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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.

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

Footnote Information



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
24 isotopes

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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 m² 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

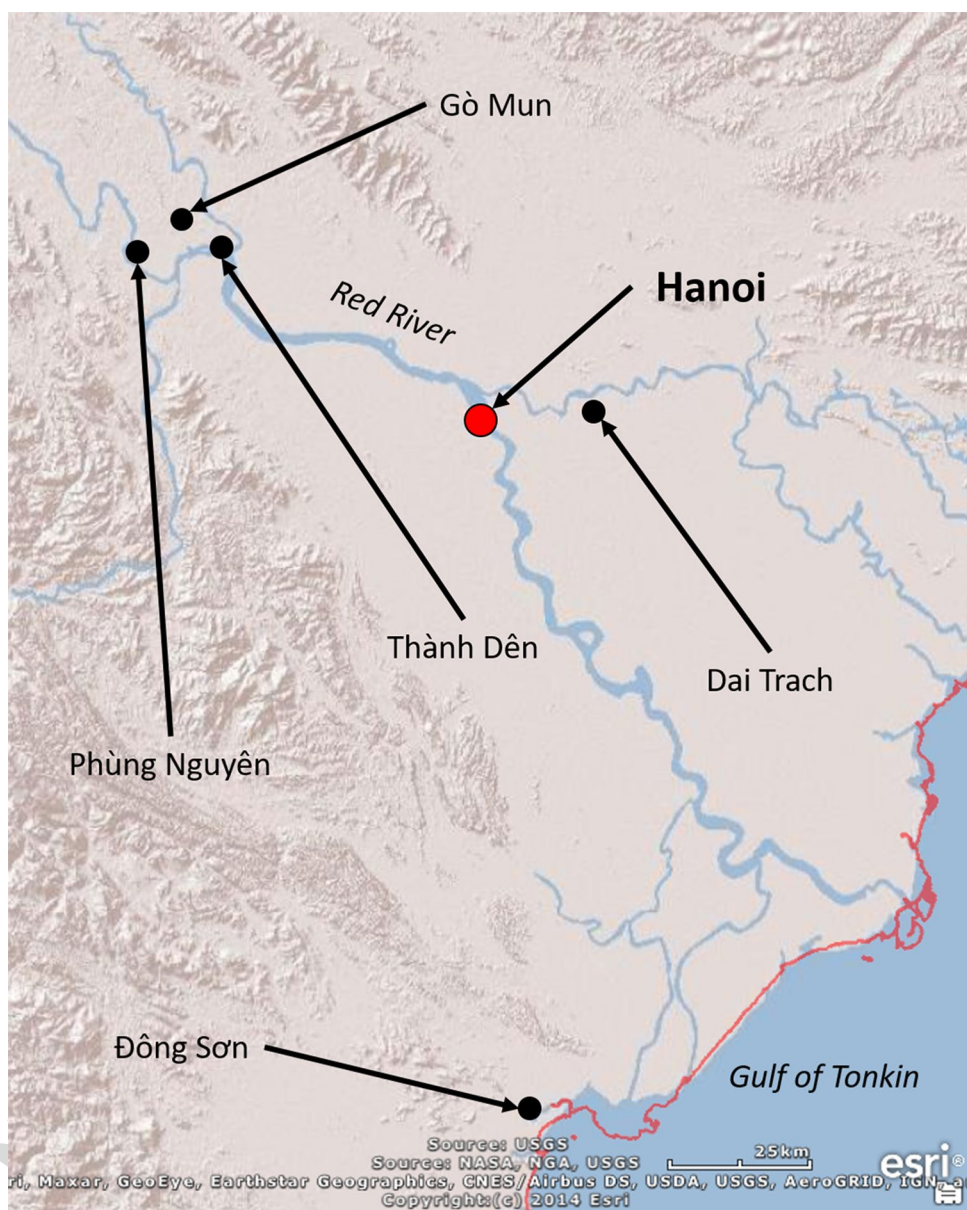
144 **Gò Mun**

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 m² 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 m² 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 μm). 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 Prédiction 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 (2σ) 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 mm²) 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/BROGLASEA¹ analytical programme,
LIA was used to look not for 'matches' but rather 'consist-
ency' with known and characterised production systems, in

