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# 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 Đồng 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, a rarity 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.

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**Keywords (separated by '-')** Vietnam - Bronze Age - Southeast Asia - Copper-base metal - Microstructure - Elemental composition - Lead isotopes

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**Footnote Information**

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

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

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

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27  
28 The ‘origin’, or more likely origins, of the Mainland South-  
29 east Asian (MSEA) Bronze Age has been a topic provok-  
30 ing significant global interest for over half a century (e.g.  
31 Higham et al. 2019; Pryce et al. 2018a). This was largely  
32 due to unexpected dates published in the 1960s and 1970s  
33 for 4th millennium BC copper metallurgy at the northeastern  
34 Thai sites of Non Nok Tha (Solheim 1968) and Ban Chiang  
35 (Gorman and Charoenwongsa 1976), during the very early  
36 days of regional scientific archaeology and associated dating  
37 techniques (radiocarbon and thermoluminescence). These  
38 dates were then among the earliest in the world, implying  
39 MSEA might have been an independent centre of invention  
40 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 overthrown 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 2018a, b; 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 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 2018a, b). 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 radiometrically dated 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 Nguyễn 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 Nguyễn culture’s status as a part-Bronze Age rather than entirely Neolithic period is somewhat disputed, and in any event we were unable to access samples from Phùng Nguyễn 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 Dâu culture site. The Đông Dâu 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 Nguyễn 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

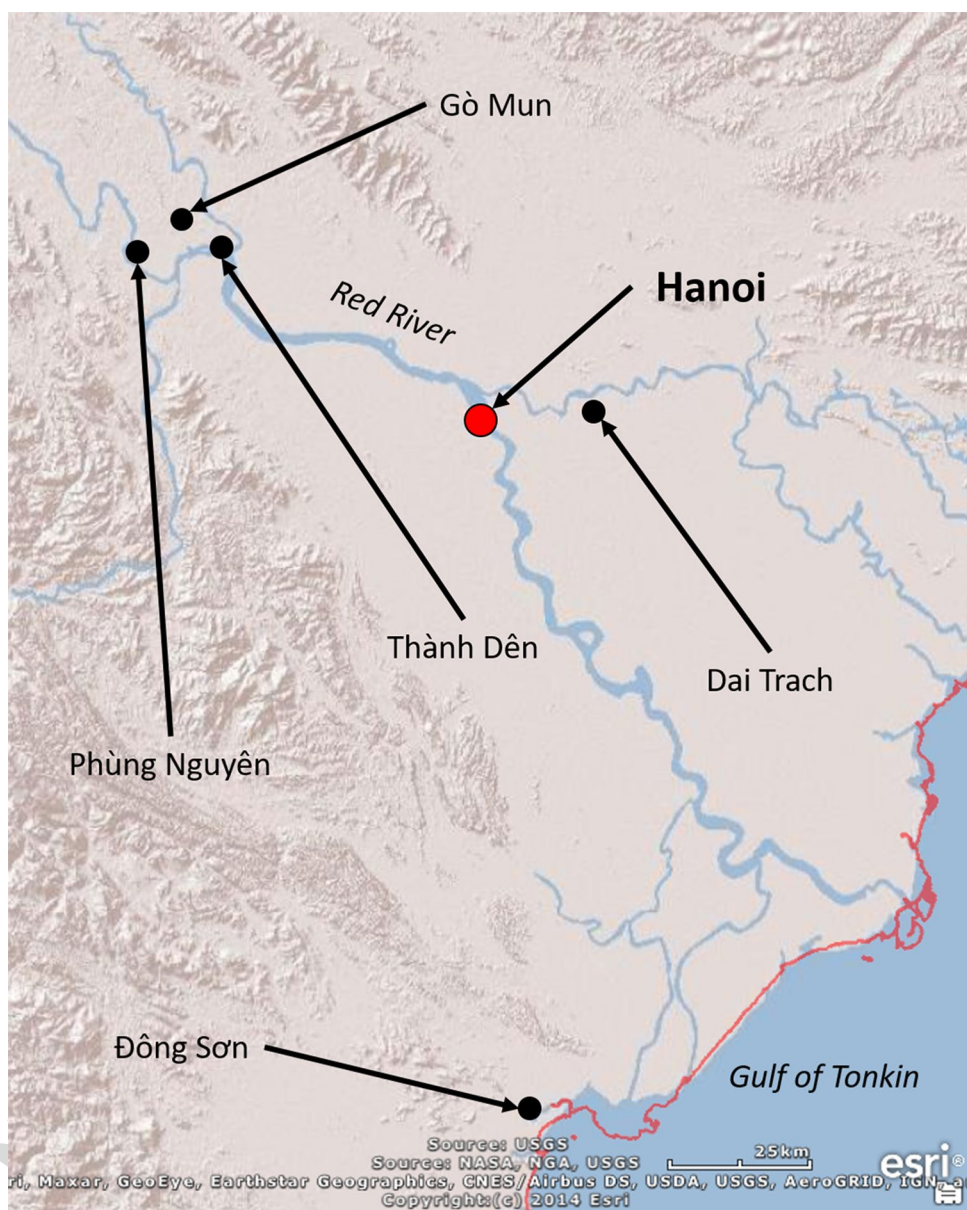
144 **Gò Mun**

145 On the southern bank of the Red River, 105.359245°E,  
 146 21.339359°N, Gò Mun (Phú Thọ Province) was exca-  
 147 vated in four seasons between 1961 and 1971, with 1500  
 148 m<sup>2</sup> exposed. Only one radiocarbon date is available (Bl-  
 149 1278, Higham 1996, Figure 4.4), which places the site  
 150 and its eponymous culture as a successor to the Đổng  
 A22 Dầu period (Higham 2014: 169; Phung 1993). In terms

of metallurgy, bronze skeumorphs of stone typologies  
 were present but fishhooks were the most abundant cat-  
 egory, followed by projectile points, 13 axes and 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 applica-  
 tions. Bivalve moulds for axes and arrowheads again  
 indicate onsite secondary production (Higham 2002:  
 152, Figure 4.15).

