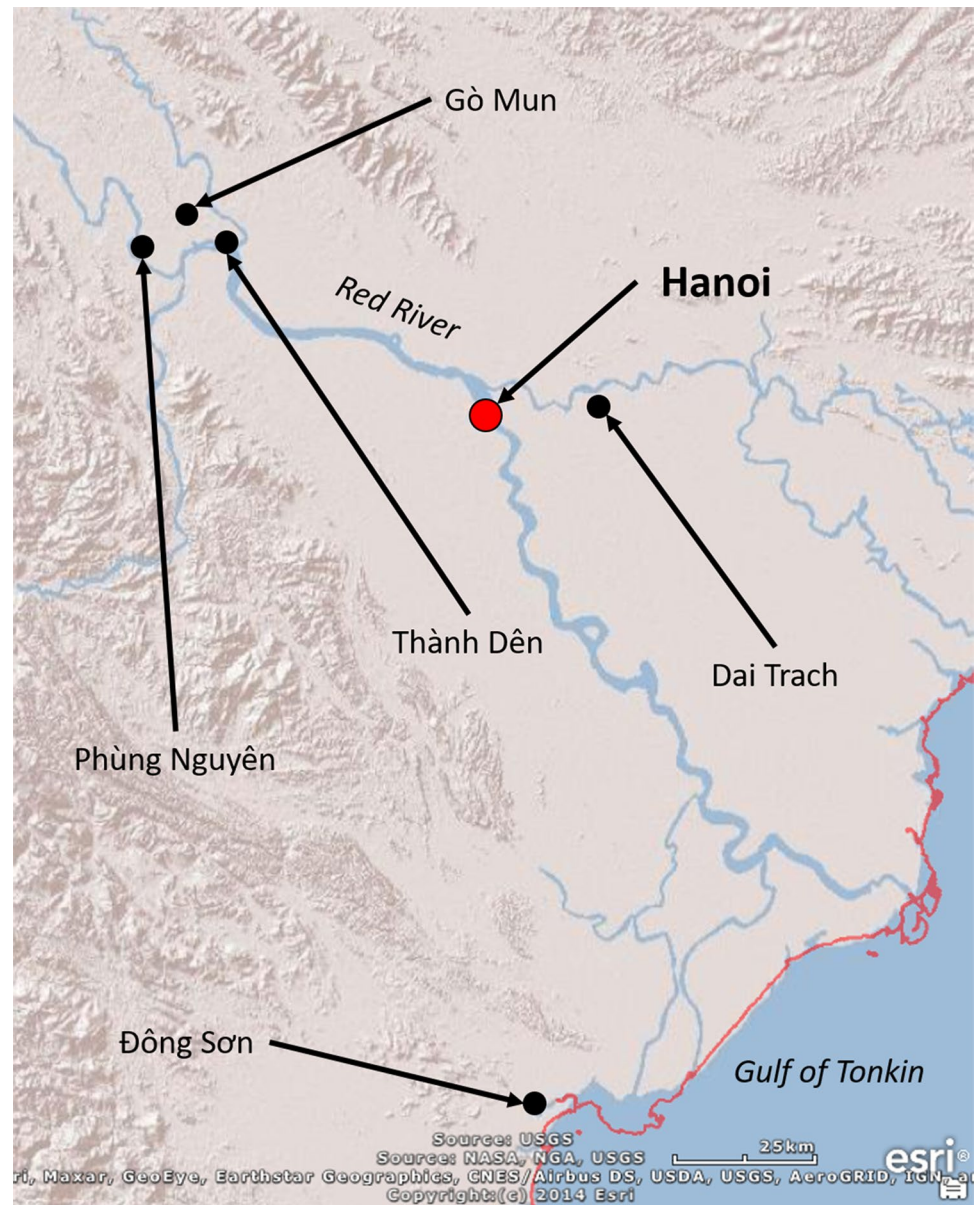
**Fig. 1** Regional map showing target zone around Hanoi and other relevant sites and features

### Gò Mun

On the southern bank of the Red River, 105.359245°E, 21.339359°N, Gò Mun (Phú Thọ Province) was excavated in four seasons between 1961 and 1971, with 1500 m<sup>2</sup> exposed. Only one radiocarbon date is available (Bln-1278, Higham 1996, Figure 4.4), which places the site and its eponymous culture as a successor to the Đồng Đậu period (Higham

2014: 169; Phung 1993). In terms of metallurgy, bronze fish-hooks were the most abundant category, followed by projectile points. Also found were 13 axes, seven chisels, one sickle, and a lostwax-cast seated individual. Thus, Gò Mun attests the use of copper-base alloys for tools, ornaments, weapons, and possible ritual applications. Bivalve moulds for axes and arrowheads again indicate onsite secondary production (Higham 2002: 152, Figure 4.15).

**Fig. 2** Red River delta area showing Hanoi and relevant sites



### Thành Dên

Located at 105.425663°E, 21.295944°N, near the eastern bank of the Red River, Thành Dên (Vĩnh Phúc Province) was excavated in three seasons between 1983 and 1986, exposing 145 m<sup>2</sup> to a relatively shallow depth of 1 m. Fourteen radiocarbon dates range from a 4000 BP outlier but concentrate between 1500 and 700 BC, with our samples attributed to the *Đông Sơn* period (Ha Van Tan 1991 in Higham 1996: 38 & Figure 4.4). Furnace remains plus twenty crucible fragments and forty-six predominantly sandstone bivalve mould fragments for copper-base axes and fishhooks with a general similarity to Hong Kong assemblages were found at the site (Dung 2015; Higham 2014: 168, 2002: 152-3, 1996: 38, 96). As far as we are aware, these assemblages have not been

analysed technologically but in the absence of significant quantities of reported slag, and applying the general rule of minimalist interpretation, we conclude there was secondary production activity on site, making objects of utilitarian form from raw or recycled metal imported from elsewhere.

### Xuân Lập

Four artefacts labelled 'Xuân Lập' were submitted for analysis, referring to pre-excavation surface collections from a site in the same province as Gò Mun, for which we do not have the exact coordinates. The artefact typology, especially XL/4, a *thap* (a decorated 'bucket') is distinctly attributable to the *Đông Sơn* culture.

## Assemblage

The 28 samples of this study were available for analysis from the Institute of Archaeology, Hanoi, and mainly consisted of fragmentary pieces. This limits the detailed typological analysis possible but we are able to determine a range of ornaments, tools, and weapons. Thus, our selection allows us to evaluate early north Vietnamese metal alloy choice and potentially raw material sourcing from both utilitarian and decorative morphologies (Fig. 3, Table 1).

## Methodology

The studied artefacts were all sampled using an ultra-fine jeweller's saw, taking into account areas of existing damage (preferred) and corrosion (avoided), penetrating to raw metal when possible. The cut samples are in the order of millimetre size and might not be representative of object heterogeneity in terms of poor alloy mixing, segregation during cooling, or any unidentified joints or welds. The cut samples were then halved, for elemental/microstructural and isotopic analyses.

### Optical microscopy (OM)

Cut samples were mounted in epoxy resin and ground using silicon carbide wet-dry paper (800–4000 grit), before final polishing with diamond pastes (3, 1, and 0.25  $\mu\text{m}$ ). The microstructure was then studied by OM (Leica LLM) before (for the corroded samples) and after etching with a ferric chloride solution to reveal the crystalline structures.

### X-ray fluorescence (XRF)

XRF was used for the OM samples' global elemental composition of major, minor, and (some) trace elements, conducted at the *Laboratoire Archéomatériaux et Prédiction de l'Altération* (LAPA-IRAMAT/CEA) in Saclay, France. XRF data were obtained using a NITON XL 3t GOLDD+ portable XRF analyser in 'laboratory mode' (fixed stand) with a max 40-kV accelerating voltage and by using the 'alloys' mode. Certified Reference Materials (CRMs) were used to check accuracy and precision, with good results for major and minor components (Table 2). Eleven different CRMs were used: B10, B12, B31, UZ 52-3, B21, and L 20-1 from the *Centre de Développement des Industries de Mise en Forme des Matériaux*, France, 71.32-4 and 51.13-4 from the Bureau of Analyzed Samples Ltd., England, and SRM 500, C1123, and 1275 from the National Institute for Standards and Technology (NIST). Note that light elements like phosphorus, silicon, aluminium, magnesium, and also sulphur at

low concentrations were not reliably detected due to non-vacuum conditions. The analyses were performed on the mounted and polished sections, as per OM, using a 3-mm beam diameter, which allowed for reliable results as long as the sample was larger than this. Three such spot analyses were made for each sample to account for heterogeneity: corrosion and inclusions. Most of the samples were corroded to some degree.

### Scanning electron microscopy with energy dispersive spectrometry (SEM-EDS)

The OM/XRF samples were then carbon coated for analysis in a JEOL 7001F instrument, in order to establish the global composition of samples too small for pXRF (<3 mm), those with intergranular corrosion, and also to study any inclusions. The SEM-EDS was operated in both secondary electron (SE) and backscattered electron (BSE) modes, using a 20-kV accelerating voltage, a 10-mm working distance with an Oxford Silicon Drift Detector, and processed using Oxford Instruments Aztec software. Detection limit was fixed at 0.5 wt% with a count rate of 4000/s (detection time of 40 s) used for a good resolution of pertinent peaks with respect to background noise. We consider that the relative quantification error ( $2\sigma$ ) is about 10% of the measured value. SEM-EDS accuracy was evaluated using the same mounted and polished CRMs as used for the pXRF analysis, and we obtained good results for the major elements (Table 2). Global composition for each sample was obtained by a mean of three to four area scans (0.4 mm<sup>2</sup>) per sample.

### Multi collector—inductively coupled plasma—mass spectrometre (MC-ICP-MS)

Lead isotope analysis (LIA) was conducted at the *Service d'Analyse des Roches et des Minéraux* of the Centre for Petrographic and Geochemical Research (SARM-CRPG) in Nancy, France, using MC-ICP-MS after lead extraction (Manhes et al. 1980) and using Thallium NIST SRM 997 to correct for instrumental mass bias (Thirlwall 2002). All parameters were adjusted to obtain the closest values relative to NIST SRM 981 as determined by DSTIMS (Thirlwall 2002). More details about the instrumentation and its performance for lead isotope analysis are available in Cloquet et al. (2006) and Pienitz et al. (2015).

As a SEALIP/BROGLASEA<sup>1</sup> analytical programme, LIA was used to look not for 'matches' but rather 'consistency' with known and characterised production systems, in

<sup>1</sup> Southeast Asian Lead Isotope Project 2008–2015, subsequently Bronze and Glass as Cultural Catalysts and Tracers in Early Southeast Asia 2016–2020, projects.



DTR/1



DTR/2



DTR/3



DTR/4



DTR/5



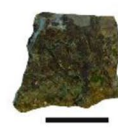
DTR/6



DTR/7



DTR/8



DTR/9



DTR/10



DTR/11



DTR/12



DTR/13



GM/1



GM/2



GM/3



GM/4



TD/1



TD/2



TD/3



TD/4



TD/5



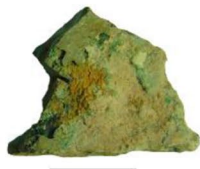
TD/6



XL/1



XL/2



XL/3



XL/4

**Fig. 3** The present study metal assemblage (excluding TD/7, slag); scale bars are 50 mm long

recognition that there could be other, as yet uncharacterised, isotopic compatibility of primary and/or secondary production systems, as well as recycling issues at play (e.g. Budd et al. 1993; Pryce et al. 2014, 2011b; Wilson and Pollard 2001)

## Results

### Technological analysis/optical microscopy

Of the 28 samples, 22 present as-cast structures, as seen by the extant dendrites and round inclusions (Fig. 4 and 5, Table 3). Three samples, a fish hook (DTR/7, Fig. 6), a socketed axe (GM/1, Fig. 7), and a spearhead (GM/2), have a homogenized microstructure with twinned crystals. This shows that the objects have been subjected to a cycle of hammering and annealing, which would be appropriate to their typology and presumed use, indicating some artisanal skill. The same can be said for the quenched microstructure of DTR/1, identified as scraper fragments. The leaded samples (Fig. 8) have lead inclusions, this element being immiscible in solid copper. Some of the bronzes have sufficient tin content to present a blue  $\alpha+\delta$  eutectoid phase, the prevalence of which depends on the cooling rates (Fig. 9).

Many of the samples present intergranular corrosion products, which will have impacted XRF analyses to a lesser or greater extent depending on the degree of corrosion. Three samples (XL/3, DTR/8, and TD/6) are entirely composed of corrosion products, meaning their elemental (Table 3) and lead isotope (Table 4) compositions must be viewed with caution, but their microstructures remain identifiable (Table 3).

DTR/1, a scraper fragment, has a very fine microstructure, suggesting quenching. In combination with its elevated tin content (see the “Elemental analyses – XRF + SEM-EDS” section, Table 3), doubtless exaggerated by corrosion, the resulting object would have been very hard but likely brittle.

### Elemental analyses – XRF + SEM-EDS

The studied assemblage contains just two classes of copper-base alloy, bronze (20) and leaded bronze (7), using 1 wt% as the cut-off for major alloying components and 0.5 wt% as the cut-off for minor contaminants (often evidence of corrosion). The elemental data display a wide range of tin (Fig. 10) and lead (Fig. 11) contents. We are inclined to view the variation as clouded due to the degree of corrosion, as shown by concentrations of iron, aluminium, and silicon, and the general

discrepancy between pXRF global compositional data and SEM-EDS compositional data targeting less corroded areas (Table 3). Therefore, we lack good evidence for multiple sub-categories of bronze ratios or deliberate adaptation of alloy to use—though this may still have been the case—and we cannot make a serious evaluation of standardisation in these circumstances. What is clear, however, is that there is no pure or effectively pure copper and all the leaded alloy samples are Iron Age. We are thus dealing with assemblages that are, at a minimum, alloyed and possibly recycled, rather than raw product coming from the primary production loci. In provenance terms, this means that our LIA data must be discussed with respect to copper networks, as well as lead exchange systems for the seven thus-alloyed samples.

### Lead isotopes

With respect to the study results in isolation, plus an example signature for north Vietnamese copper (Nhon [Lao Cai Province], see Pryce et al. 2014), the isotope ratios have a general coherence but the sites and alloy types (leaded vs unleaded) are mixed rather than forming discrete clusters (Table 4, Fig. 12). The one slag sample, TD/7, does have reasonable compatibility with a number of metal samples but none is consistent with the Nhon slag data. It should be noted there are tens if not hundreds of uncharacterised copper deposits in northern Vietnam (Workman 1977). Three of four leaded Xuân Lập samples group well, and are consistent with a Đông Sơn period (Iron Age) leaded bronze spearhead (DTR/12) and a corroded axe from Dai Trach (DTR/8) but as a reminder that copper (trace lead) and lead signatures can overlap, GM/2 (0.7 wt. % Pb in a corroded matrix) also plots in this area. Three Dai Trach artefacts (DTR/5, 7, and 11) are plot closely near the top-centre of Fig. 12, which could represent a shared primary or secondary copper source. Finally, a potential group consisting exclusively of unleaded alloys (as far as the corroded matrices permit us to evaluate) plots towards the bottom but the level of compatibility is not high and not to be relied upon as indicating shared raw material sources. To make some sense of the study data, we must incorporate existing SEALIP/BROGLASEA datasets for MSEA copper production and Bronze Age consumption (Fig. 13).