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



161 **Thành Dên**

162 Located at 105.425663°E, 21.295944°N, near the eastern  
 163 bank of the Red River, Thành Dên (Vĩnh Phúc Province) was  
 164 excavated in three seasons between 1983 and 1986, exposing  
 165 145 m<sup>2</sup> to a relatively shallow depth of 1 m. Fourteen radio-  
 166 carbon dates range from a 4000 BP outlier but concentrate  
 167 between 1500 and 700 BC, with our samples attributed to  
 168 the Đồng Đậu period (Ha Van Tan 1991 in Higham 1996:  
 169 38 & Figure 4.4). Furnace remains plus twenty crucible  
 170 fragments and forty-six predominantly sandstone bivalve  
 171 mould fragments for copper-base axes and fishhooks with a  
 172 general similarity to Hong Kong assemblages (Dung 2015;  
 173 Higham 2014: 168, 2002: 152-3, 1996: 38, 96). As far as  
 174 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 analy-  
 sis, 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.



## 187 **Assemblage**

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

## 196 **Methodology**

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

## 206 **Optical microscopy (OM)**

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

## 213 **X-ray fluorescence (XRF)**

214 XRF was used for the OM samples' global elemental com-  
215 position of major, minor, and (some) trace elements, con-  
216 ducted at the *Laboratoire Archéomatériaux et Préviation de*  
217 *l'Altération* (LAPA-IRAMAT/CEA) in Saclay, France. XRF  
218 data were obtained using a NITON XL 3t GOLDD+ port-  
219 able XRF analyser in 'laboratory mode' (fixed stand) with  
220 a max 40-kV accelerating voltage and by using the 'alloys'  
221 mode. Certified Reference Materials (CRMs) were used to  
222 check accuracy and precision, with good results for major  
223 and minor components (Table 2). Eleven different CRMs  
224 were used: B10, B12, B31, UZ 52-3, B21, and L 20-1 from  
225 the *Centre de Développement des Industries de Mise en Forme*  
226 *des Matériaux*, France, 71.32-4 and 51.13-4 from the Bureau  
227 of Analyzed Samples Ltd., England, and SRM 500, C1123,  
228 and 1275 from the National Institute for Standards and  
229 Technology (NIST). Note that light elements like phospho-  
230 rous, 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 analy-  
sis 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 second-  
ary electron (SE) and backscattered electron (BSE) modes,  
using a 20-kV accelerating voltage, a 10-mm working dis-  
tance 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 rela-  
tive 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 analy-  
sis, 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 rela-  
tive to NIST SRM 981 as determined by DSTIMS (Thirlwall  
2002). More details about the instrumentation and its per-  
formance 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 'consist-  
ency' 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



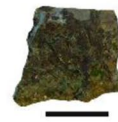
DTR/6



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



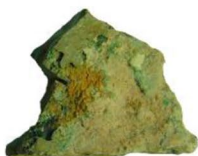
TD/6



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

275 recognition that there could be other, as yet uncharacterised,  
276 isotopic compatibility of primary and/or secondary produc-  
277 tion systems, as well as recycling issues at play (e.g. Budd  
278 et al. 1993; Pryce et al. 2014, 2011b; Wilson and Pollard  
279 2001)

## 280 Results

### 281 Technological analysis/optical microscopy

282 Of the 28 samples, 22 present as-cast structures, as seen  
283 by the extant dendrites and round inclusions (Fig. 4 and  
284 5, Table 3). Three samples, a fish hook (DTR/7, Fig. 6), a  
285 socketed axe (GM/1, Fig. 7), and a spearhead (GM/2), have  
286 a homogenized microstructure with twinned crystals. This  
287 shows that the objects have been subjected to a cycle of ham-  
288 mering and annealing, which would be appropriate to their  
289 typology and presumed use, indicating some artisanal skill.  
290 The same can be said for the quenched microstructure of  
291 DTR/1, identified as scraper fragments. The leaded samples  
292 (Fig. 8) have lead inclusions, this element being immiscible  
293 in solid copper. Some of the bronzes have sufficient tin con-  
294 tent to present a blue  $\alpha+\delta$  eutectoid phase, the prevalence of  
295 **A33** which depends on the cooling rates (Fig. 9).

296 Many of the samples present intergranular corrosion  
297 products, which will have impacted XRF analyses to a  
298 lesser or greater extent depending on the degree of corro-  
299 sion. Three samples (XL/3, DTR/8, and TD/6) are entirely  
300 composed of corrosion products, meaning their elemental  
301 (Table 3) and lead isotope (Table 4) compositions must be  
302 viewed with caution, but their microstructures remain iden-  
303 tifiable (Table 3).

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

### 310 Elemental analyses – XRF + SEM-EDS

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

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

### 333 Lead isotopes

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

360 Here, we see that our new data are not consistent with  
361 any of the known prehistoric MSEA copper production cen-  
362 tres in central and northern Thailand and central Laos: the  
363 Khao Wong Prachan Valley, Phu Lon, and the Vilabouly  
364 Complex, respectively (Cadet et al. 2019; Pryce et al. 2014,  
365 2011a). For the leaded artefacts, all Iron Age, there are no  
366 MSEA primary production signatures available for compar-  
367 ison (Pryce 2012). It may appear there is compatibility  
368 with central Lao copper production but this area of the com-  
369 plete 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

370 incomprehensible) is densely populated and the SEALIP/  
 371 BROGLASEA programme has always been extremely con-  
 372 servative about what constitutes a claim for ‘provenance’.  
 373 The study data do not match available Yunnan copper pro-  
 374 duction signatures, from Guangfentou in Yunnan Province  
 375 (Zou et al. 2019), and none was to be found for Lingnan  
 376 (Guangxi and Guangdong). There is, however, some consist-  
 377 ency with a few MSEA Bronze Age artefact signatures from  
 378 Ban Non Wat (SEALIP/TH/BNW/4 - copper axe, Pryce  
 379 2011), Ban Chiang (SEALIP/TH/BC/5 - tanged arrowhead,  
 380 Pryce 2019), and the sole bronze artefact from the Phu Lon  
 381 production site (SEALIP/TH/PL/10 - axe, Pryce et al. 2014).  
 382 As some other Ban Non Wat and Ban Chiang Bronze Age  
 383 samples do present high consistency with central Thai and  
 384 central Lao primary copper production, it suggests there is  
 385 weak network overlap between northeast Thailand and the  
 386 present study area. Where northern Vietnam Bronze Age  
 387 copper-base metal signatures currently stand out from the  
 388 rest of MSEA is by not matching *any* known production  
 389 centre. We are, at present, limited to saying where the metal