Here, we see that our new data are not consistent with any of the known prehistoric MSEA copper production centres in central and northern Thailand and central Laos: the Khao Wong Prachan Valley, Phu Lon, and the Vilabouly Complex, respectively (Cadet et al. 2019; Pryce et al. 2014, 2011a). For the leaded artefacts, all Iron Age, there are no MSEA primary production signatures available for comparison (Pryce 2012). It may appear there is compatibility with central Lao copper production but this area of the complete dataset plot ( $n=1000+$ , not shown here as it would be

**Table 1** Nomenclature and context data for the studied assemblages from Thành Dên, Gò Mun, Dai Trach, and Xuân Lập.

SEALIP#	Site	Context	Culture	Period	Object
SEALIP/VN/DTR/1	Dai Trach	Bac Ninh Province, DT. C5.LII-I:195	Đồng Dầu	1300–1000 BC	Scraper frags
SEALIP/VN/DTR/2	Dai Trach	Bac Ninh Province, DT.B5.L1-4:71	Đồng Dầu	1300–1000 BC	Knife
SEALIP/VN/DTR/3	Dai Trach	Bac Ninh Province, DT.H1.B2.L2-6:112	Đồng Dầu	1300–1000 BC	Drill
SEALIP/VN/DTR/4	Dai Trach	Bac Ninh Province, DT.B2.L1-3:46	Đồng Dầu	1300–1000 BC	Fish hook
SEALIP/VN/DTR/5	Dai Trach	Bac Ninh Province, DT.H1.D2.L1-3:62	Đồng Dầu	1300–1000 BC	Needle
SEALIP/VN/DTR/6	Dai Trach	Bac Ninh Province, DT.B3.L1-3:37	Đồng Dầu	1300–1000 BC	Arrowhead
SEALIP/VN/DTR/7	Dai Trach	Bac Ninh Province, DT.C5.L1-4:84	Đồng Dầu	1300–1000 BC	Fish hook
SEALIP/VN/DTR/8	Dai Trach	Bac Ninh Province, DT.L1-4.F13:7	Đông Sơn	700 BC–AD 100	Pediform axe fragment
SEALIP/VN/DTR/9	Dai Trach	Bac Ninh Province, DT.H1.C5L1-4:194	Đông Sơn	700 BC–AD 100	Knife
SEALIP/VN/DTR/10	Dai Trach	Bac Ninh Province, DT.F13:8	Đông Sơn	700 BC–AD 100	Thap fragment
SEALIP/VN/DTR/11	Dai Trach	Bac Ninh Province, DT.B4.L1-3.F14:1	Đông Sơn	700 BC–AD 100	Spear socket
SEALIP/VN/DTR/12	Dai Trach	Bac Ninh Province, DT.F13:2	Đông Sơn	700 BC–AD 100	Spearhead fragment
SEALIP/VN/DTR/13	Dai Trach	Bac Ninh Province, DT.H1.B2.L1-2:9	Đông Sơn	700 BC–AD 100	Chisel
SEALIP/VN/TD/1	Thành Dên	Vinh Phuc Province, #6	Đồng Dầu	1300–1000 BC	Awl? Ingot?
SEALIP/VN/TD/2	Thành Dên	Vinh Phuc Province, 10.TD.H3.L2.B4:169	Đồng Dầu	1300–1000 BC	Awl? Rod?
SEALIP/VN/TD/3	Thành Dên	Vinh Phuc Province, 10. TD.H3.L2a <sup>2</sup> (15)	Đồng Dầu	1300–1000 BC	Knife
SEALIP/VN/TD/4	Thành Dên	Vinh Phuc Province, 10.TD.H3.L1	Đồng Dầu	1300–1000 BC	Floral decoration?
SEALIP/VN/TD/5	Thành Dên	Vinh Phuc Province, DT.HI.D2.L1-3:62	Đồng Dầu	1300–1000 BC	Awl? Ingot?
SEALIP/VN/TD/6	Thành Dên	Vinh Phuc Province, 10.TD.H3.L1	Đồng Dầu	1300–1000 BC	Awl? Ingot?
SEALIP/VN/TD/7	Thành Dên	Vinh Phuc Province, 10.TD.#8	Đồng Dầu	1300–1000 BC	Slag
SEALIP/VN/GM/1	Gò Mun	Phu To Province, pre-excavation	Gò Mun	1000–700 BC	Socketed axe
SEALIP/VN/GM/2	Gò Mun	Phu To Province, pre-excavation	Gò Mun	1000–700 BC	Spearhead
SEALIP/VN/GM/3	Gò Mun	Phu To Province, pre-excavation	Gò Mun	1000–700 BC	Spearpoint
SEALIP/VN/GM/4	Gò Mun	Phu To Province, pre-excavation	Gò Mun	1000–700 BC	Socketed axe
SEALIP/VN/XL/1	Xuân Lập	Phu To Province, pre-excavation	Đông Sơn	700 BC–AD 100	Vessel handle
SEALIP/VN/XL/2	Xuân Lập	Phu To Province, pre-excavation	Đông Sơn	700 BC–AD 100	Socketed axe
SEALIP/VN/XL/3	Xuân Lập	Phu To Province, pre-excavation	Đông Sơn	700 BC–AD 100	Socketed with wood
SEALIP/VN/XL/4	Xuân Lập	Phu To Province, pre-excavation	Đông Sơn	700 BC–AD 100	Thap fragment

incomprehensible) is densely populated and the SEALIP/BROGLASEA programme has always been extremely conservative about what constitutes a claim for ‘provenance’. The study data do not match available Yunnan copper production signatures, from Guangfentou in Yunnan Province (Zou et al. 2019), and none are known for Lingnan (Guangxi and Guangdong). There is, however, some consistency with a few MSEA Bronze Age artefact signatures from Ban Non Wat (SEALIP/TH/BNW/4 - copper axe, Pryce 2011), Ban Chiang (SEALIP/TH/BC/5 - tanged arrowhead, Pryce 2019), and the sole bronze artefact from the Phu Lon production site (SEALIP/TH/PL/10 - axe, Pryce et al. 2014). As some other Ban Non Wat and Ban Chiang Bronze Age samples do present high consistency with central Thai and central Lao primary copper production, it suggests there is weak network overlap between northeast Thailand and the present study area. Where northern Vietnam Bronze Age copper-base metal signatures currently stand out from the rest of MSEA is by not matching *any* known production centre. We are, at present, limited to saying where the metal

is *not* from, and LIA is a reliable method for making this interpretation.

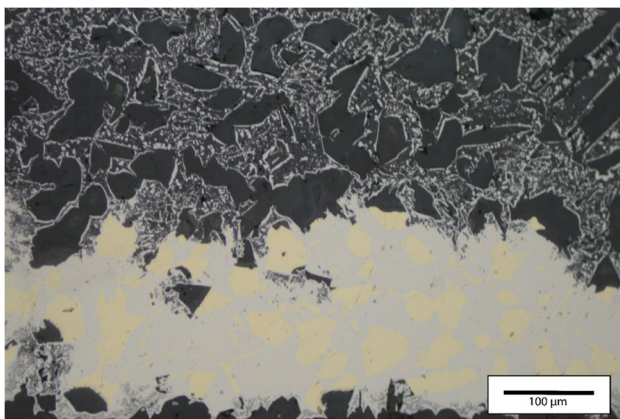
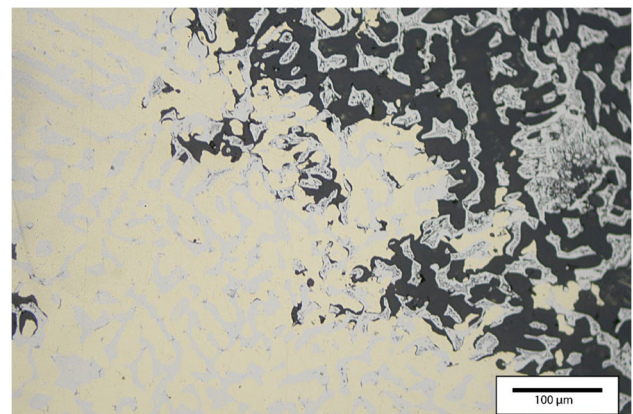
## Discussion and conclusion

Clearly, 28 data points must not be over-stretched in their interpretation, especially given that they represent a large and potentially critical area for understanding early South-east Asian metallurgy (Pryce et al. 2014). Nevertheless, 18 of our samples date to the Bronze Age, a substantial proportion of the analysed contemporary regional examples (ca. 54 at the time of writing), from sites that are far fewer in number and generally have less in the way of metal material culture than their Iron Age counterparts (Pryce 2014). A straightforward reading of our new Bronze Age data for northern Vietnam is that they are not compatible with the known Southeast Asian prehistoric primary copper production signatures, nor is there strong compatibility with those other regional Bronze Age artefacts that are themselves



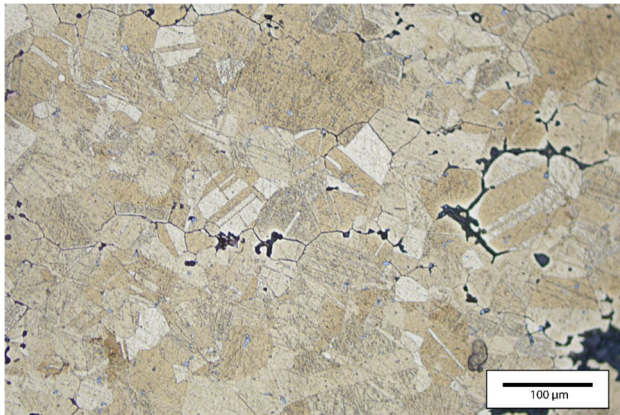
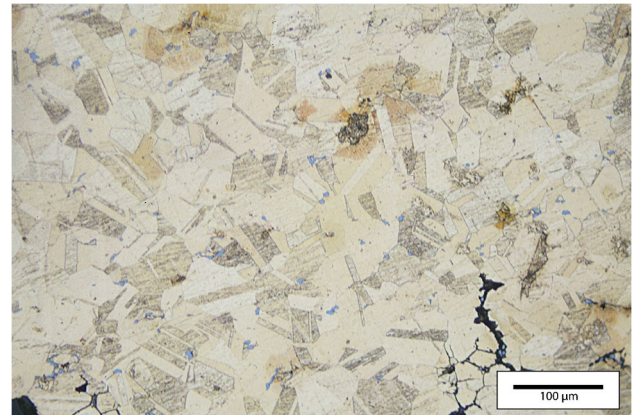
**Table 2** XRF, SEM-EDS, and certified data for study CRMs.

SAMPLE	Sb	Sn	Bi	Pb	Zn	Cu	Ni	Co	Fe	Mn	Al	S
B10 pXRF	1.16	7.18	nd	4.14	2.95	83.17	1.12	nd	0.18	nd	nd	nd
B10 SEM-EDS	1.7	6.6	nd	3.6	3.0	82.7	1.0	nd	nd	nd	nd	nd
B10 certified value	1.14	6.95	0.00	4.07	2.75	83.65	1.01	0.00	0.17	0.00	0.21	0.00
B12 pXRF	0.12	10.06	nd	0.21	0.66	85.22	2.79	nd	0.17	0.24	nd	nd
B12 SEM-EDS	nd	9.5	nd	nd	0.9	84.9	3.1	nd	nd	nd	nd	nd
B12 certified value	0.12	9.57	0.00	0.20	0.61	85.65	2.63	0.00	0.16	0.24	0.13	0.00
51.13-4 pXRF	nd	0.30	nd	0.11	0.4	90.96	nd	nd	1.94	0.92	4.95	nd
51.13-4 SEM-EDS	nd	nd	nd	nd	0.7	87.7	nd	nd	1.9	1.1	7.8	nd
51.13-4 certified value	0.00	0.27	0.00	0.00	0.34	88.79	0.06	0.00	1.81	0.90	7.30	0.00
71.32-4 pXRF	0.25	6.43	nd	4.27	7.07	80.52	0.78	nd	0.43	nd	nd	nd
71.32-4 SEM-EDS	nd	6.4	nd	3.1	7.3	81.8	0.8	nd	0.4	nd	nd	nd
71.32-4 certified value	0.26	6.46	0.05	4.43	6.52	80.48	0.70	0.00	0.35	0.05	0.12	0.00
SRM-500 pXRF	nd	nd	nd	nd	0.13	99.66	0.08	nd	nd	nd	nd	nd
SRM-500 SEM-EDS	nd	nd	nd	nd	0.4	99.4	nd	nd	nd	nd	nd	nd
SRM-500 certified value	0.01	0.00	0.00	0.01	0.01	99.70	0.06	0.00	0.00	0.00	0.00	0.00
C1123 pXRF	nd	nd	nd	nd	nd	97.37	nd	2.49	nd	nd	nd	nd
C1123 SEM-EDS	nd	nd	nd	nd	nd	96.5	nd	3.4	nd	nd	nd	nd
C1123 certified value	0.00	0.01	0.00	0.00	0.01	97.40	0.01	2.30	0.00	0.00	0.02	0.00
SRM1275 pXRF	nd	nd	nd	nd	nd	86.92	10.69	nd	1.63	0.39	nd	nd
SRM1275 SEM-EDS	nd	nd	nd	nd	nd	87.9	10.1	nd	1.5	0.5	nd	nd
SRM1275 certified value	0.00	0.01	0.00	0.01	0.09	88.20	9.76	0.02	1.46	0.42	0.00	0.00
L-20-1 pXRF	nd	0.54	nd	0.30	14.35	84.15	0.25	nd	nd	0.15	nd	nd
L-20-1 SEM-EDS	nd	0.5	nd	nd	14.6	84.0	nd	nd	nd	nd	nd	nd
L-20-1 certified value	0.00	0.49	0.00	0.27	13.33	85.20	0.22	0.00	0.04	0.13	0.07	0.00
B21 pXRF	0.19	5.35	nd	3.75	6.53	82.24	1.35	nd	0.32	nd	nd	nd
B21 SEM-EDS	nd	5.2	nd	3.9	7.0	82.2	1.3	nd	nd	nd	nd	nd
B21 certified value	0.18	5.13	0.00	3.79	6.22	83.00	1.21	0.00	0.29	0.00	0.14	0.05
B31 pXRF	0.52	7.96	nd	10.61	0.84	79.41	0.55	nd	nd	nd	nd	nd
B31 SEM-EDS	1.8	8.0	nd	9.9	1.1	78.6	0.5	nd	nd	nd	nd	nd
B31 certified value	0.48	7.70	0.00	11.79	0.82	78.55	0.49	0.00	0.02	0.00	0.04	0.03
UZ-52-3 pXRF	0.08	0.99	nd	0.10	18.01	80.28	0.10	nd	0.34	nd	nd	nd
UZ-52-3 SEM-EDS	nd	1.0	nd	nd	18.2	80.2	nd	nd	nd	nd	nd	nd
UZ-52-3 certified value	0.08	1.06	0.00	0.11	17.00	81.08	0.08	0.00	0.31	0.00	0.00	0.00

**Fig. 4** Optical plane-polarised light micrograph of DTR/9: as-cast/ $\alpha$  +  $\delta$  eutectoid structure (bottom) and corrosion (top)**Fig. 5** Optical plane-polarised light micrograph of DTR/11: as-cast/ $\alpha$  +  $\delta$  eutectoid structure (left) and corrosion (right)

**Table 3** Elemental data for the studied assemblages from Thành Dên, Gò Mun, Dai Trach, and Xuân Lập. Major alloying components (Sn, Pb, Cu) are highlighted, and those indicative of corrosion and thus interpretative caution are italicised. Detection limit is 0.5 wt%.