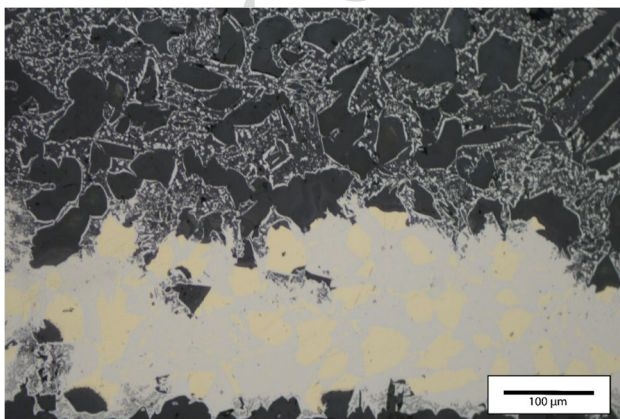
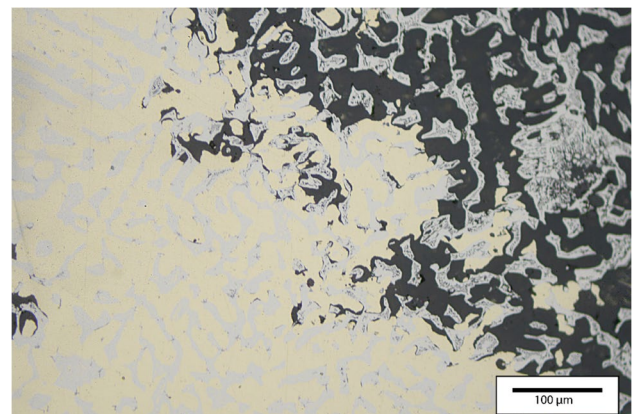
is *not* coming from, and LIA is a reliable method for making  
 this interpretation.

### 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 propor-  
 tion 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 mate-  
 rial 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 produc-  
 tion signatures, nor is there strong compatibility with those  
 other regional Bronze Age artefacts that are themselves not

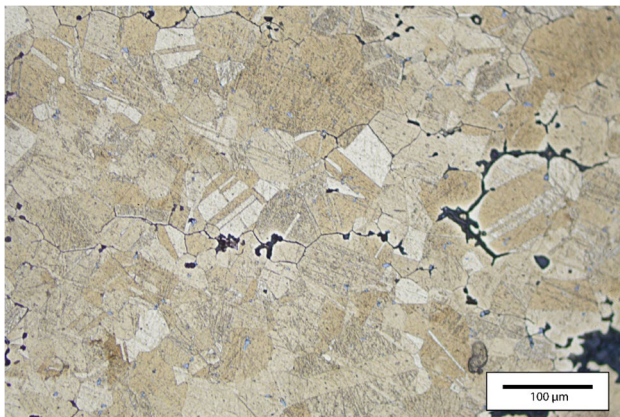
**Table 2** XRF, SEM-EDS, and certified data for study CRMs.

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

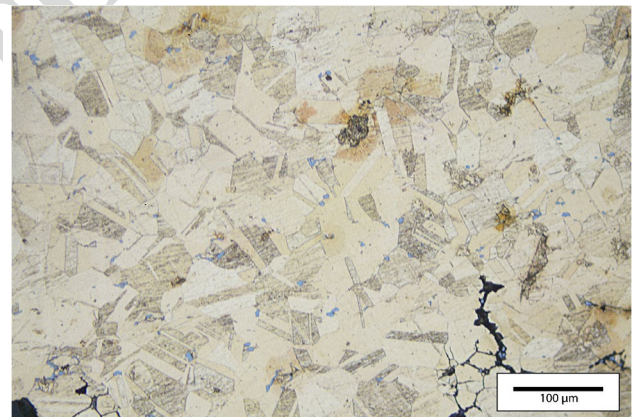
**Fig. 4** Optical plane-polarised light micrograph of DTR/9: as-cast/ $\alpha$  +  $\delta$  eutectoid structure (bottom) and corrosion (top)**Fig. 5** Optical plane-polarised light micrograph of DTR/11: as-cast/ $\alpha$  +  $\delta$  eutectoid structure (left) and corrosion (right)

**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

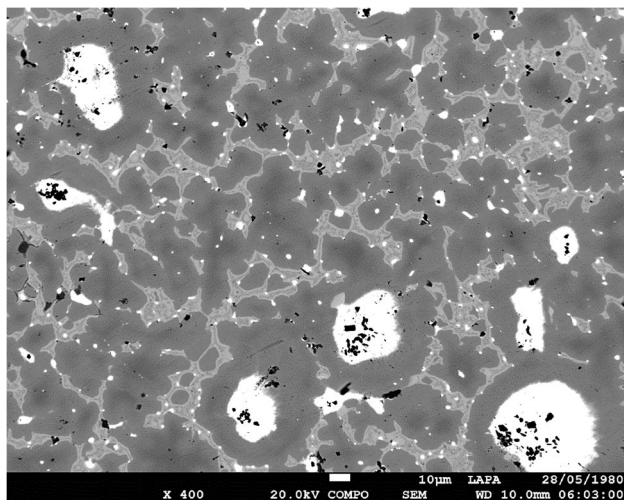


**Fig. 7** Optical plane-polarised light micrograph of GM/1: homogenised and annealed microstructure with intergranular corrosion