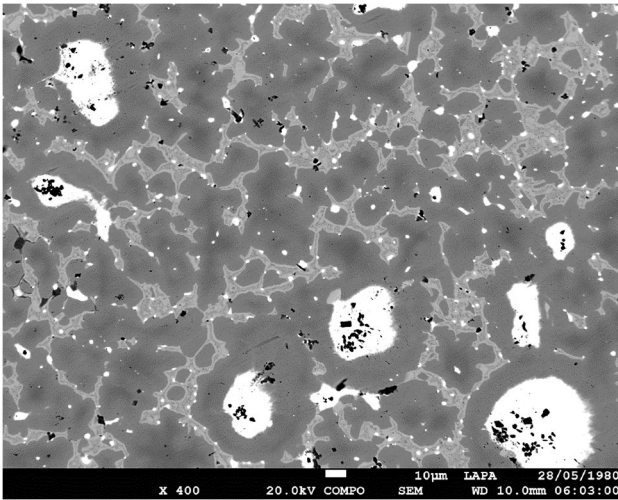
SEALIP#	Sb	Sn	Ag	Bi	Pb	As	Zn	Cu	Ni	Fe	Al	S	P	Si	Analytical total	Analytical technique	Alloy	Microstructure
SEALIP/VN/DTR/1	0.0	31.1	0.0	0.0	0.0	0.0	0.0	68.8	0.0	0.0	0.0	0.0	0.0	0.0	99.9	pXRF	Bronze	Quenched?
SEALIP/VN/DTR/2	0.0	20.0	0.0	0.0	0.0	0.1	0.0	77.2	0.0	0.1	0.0	0.0	2.0	0.5	99.9	pXRF	Bronze	As cast
SEALIP/VN/DTR/3	0.0	33.4	0.0	0.0	0.0	0.1	0.0	60.9	0.0	1.9	0.0	0.0	2.5	1.0	99.9	pXRF	Bronze	As cast/ $\alpha + \delta$ eutectoid
SEALIP/VN/DTR/4	0.0	11.3	0.0	0.0	0.0	0.1	0.0	88.1	0.0	0.0	0.0	0.4	0.0	0.0	99.9	pXRF	Bronze	As cast/ $\alpha + \delta$ eutectoid
SEALIP/VN/DTR/5	0.0	18.4	0.0	0.0	0.2	0.0	0.0	79.7	0.0	0.0	0.0	0.0	0.7	0.8	99.9	pXRF	Bronze	As cast/ $\alpha + \delta$ eutectoid
SEALIP/VN/DTR/6	0.0	23.9	0.0	0.0	0.0	0.0	0.0	64.7	0.0	0.5	0.0	0.0	8.5	2.5	100.0	pXRF	Bronze	As cast
SEALIP/VN/DTR/7	0.0	23.9	0.0	0.0	0.4	0.0	0.0	72.0	0.0	0.1	0.0	0.0	2.8	0.7	99.8	pXRF	Bronze	Annealed-Hammered
SEALIP/VN/DTR/8	nd	30.9	nd	nd	13.0	0.5	nd	25.4	nd	0.5	nd	nd	1.5	1.2	73.0	SEM-EDS	Leaded bronze	Highly corroded
SEALIP/VN/DTR/9	0.0	52.1	0.0	0.0	0.0	0.1	0.1	44.2	0.0	0.3	0.0	0.0	2.2	0.9	99.9	pXRF	Bronze	As cast / $\alpha + \delta$ eutectoid
SEALIP/VN/DTR/10	0.2	17.9	0.0	0.0	23.3	0.0	0.1	56.6	0.0	1.0	0.8	0.0	0.0	0.0	99.9	pXRF	Leaded bronze	As cast / $\alpha + \delta$ eutectoid
SEALIP/VN/DTR/11	0.0	29.2	0.0	0.0	0.1	0.0	0.1	68.4	0.0	0.3	0.0	0.0	0.8	0.9	99.9	pXRF	Bronze	As cast / $\alpha + \delta$ eutectoid
SEALIP/VN/DTR/12	0.0	18.1	0.0	0.0	16.5	0.0	0.0	64.3	0.0	0.4	0.0	0.0	0.0	0.7	100.0	pXRF	Leaded bronze	As cast / $\alpha + \delta$ eutectoid
SEALIP/VN/DTR/13	0.0	19.3	0.0	0.0	0.0	0.0	0.0	79.6	0.0	0.2	0.0	0.3	0.0	0.4	99.9	pXRF	Bronze	As cast?
SEALIP/VN/TD/1	0.0	22.6	0.0	0.0	0.0	0.1	0.0	75.1	0.0	0.1	0.0	0.0	1.4	0.7	99.9	pXRF	Bronze	As cast
SEALIP/VN/TD/2	0.0	31.2	0.0	0.0	0.0	0.1	0.1	66.5	0.0	0.0	0.0	0.1	1.2	0.6	99.8	pXRF	Bronze	As cast
SEALIP/VN/TD/3	0.0	23.4	0.0	0.0	0.0	0.1	0.1	74.6	0.0	0.0	0.0	0.1	0.7	0.8	99.8	pXRF	Bronze	As cast/ $\alpha + \delta$ eutectoid
SEALIP/VN/TD/4	0.0	34.0	0.0	0.0	0.0	0.1	0.0	62.7	0.0	0.2	0.0	0.0	1.4	1.6	100.0	pXRF	Bronze	As cast/ $\alpha + \delta$ eutectoid
SEALIP/VN/TD/5	0.0	11.6	0.0	0.0	0.0	0.0	0.0	86.9	0.0	0.0	0.0	0.3	0.7	0.3	99.9	pXRF	Bronze	As cast
SEALIP/VN/TD/6	0.0	29.6	0.0	0.3	0.1	0.2	0.2	55.5	0.0	1.0	1.5	0.0	2.5	5.3	95.9	pXRF	Bronze	As cast
SEALIP/VN/TD/7	slag sample, no elemental data																	
SEALIP/VN/GM/1	0.0	15.4	0.0	0.0	0.0	0.2	0.0	82.5	0.0	0.7	0.0	0.2	0.4	0.6	100.0	pXRF	Bronze	Annealed-Hammered
SEALIP/VN/GM/2	0	12.0	0.0	0.0	0.7	0.0	0.0	87.1	0.0	0.0	0.0	0.0	0.0	0.0	99.9	pXRF	Bronze	Annealed-Hammered
SEALIP/VN/GM/3	0.0	7.7	0.0	0.0	0.4	0.2	0.0	91.6	0.0	0.1	0.0	0.0	0.0	0.0	100.0	pXRF	Bronze	As cast / $\alpha + \delta$ eutectoid
SEALIP/VN/GM/4	0.0	17.6	0.0	0.0	0.7	0.0	0.0	81.4	0.0	0.1	0.0	0.0	0.0	0.0	99.7	pXRF	Bronze	As cast
SEALIP/VN/XL/1	0.0	8.4	0.0	0.0	15.0	0.0	0.0	76.5	0.0	0.0	0.0	0.0	0.0	0.0	99.8	pXRF	Leaded bronze	As cast/ $\alpha + \delta$ eutectoid
SEALIP/VN/XL/2	0.0	10.8	0.0	0.0	10.7	0.0	0.0	78.4	0.0	0.0	0.0	0.0	0.0	0.0	99.9	pXRF	Leaded bronze	As cast/ $\alpha + \delta$ eutectoid
SEALIP/VN/XL/3	0.1	27.2	0.0	0.0	33.4	0.0	0.0	35.8	0.0	0.8	2.3	0.0	0.0	0.3	99.9	pXRF	Leaded bronze	As cast?
SEALIP/VN/XL/4	0.0	8.8	0.0	0.2	29.2	0.0	0.0	60.1	0.1	0.2	1.4	0.0	0.0	0.0	99.9	pXRF	Leaded bronze	As cast/ $\alpha + \delta$ eutectoid