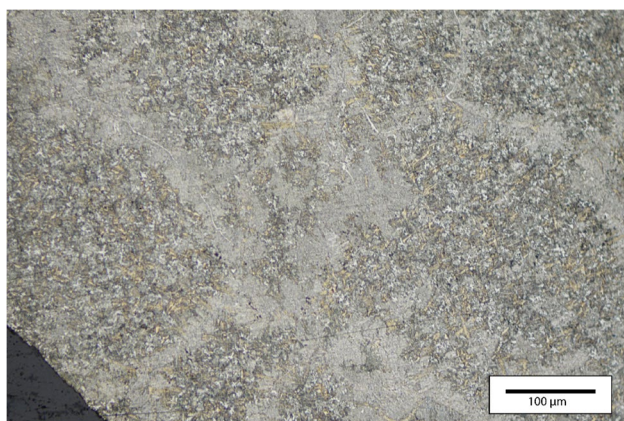
407 compatible with the known sources—i.e. there are no evi- 417  
 408 dent unknown source signatures. This minimalist reading 418  
 409 of the available metallurgical data would suggest social net- 419  
 410 works between northern Vietnam and the rest of Mainland 420  
 411 Southeast Asia were of lower rather than greater intensity, 421  
 412 despite the apparent passage of Neolithic-behaving popu- 422  
 413 lations ca. 1000 years earlier (e.g. Higham et al. 2011a). 423  
 414 More specifically, we do not see metallurgical evidence sup- 424  
 415 porting interaction intensity between Bronze Age northern 425  
 416 Vietnam and those areas for which we have complementary 426

data, namely central and northeast Thailand, central Laos, 417  
 and north-central Myanmar. 418

We remain at an intermediate stage of regional archaeo- 419  
 metallurgical research but these findings are consistent with 420  
 previous studies, in that there seems to be a major lacuna in 421  
 Bronze Age evidence from northern Laos, which is obvi- 422  
 ously the critical zone for directly linking the two major 423  
 areas under discussion (Myanmar lying at a considerable dis- 424  
 tance to the west). Pryce et al. (2014: 292) previously noted 425  
 this tendency for what might be termed a ca. 450 geodesic 426



**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

427 kilometre ‘north Laotian data gap’, if one accepts, as do  
 428 we, the prevalent hypothesis that early Mainland Southeast  
 429 Asian metallurgy was proximally derived from technolo-  
 430 gies practiced in southern China (Higham 1996; Higham  
 431 et al. 2015; Pryce et al. 2010; White 1988). The lead author’s  
 432 subsequent suggestion (Pryce 2018; Pryce et al. 2018b) that  
 433 the late 2nd millennium BC technological transmission may  
 434 have been littoral via the Gulf of Tonkin and thus avoid-  
 435 ing northern Laos, was only intended as a possible nuanced  
 436 variation on the general north-to-south theme. Potential evi-  
 437 dence to the contrary was noted at the site of Tam Pà Ping  
 438 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 ca. BC (Pryce  
 and Cadet 2018). At the time, Pryce (2018), Pryce et al.  
 (2018b) proposed that Tam Pà Ping should perhaps been 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 nevertheless highly consistent with the Vilabouly  
 Complex copper production signature, located another ca.  
 450 km to the southeast (Fig. 1). Tam Pà Ping remains some-  
 thing of an enigma but it does support the idea of northern Viet-  
 namese 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. How-  
 ever, 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. Nevertheless, there is no evidence to  
 suggest prehistoric copper production activity in the area,  
 despite extensive local copper deposits, and no clear occu-  
 pation 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 partic-  
 ular 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/

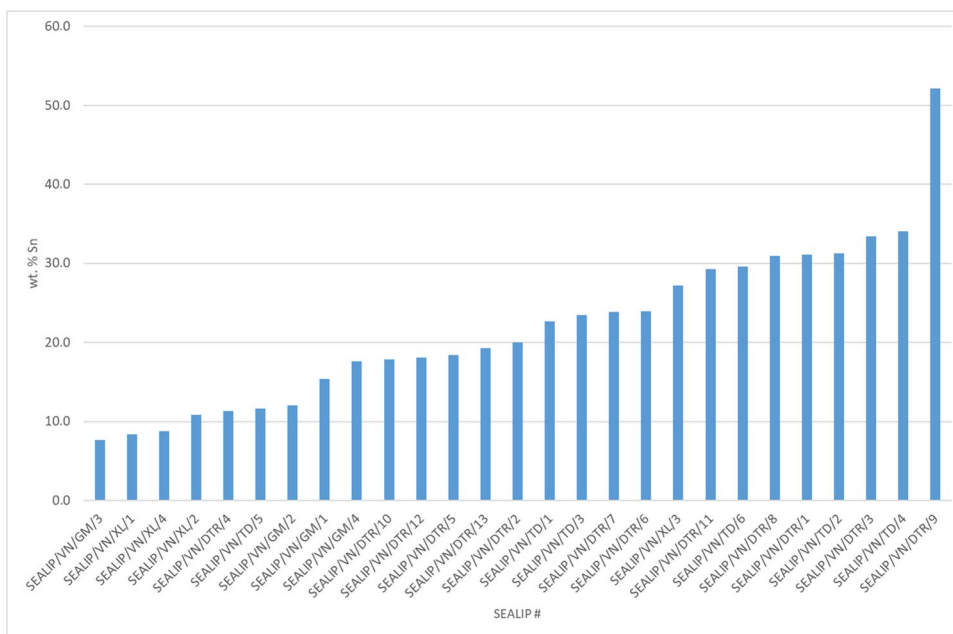
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**Table 4** Raw lead isotope data and error margins for the study samples.