**Fig. 6** Optical plane-polarised light micrograph of DTR/7: homogenised and annealed microstructure with intergranular corrosion**Fig. 7** Optical plane-polarised light micrograph of GM/1: homogenised and annealed microstructure with intergranular corrosion

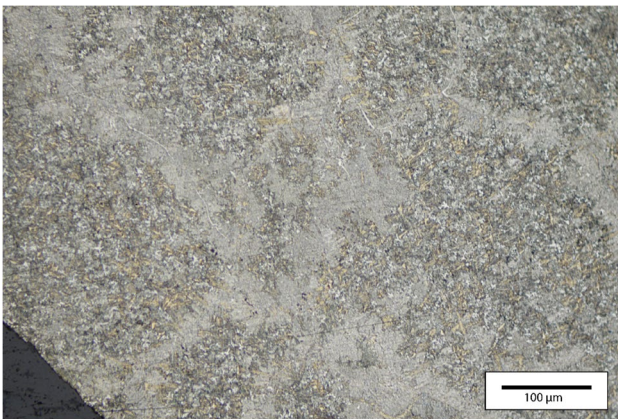
not compatible with the known sources—i.e. there are no evident unknown source signatures. This minimalist reading of the available metallurgical data would suggest social networks between northern Vietnam and the rest of Mainland Southeast Asia operated at a lower rather than greater intensity, despite the apparent passage of Neolithic-behaving populations ca. 1000 years earlier (e.g. Higham et al. 2011a). More specifically, we do not see metallurgical evidence supporting interaction intensity between Bronze Age northern Vietnam and those areas for which we have complementary

data, namely central and northeast Thailand, central Laos, and north-central Myanmar.

We remain at an intermediate stage of regional archaeo-metallurgical research but these findings are consistent with previous studies, in that there seems to be a major lacuna in Bronze Age evidence from northern Laos, which is obviously the critical zone for directly linking the two major areas under discussion (Myanmar lying at a considerable distance to the west). Pryce et al. (2014: 292) previously noted this tendency for what might be termed a ca. 450 geodesic



**Fig. 8** BSE image showing as-cast (mid-grey and grey) microstructure to DTR/10, a leaded-bronze thap (bucket), with prills of immiscible lead (bright white) and intergranular tin-rich phase (light grey)



**Fig. 9** Optical plane-polarised light micrograph of DTR/1: homogenised and annealed microstructure with intergranular corrosion, fragments of a scraper

kilometre ‘north Laotian data gap’, if one accepts, as do we, the prevalent hypothesis that early Mainland Southeast Asian metallurgy was proximally derived from technologies practiced in southern China (Higham 1996; Higham et al. 2015; Pryce et al. 2010; White 1988). The lead author’s subsequent suggestion (Pryce 2018; Pryce et al. 2018b) that the late 2nd millennium BC technological transmission may have been littoral via the Gulf of Tonkin and thus avoiding northern Laos, was only intended as a possible nuanced variation on the general north-to-south theme. Potential evidence to the contrary was noted at the site of Tam Pà Ping in Laos’ northern Houaphan province, only 60 km from the

Vietnamese border, where a single bronze axe was found in a burial radiocarbon—dated to the 11th/10th c. BC (Pryce and Cadet 2018). At the time, Pryce (2018), Pryce et al. (2018b) proposed that Tam Pà Ping should perhaps be seen as an outlying northern Vietnamese Bronze Age culture site rather than a ‘Lao’ one. However, subsequent (unpublished) elemental and lead isotopic analyses have shown that the axe had an unusual antimony-rich composition that does not match this study’s or previous results, but its lead isotope ratios were highly consistent with the Vilabouly Complex copper production signature, located another ca. 450 km to the southeast (Fig. 1). Tam Pà Ping remains something of an enigma but it does support the idea of northern Vietnamese metallurgy being separate from the rest of Bronze Age MSEA. A final piece of pertinent information comes from the Plain of Jars, ca. 70 km south of Tam Pà Ping in Xiangkhouang province. This ‘megalithic jar culture’ was long thought to be Iron Age due to assemblages including iron, glass, and carnelian beads (all regional post-500 BC type markers) in addition to copper-base ornaments. However, recent excavations have radiocarbon dated local burials to the late 1st and early 2nd millennium AD (O’Reilly et al. 2019), whilst optically stimulated luminescence sediment dates suggest the stone jars were positioned from 1240 BC to 660 BC (Shewan et al. 2021), which corresponds to the MSEA Bronze Age. However, there is no evidence to suggest prehistoric copper production activity in the area, despite extensive local copper deposits, and no clear occupation by a metal-using population—metallurgy not being adopted across MSEA at the same time, or even at all. Thus, for the time being, evidence of a northern Lao Bronze Age remains thin indeed.

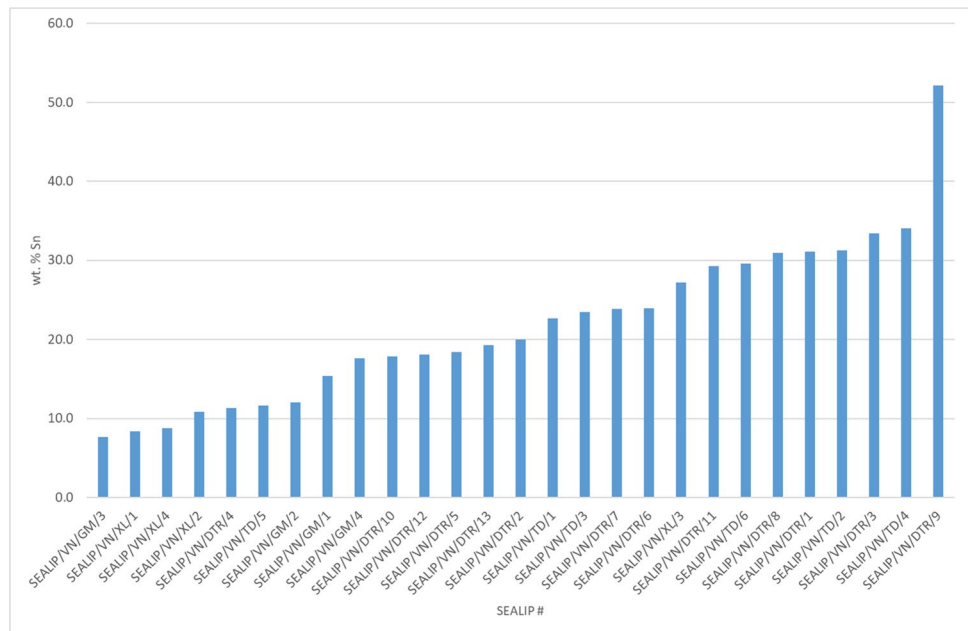
For our Iron Age north Vietnamese samples, seven out of ten are leaded bronze; there is as yet no means to provenance to a regional lead source, as no such production site has been excavated and studied (Pryce 2012). The present study’s lead signatures are broadly consistent with those of other Iron Age MSEA leaded samples (Pryce et al. 2014), and in particular those recently analysed from the actual Đông Sơn site (Le Meur et al. 2021). This patterning suggests a common source or sources of lead used in Iron Age northern Vietnam, though there are outliers.