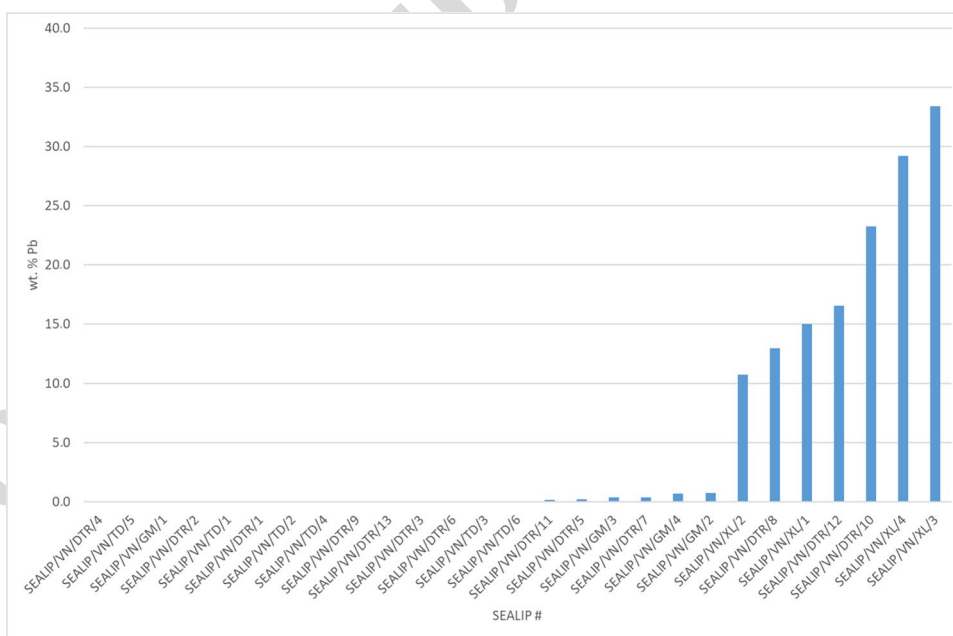
SEALIP#	$^{206}\text{Pb}/^{204}\text{Pb}$	err ( $2\sigma$ )	$^{207}\text{Pb}/^{204}\text{Pb}$	err ( $2\sigma$ )	$^{208}\text{Pb}/^{204}\text{Pb}$	err ( $2\sigma$ )	$^{207}\text{Pb}/^{206}\text{Pb}$	err ( $2\sigma$ )	$^{206}\text{Pb}/^{207}\text{Pb}$	err ( $2\sigma$ )	$^{208}\text{Pb}/^{206}\text{Pb}$	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

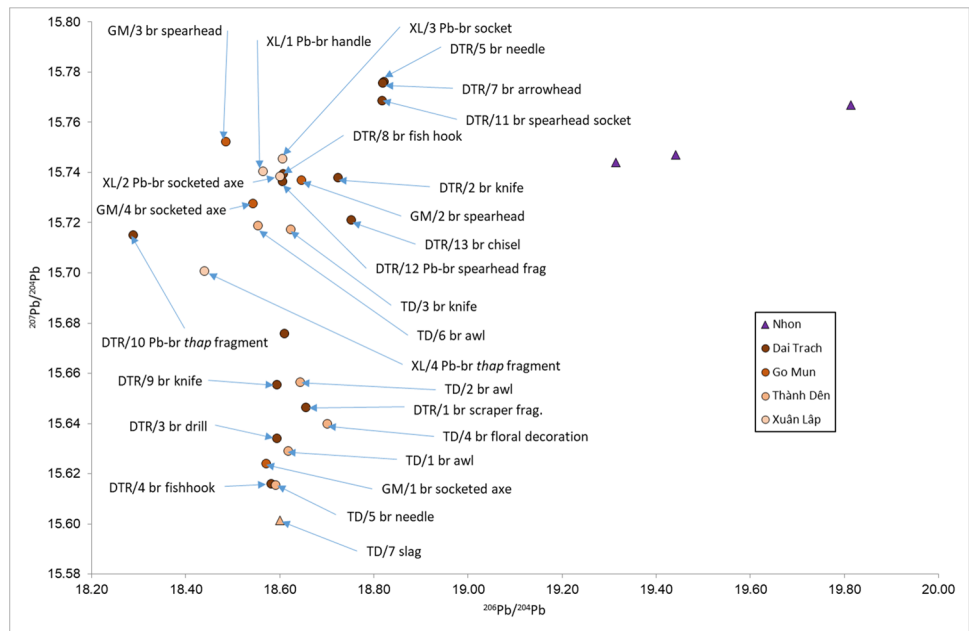


490 bronze-rich archaeological assemblages and extensive  
 491 metallogenic deposits makes the complete absence of  
 492 local prehistoric production unlikely. However, for the  
 493 earliest metals, we note the dominating presence of  
 494 the Red River leading straight into Yunnan, and the  
 495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

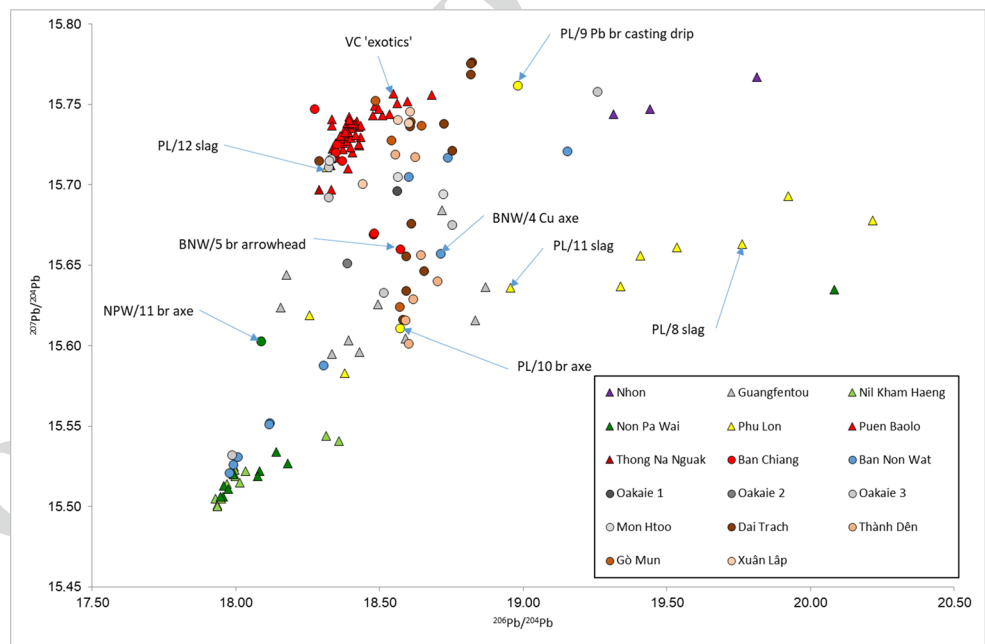
ongoing work by BROGLASEA and other teams in the  
 Dali, Kunming, and neighbouring areas will provide  
 us with important new understanding of trans-regional  
 metal production and consumption networks in the  
 short to medium term, with all the precious informa-  
 tion for human exchange and interaction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

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**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**

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**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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**References**

517

Agrawal DP (1971) The Copper Hoards problem: a technological angle. *Asian Perspect* 12:113–9

518  
519

- 520 Allard F (2018) The lives of shovels, vessels, and bells in early South  
521 China: memory, ritual, and the power of destination. In: Allard  
522 F, Linduff KM, Sun Y (eds.), *Memory and Agency in Ancient*  
523 *China: Shaping the Life History of Objects*. Cambridge Univer-  
524 sity Press, Cambridge, pp. 50–71 [https://doi.org/10.1017/97811](https://doi.org/10.1017/9781108560726.004)  
525 [08560726.004](https://doi.org/10.1017/9781108560726.004)
- 526 Budd P, Gale D, Pollard AM, Thomas RG, Williams PA (1993) Evalu-  
527 ating lead isotope data: further observations. *Archaeometry*  
528 35:241–246
- 529 Cadet M, Sayavongkhamdy T, Souksavady V, Luangkhoth T, Dillmann  
530 P, Cloquet C, Vernet J, Piccardo P, Chang N, Edgar J, Foy E,  
531 Pryce TO (2019) Laos' central role in Southeast Asian copper  
532 exchange networks: a multi-method study of bronzes from the  
533 Vilabouly Complex. *J Archaeol Sci* 109:104988. [https://doi.org/](https://doi.org/10.1016/j.jas.2019.104988)  
534 [10.1016/j.jas.2019.104988](https://doi.org/10.1016/j.jas.2019.104988)
- 535 Ciarla R (2007) Rethinking Yuanlongpo: the case for technological  
536 links between the Lingnan (PRC) and Central Thailand in the  
537 Bronze Age. *East West* 57:305–328
- 538 Cloquet C, Carignan J, Libourel G (2006) Atmospheric pollutant disper-  
539 sion around an urban area using trace metal concentrations  
540 and Pb isotopic compositions in epiphytic lichens. *Atmos Environ*  
541 40:574–587
- 542 Dung LTM (2015) Địa điểm Khảo Cổ Học Thành Dền (The archaeo-  
543 logical site of Thành Dền). Nhà Xuất Bản Đại Học Quốc Gia,  
544 Hà Nội.
- 545 Gorman C, Charoenwongsa P (1976) Ban Chiang: a mosaic of impres-  
546 sions from the first two years. *Exped* 18:14–26
- 547 Higham C, Higham T (2009) A new chronological framework for pre-  
548 historic Southeast Asia, based on a Bayesian model from Ban  
549 Non Wat. *Antiquity* 83:125–144. [https://doi.org/10.1017/S0003](https://doi.org/10.1017/S0003598X00098136)  
550 [598X00098136](https://doi.org/10.1017/S0003598X00098136)
- 551 Higham CFW (2014) *Early mainland Southeast Asia: from first humans*  
552 *to Angkor*. River Books, Bangkok
- 553 Higham CFW (2002) *Early cultures of mainland Southeast Asia*. River  
554 Books Ltd, Bangkok
- 555 Higham CFW (1996) *The Bronze Age of Southeast Asia*. Cambridge  
556 University Press, Cambridge
- 557 Higham CFW (1975) Aspects of economy and ritual in prehistoric  
558 Northeast Thailand. *JAS* 2:245–88
- 559 Higham CFW, Douka K, Higham TFG (2015) A new chronology for  
560 the Bronze Age of northeastern Thailand and its implications for  
561 Southeast Asian Prehistory. *PLOS ONE* 10:e0137542. [https://doi.](https://doi.org/10.1371/journal.pone.0137542)  
562 [org/10.1371/journal.pone.0137542](https://doi.org/10.1371/journal.pone.0137542)
- 563 Higham CFW, Guangmao X, Qiang L (2011) The prehistory of a Friction  
564 Zone: first farmers and hunters-gatherers in Southeast Asia.  
565 *Antiquity* 85:529–543
- 566 Higham CFW, Higham TFG, Douka K (2019) Dating the Bronze Age  
567 Of Southeast Asia. Why Does It Matter? *J Indo-Pac Archaeol*  
568 43:43–67
- 569 Higham CFW, Higham TFG, Kijngam A (2011) Cutting a Gordian  
570 Knot: the Bronze Age of Southeast Asia: origins, timing and  
571 impact. *Antiquity* 85:583–598
- 572 Higham TFG, Weiss AD, Higham CFW, Ramsey CB, Guedes J,  
573 d'Alpoim, Hanson S, Weber SA, Rispoli F, Ciarla R, Pryce TO,  
574 Pigott VC (2020) A prehistoric copper-production centre in cen-  
575 tral Thailand: its dating and wider implications. *Antiquity* 94:948–  
576 965. <https://doi.org/10.15184/aqy.2020.120>
- 577 Huyền, P.M., 1996. Văn Hoá Đông Sơn tính thống nhất và đa dạng  
578 (The culture of Đông Sơn : unity and diversity). Nhà Xuất Bản  
579 Khoa Học Xã Hội, Trung Tâm Khảo, Hanoi.
- 580 Le Meur C, Cadet M, Partner V, Foy E, Cloquet C, Dillmann P, Thote  
581 A, Pryce TO (2021) Typo-technological, elemental and lead iso-  
582 topic characterization and interpretation of Đông Sơn miniature  
583 drums. *J Archaeol Sci Rep*
- 584 Liêm BV (2013) Mộ thuyền trong văn hoá Đông Sơn ở Việt Nam (The  
585 boat burials of the Đông Sơn culture in Vietnam). Nhà xuất bản  
586 từ điển bách khoa, Hà Nội.
- 587 Manhes G, Allègre CJ, Dupré B, Hamelin B (1980) Lead isotope study  
588 of basic-ultrabasic layered complexes: speculations about the age  
589 of the earth and primitive mantle characteristics. *Earth Planet Sci*  
590 *Lett* 47:370–382. [https://doi.org/10.1016/0012-821X\(80\)90024-2](https://doi.org/10.1016/0012-821X(80)90024-2)
- 591 Mansuy, H., 1902. Stations préhistoriques de Samrong-sen et de Long-  
592 prao (Cambodge). Schneider, Hanoi.
- 593 Masanari N (2005) Settlement patterns on the Red River plain from  
594 the late prehistoric period to the 10th century AD. *Bull Indo-Pac*  
595 *Prehistory Assoc* 25:99–107
- 596 Muhly JD (1981) *The Origin of Agriculture and Technology - Aarhus,*  
597 *Denmark, November 21-25, 1978. 2. Summary - the Origin of*  
598 *Agriculture and Technology - West or East-Asia*. Journal Article  
599 workform (42) ISO Source Title Abbreviation: Technol. Cult. ISI  
600 Document Solutions: LK017 29-Character Source Title Abbrevia-  
601 tion: Technol Culture 22, 125–148.
- 602 Murowchick RE (1988) The development of early bronze metallurgy  
603 in Vietnam and Kampuchea: a reexamination of recent work. In:  
604 Maddin R (ed.). *The Beginning of the Use of Metals and Alloys:*  
605 *Papers from the Second International Conference on the Begin-*  
606 *ning of the Use of Metals and Alloys, Zhengzhou, China, 21-26*  
607 *October, 1986*. MIT Press., Cambridge, Mass., pp. 182–199
- 608 O'Reilly D, Shewan L, Domett K, Halcrow SE, Luangkhoth T (2019)  
609 Excavating among the megaliths: recent research at the 'Plain  
610 of Jars' site 1 in Laos. *Antiquity* 93:970–989 [https://doi.org/10.](https://doi.org/10.15184/aqy.2019.102)  
611 [15184/aqy.2019.102](https://doi.org/10.15184/aqy.2019.102)
- 612 Phung HV (1993) Stages of development of Go Mun culture [in Viet-  
613 namese]. *Khao Co Hoc* 85:48–63
- 614 Pienitz R, Aebischer S, Cloquet C, Carignan J, Maurice C (2015) Dis-  
615 ruption of the geochemical metal cycle during mining: multiple  
616 isotope studies of lake sediments from Schefferville, subarctic  
617 Québec. *Chem Geol* 412:167–178. [https://doi.org/10.1016/j.](https://doi.org/10.1016/j.chemgeo.2015.07.028)  
618 [chemgeo.2015.07.028](https://doi.org/10.1016/j.chemgeo.2015.07.028)
- 619 Pigott VC, Ciarla R (2007) On the origins of metallurgy in prehistoric  
620 Southeast Asia: the view from Thailand. In: *Metals and Mining:*  
621 *Studies in Archaeometallurgy*. Archetype, London, pp. 76–88
- 622 Pottier C (2006) Under the western Baray waters. In: *Uncovering*  
623 *Southeast Asia's Past: Selected Papers from the 10th Interna-*  
624 *tional Conference of the European Association of Southeast Asian*  
625 *Archaeologists*. NUS Press, Singapore, pp. 298–309
- 626 Pryce TO (2019) Lead isotope characterization and provenance of  
627 copper-base artifacts from Ban Chiang and Don Klang. In: White  
628 JC, Hamilton EG (eds.), *Ban Chiang, Northeast Thailand, Volume*  
629 *2C: The Metal Remains in Regional Context*. University of Penn-  
630 sylvania Press, Philadelphia, P.A., pp. 57–64
- 631 Pryce TO (2018) Initiating discourse on the (multi?) directionality of  
632 the Mainland Southeast Asian Bronze Age transition. In: *Proceed-*  
633 *ings of The Ninth International Conference on the Beginning of the*  
634 *Use of Metals and Alloys (BUMA-IX), 16-19 October 2017 Inter-*  
635 *national Center, Dong-A University, Busan, Korea*. The Korean  
636 Institute of Metals and Materials, Seoul, pp. 160–175
- 637 Pryce, T.O., 2014. *Metallurgy in Southeast Asia*. Encyclopaedia of the  
638 *History of Science, Technology, and Medicine in Non-Western*  
639 *Cultures*.
- 640 Pryce TO (2012) Proceedings of the 5th Forbes Symposium on ancient  
641 Asian bronzes. In: Jett P, Douglas J (eds.), *A Flux That Binds?*  
642 *The Southeast Asian Lead Isotope Project*. Smithsonian, Wash-  
643 ington D.C., pp. 113–121
- 644 Pryce TO (2011) The excavation of Ban Non Wat: The Bronze Age.  
645 In: Higham CFW, Kijngam A (eds) *XIX Technical Analysis of*  
646 *Bronze Age Ban Non Wat Copper-Base Artefacts*. The Fine Arts  
647 Department, Bangkok, pp 489–498
- 648 Pryce TO, Baron S, Bellina BHM, Bellwood PS, Chang N, Chattopad-  
649 hyay P, Dizon E, Glover IC, Hamilton E, Higham CFW, Kyaw