On the balance of probabilities, we consider it likely the present study’s samples were made from copper, tin, and lead probably produced in northern Vietnam itself (for copper and lead) or in the southern Chinese provinces of Yunnan, Guangxi, and/or Guangdong. The evidence suggests networks connecting the study area to northeast Thailand were present but weak. Much archaeometallurgical exploration is required in northern Vietnam, where the confluence of copper/

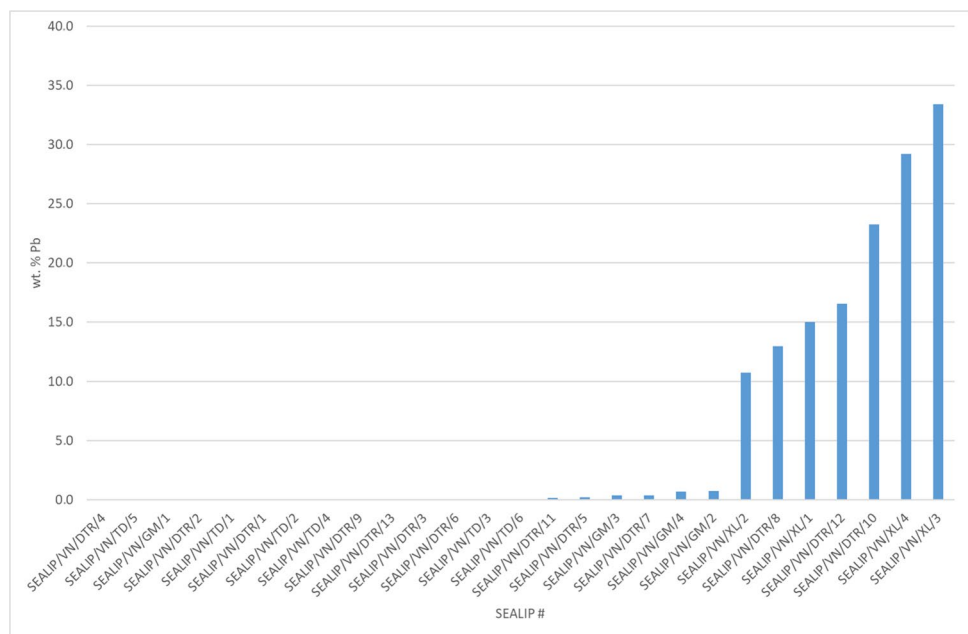
**Table 4** Raw lead isotope data and error margins for the study samples.

SEALIP#	$^{206}\text{Pb}/^{204}\text{Pb}$	err ( $2\sigma$ )	$^{207}\text{Pb}/^{204}\text{Pb}$	err ( $2\sigma$ )	$^{208}\text{Pb}/^{204}\text{Pb}$	err ( $2\sigma$ )	$^{207}\text{Pb}/^{206}\text{Pb}$	err ( $2\sigma$ )	$^{206}\text{Pb}/^{207}\text{Pb}$	err ( $2\sigma$ )	$^{208}\text{Pb}/^{206}\text{Pb}$	err ( $2\sigma$ )
SEALIP/VN/DTR/1	18.656 ± 0.002		15.646 ± 0.002		38.824 ± 0.005		0.83896 ± 0.00002		1.19195 ± 0.00002		2.08103 ± 0.00009	
SEALIP/VN/DTR/2	18.724 ± 0.001		15.738 ± 0.002		39.180 ± 0.005		0.84061 ± 0.00002		1.18961 ± 0.00002		2.09257 ± 0.00012	
SEALIP/VN/DTR/3	18.594 ± 0.002		15.634 ± 0.002		38.857 ± 0.006		0.84100 ± 0.00002		1.18906 ± 0.00002		2.08980 ± 0.00012	
SEALIP/VN/DTR/4	18.581 ± 0.002		15.616 ± 0.001		38.832 ± 0.004		0.84030 ± 0.00002		1.19005 ± 0.00002		2.08985 ± 0.00008	
SEALIP/VN/DTR/5	18.821 ± 0.001		15.776 ± 0.001		39.387 ± 0.004		0.83805 ± 0.00001		1.19325 ± 0.00001		2.09274 ± 0.00010	
SEALIP/VN/DTR/6	18.610 ± 0.001		15.676 ± 0.001		38.905 ± 0.003		0.84279 ± 0.00002		1.18653 ± 0.00002		2.09048 ± 0.00008	
SEALIP/VN/DTR/7	18.818 ± 0.003		15.776 ± 0.002		39.388 ± 0.006		0.83812 ± 0.00002		1.19315 ± 0.00002		2.09314 ± 0.00011	
SEALIP/VN/DTR/8	18.608 ± 0.001		15.739 ± 0.001		39.015 ± 0.003		0.84563 ± 0.00002		1.18255 ± 0.00002		2.09678 ± 0.00009	
SEALIP/VN/DTR/9	18.594 ± 0.005		15.655 ± 0.005		38.889 ± 0.011		0.89404 ± 0.00002		1.11852 ± 0.00002		2.16743 ± 0.00014	
SEALIP/VN/DTR/10	18.289 ± 0.003		15.715 ± 0.003		38.713 ± 0.007		0.85932 ± 0.00002		1.16371 ± 0.00002		2.11684 ± 0.00013	
SEALIP/VN/DTR/11	18.817 ± 0.002		15.769 ± 0.002		39.360 ± 0.006		0.83808 ± 0.00001		1.19320 ± 0.00001		2.09185 ± 0.00010	
SEALIP/VN/DTR/12	18.607 ± 0.001		15.736 ± 0.002		39.005 ± 0.005		0.84584 ± 0.00001		1.18226 ± 0.00001		2.09638 ± 0.00016	
SEALIP/VN/DTR/13	18.752 ± 0.003		15.721 ± 0.003		39.115 ± 0.009		0.83846 ± 0.00002		1.19266 ± 0.00002		2.08601 ± 0.00021	
SEALIP/VN/TD/1	18.618 ± 0.002		15.629 ± 0.002		38.784 ± 0.009		0.83940 ± 0.00010		1.19133 ± 0.00012		2.08304 ± 0.00024	
SEALIP/VN/TD/2	18.643 ± 0.001		15.656 ± 0.002		38.879 ± 0.005		0.84020 ± 0.00001		1.19019 ± 0.00001		2.08546 ± 0.00014	
SEALIP/VN/TD/3	18.624 ± 0.002		15.717 ± 0.002		39.020 ± 0.005		0.84403 ± 0.00003		1.18479 ± 0.00003		2.09515 ± 0.00013	
SEALIP/VN/TD/4	18.701 ± 0.001		15.640 ± 0.001		38.950 ± 0.004		0.83656 ± 0.00002		1.19537 ± 0.00002		2.08276 ± 0.00012	
SEALIP/VN/TD/5	18.592 ± 0.001		15.616 ± 0.001		38.819 ± 0.004		0.84011 ± 0.00002		1.19032 ± 0.00002		2.08806 ± 0.00009	
SEALIP/VN/TD/6	18.554 ± 0.002		15.719 ± 0.002		38.913 ± 0.005		0.84709 ± 0.00002		1.18051 ± 0.00002		2.09726 ± 0.00014	
SEALIP/VN/TD/7	18.601 ± 0.001		15.602 ± 0.001		38.829 ± 0.004		0.83923 ± 0.00003		1.19157 ± 0.00003		2.08747 ± 0.00007	
SEALIP/VN/GM/1	18.571 ± 0.002		15.624 ± 0.002		38.794 ± 0.009		0.84126 ± 0.00010		1.18869 ± 0.00012		2.08899 ± 0.00024	
SEALIP/VN/GM/2	18.646 ± 0.002		15.737 ± 0.002		39.041 ± 0.009		0.84404 ± 0.00010		1.18478 ± 0.00012		2.09383 ± 0.00024	
SEALIP/VN/GM/3	18.485 ± 0.002		15.752 ± 0.002		38.858 ± 0.006		0.85201 ± 0.00001		1.17369 ± 0.00001		2.10229 ± 0.00014	
SEALIP/VN/GM/4	18.543 ± 0.001		15.728 ± 0.002		38.913 ± 0.005		0.84815 ± 0.00001		1.17904 ± 0.00001		2.09861 ± 0.00012	
SEALIP/VN/XL/1	18.565 ± 0.002		15.741 ± 0.001		38.967 ± 0.004		0.84773 ± 0.00003		1.17962 ± 0.00003		2.09896 ± 0.00011	
SEALIP/VN/XL/2	18.601 ± 0.001		15.738 ± 0.001		38.996 ± 0.004		0.84603 ± 0.00002		1.18200 ± 0.00002		2.09652 ± 0.00010	
SEALIP/VN/XL/3	18.606 ± 0.002		15.746 ± 0.002		38.996 ± 0.006		0.84615 ± 0.00002		1.18182 ± 0.00002		2.09588 ± 0.00014	
SEALIP/VN/XL/4	18.441 ± 0.001		15.701 ± 0.001		38.970 ± 0.005		0.85134 ± 0.00001		1.17462 ± 0.00001		2.11336 ± 0.00012	

**Fig. 10** Variance in tin composition, probably dependent on corrosion condition rather than reflecting deliberate alloying choices



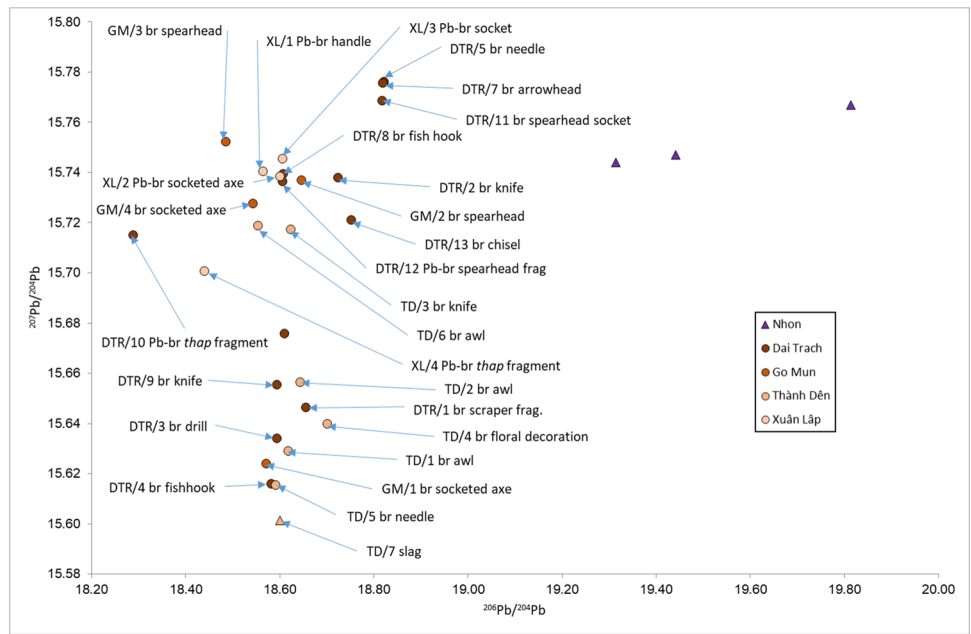
**Fig. 11** Lead content, with no doubt some corrosion influence but certainly a chronological difference as Iron Age artefacts are preferentially leaded alloys



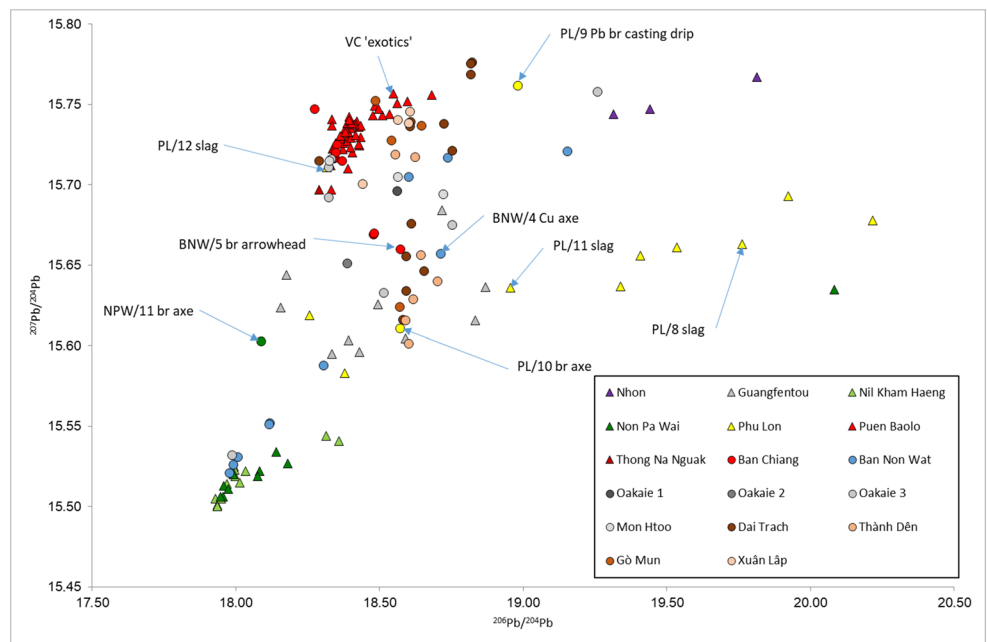
bronze-rich archaeological assemblages and extensive metallogenic deposits makes the complete absence of local prehistoric production unlikely. However, for the earliest metals, we note the dominating presence of the Red River leading straight into Yunnan, and the geographically arbitrary border with Guangxi. Whilst none of the currently known signatures match, we hope

ongoing work by BROGLASEA and other teams in the Dali, Kunming, and neighbouring areas will provide us with important new understanding of trans-regional metal production and consumption networks in the short to medium term, with all the precious information for human exchange and interaction such evidence would provide.

**Fig. 12** LI ratios seen for the study assemblages and Nhon copper slag samples (data from Pryce et al. 2014); error bars are smaller than symbols



**Fig. 13** Study and published SEALIP/BROGLASEA data for MSEA copper production and Bronze Age consumption. Nil Kham Haeng/Non Pa Wai represent central Thai production, Phu Lon northern Thai production, and Thong Na Nguak/Puen Baolo central Lao production. Production site artefacts/imports/exotics are marked; error bars are smaller than symbols



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**Declarations**

**Competing interests** The authors declare no competing interests. All samples were exported from Vietnam with the express permission of the relevant authorities.

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