650 AA, Laychour V, Natapintu S, Nguyen V, Pautreau J-P, Pernicka  
 651 E, Pigott VC, Pollard M, Pottier C, Reinecke A, Sayavongkhamdy  
 652 T, Souksavatdy V, White J (2014) More questions than answers:  
 653 the Southeast Asian Lead Isotope Project 2009–2012. *J Archaeol*  
 654 *Sci* 42:273–294. <https://doi.org/10.1016/j.jas.2013.08.024>

655 Pryce TO, Brauns M, Chang N, Pernicka E, Pollard M, Ramsey C,  
 656 Rehren T, Souksavatdy V, Sayavongkhamdy T (2011) Isotopic  
 657 and technological variation in prehistoric primary Southeast Asian  
 658 copper production. *J Archaeol Sci* 38:3309–3322

659 Pryce TO, Cadet M (2018) Ancient copper-base metallurgy in the  
 660 Lao PDR. In: Patole-Edoumba E, Demeter F (eds.), Pà Hang:  
 661 La Montagne Habitée. 100000 Ans d'histoire de La Biodiversité  
 662 et de l'occupation Humaine Au Nord Du Laos. La Rochelle, pp.  
 663 196–207

664 Pryce TO, Htwe KMM, Georgakopoulou M, Martin T, Vega E, Rehren  
 665 T, Win Tin Tin, Win ThuThu, Petchey P, Innanchai J, Pradier  
 666 B (2018a) Metallurgical traditions and metal exchange networks  
 667 in late prehistoric central Myanmar, c. 1000 BC to c. AD 500.  
 668 *Archaeol Anthropol Sci* 10:1087–1109. <https://doi.org/10.1007/s12520-016-0436-7>

669 Pryce TO, Kyaw AA, Kyaw MM, Win Tin Tin, Win ThuThu, Win  
 670 KH, Mon MM, Aye MM, Htay SH, Mar AA, Bellina B, Bentley  
 671 RA, Champion L, Colonna C, Cook AJ, Favereau A, Fuller DQ,  
 672 Georjon C, Higham C, Htwe KMM, Iizuka Y, Innanchai J, Le  
 673 Meur C, Peixoto X, Petchey P, Pinhasi R, Pradier B, Valentin F,  
 674 Willis A, Zazzo A (2018b) A first absolute chronology for Late  
 675 Neolithic to Early Bronze Age Myanmar: new AMS 14C dates  
 676 from Nyaung'gan and Oakaie. *Antiquity* 92:690–708. <https://doi.org/10.15184/aqy.2018.66>

677 Pryce TO, Kyaw Oo Lwin U, Pradier B, Hrysiewicz B, Favereau A,  
 678 Than Htike U, Tun Tun Aye U, Kyi Khin U, Saw Naing Oo U, Tin  
 679 Tin Win D, Le Meur C, Kay Thwe Oo D, Arkar Aye U, Thu Thu  
 680 Win D, Kalayar Myat Myat Htwe D, Langowska KA, Hanus K,  
 681 Iizuka Y, Georjon C, Zhuang Y, Castillo CC, Fuller DQ, Bentley  
 682 RA, Dussubieux L, Hlaing Sabai Win D, Aye Aye Mar D, Mi Tin  
 683 Nilar Aye D, Cherry Thin D, Han Myo Kyi Aung D, Champion  
 684 L, Myo Minh Oo U, Min Naing Oo U, Zeyar Phyo U, Khin Thidar  
 685 Lin D, Phyo Wai Mg U, Atiphath Paibool K, Varis Domethong K,  
 686 Higham CFW, Higham TFG (in preparation) Honing the Main-  
 687 land Southeast Asian late prehistoric and early historic chronol-  
 688 ogy: an 80 14C determination, up to four millennia, sequence from  
 689 Halin in central-northern Myanmar.

690 Pryce TO, Pigott VC, Martinon-Torres M, Rehren Th (2010) Prehis-  
 691 toric copper production and technological reproduction in the  
 692 Khao Wong Prachan Valley of Central Thailand | SpringerLink.  
 693 *Archaeol Anthropol Sci* 2:237–264

694 Pryce TO, Pollard M, Martinon-Torres M, Pigott VC, Pernicka E  
 695 (2011) Southeast Asia's first isotopically-defined prehistoric cop-  
 696 per production system: when did extractive metallurgy begin in  
 697 the Khao Wong Prachan Valley of central Thailand? *Archaeom-*  
 698 *etry* 53:146–163

Shewan L, O'Reilly D, Armstrong R, Toms P, Webb J, Beavan N, 701  
 Luangkhoth T, Wood J, Halcrow S, Domett K, Bergh JVD, Chang 702  
 N (2021) Dating the megalithic culture of Laos: Radiocarbon, opti- 703  
 cally stimulated luminescence and U/Pb zircon results. *PLOS* 704  
*ONE* 16:e0247167. <https://doi.org/10.1371/journal.pone.0247167> 705

Solheim WG (1968) Early bronze in Northeastern Thailand. *CA* 9, 706  
 59–62 707

Thirlwall MF (2002) Multicollector ICP-MS analysis of Pb isotopes 708  
 using a 207Pb - 204Pb double spike demonstrates up to 400 709  
 ppm/amu systematic errors in Tl-normalization. *Chem Geol* 710  
 184:255–279 711

Trinh S (1990) Spectrographic analysis of bronze artefacts in Go Mun 712  
 and Dong Dau Cultures. *Khao Co Hoc* 1990:49–59 713

Trinh S (1979) Some features of cultural contacts in the Metal Age 714  
 within the historical context of the South Eastern Asia (in Viet- 715  
 namese). *Khảo Cổ Học* 3 716

White JC (1988) Early East Asian metallurgy: the Southern tradition. 717  
 In: Maddin R (ed.), *The Beginning of the Use of Metals and* 718  
*Alloys: Papers from the Second International Conference on the* 719  
*Beginning of the Use of Metals and Alloys*, Zhengzhou, China, 720  
 21–26 October, 1986. MIT Press., Cambridge, Mass., pp. 175–181 721

White JC (1986) A revision of the chronology at Ban Chiang and its 722  
 implications for the prehistory of Northeast Thailand (Ph.D.). 723  
 University of Pennsylvania, Philadelphia 724

White JC, Hamilton EG (2009) The transmission of early Bronze 725  
 technology to Thailand: new perspectives. *J World Prehistory* 726  
 22:357–397 727

Wilson L, Pollard AM (2001) *Handbook of archaeological sciences.* 728  
 In: Brothwell DR, Pollard AM (eds) *The Provenance Hypothesis.* 729  
 John Wiley & Sons Ltd, Chichester, UK, pp 507–517 730

Workman DR (1977) *Geology of Laos, Cambodia, South Vietnam and* 731  
*the eastern part of Thailand. Overseas Geological and Mineral* 732  
*Resources* 50, Institute of Geological Sciences. 733

Yao A, Darré V, Zhilong J, Lam W, Wei Y (2020) Bridging the time 734  
 gap in the Bronze Age of Southeast Asia and Southwest China. 735  
*Archaeol Res Asia* 22:100189. <https://doi.org/10.1016/j.ara.2020.100189> 736

Yule P (1997) The copper hoards of Northern India. *Exp.* 39:22–32 737

Zou G, Cui J, Liu X, Li X, Min R (2019) Investigation of early 738  
 Bronze Age civilizations in Yunnan: a scientific analysis of met- 739  
 allurgical relics found at the Guangfentou ruins in Jiangchuan. 740  
*Archaeol Anthropol Sci* 11:15–31. <https://doi.org/10.1007/s12520-017-0530-5> 741

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