¹ 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



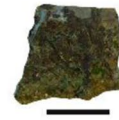
DTR/6



DTR/7



DTR/8



DTR/9



DTR/10



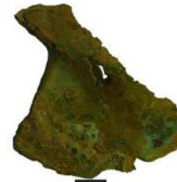
DTR/11



DTR/12



DTR/13



GM/1



GM/2



GM/3



GM/4



TD/1



TD/2



TD/3



TD/4



TD/5



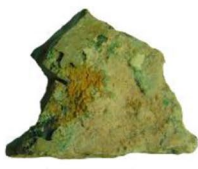
TD/6



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% as
313 the cut-off for major alloying components and 0.5 wt% as the
314 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 ² (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

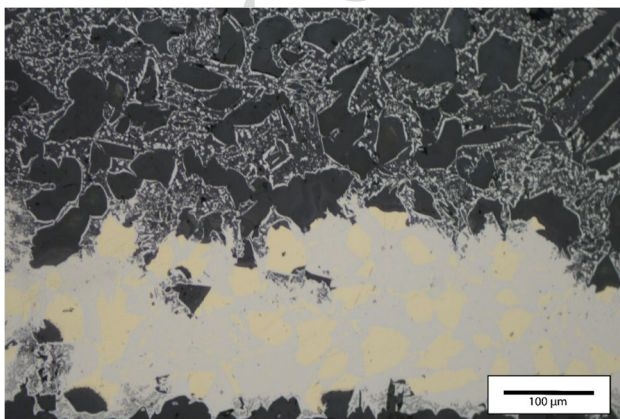
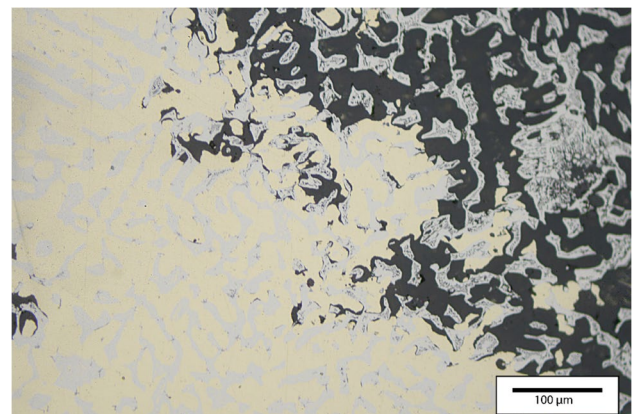
**Fig. 4** Optical plane-polarised light micrograph of DTR/9: as-cast/ α + δ eutectoid structure (bottom) and corrosion (top)**Fig. 5** Optical plane-polarised light micrograph of DTR/11: as-cast/ α + δ eutectoid structure (left) and corrosion (right)

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

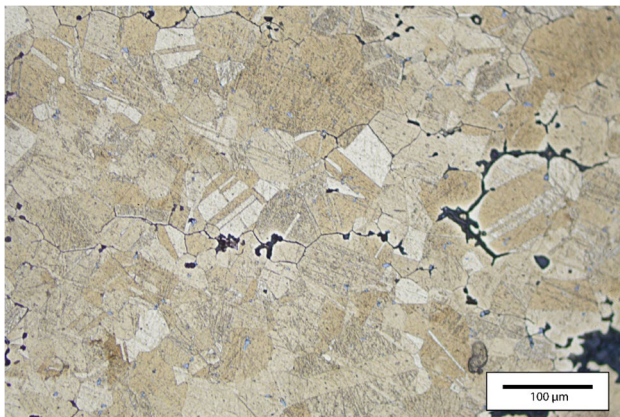


Fig. 6 Optical plane-polarised light micrograph of DTR/7: homogenised and annealed microstructure with intergranular corrosion

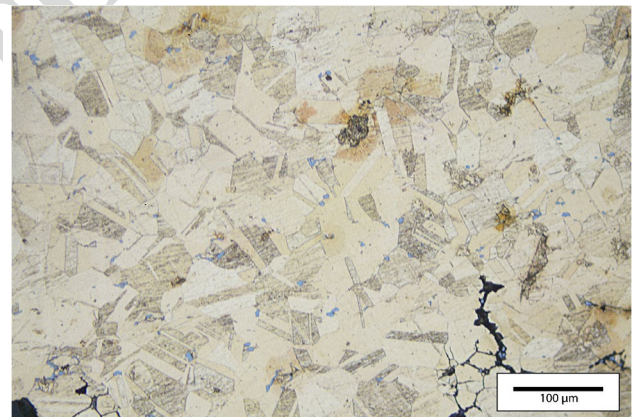


Fig. 7 Optical plane-polarised light micrograph of GM/1: homogenised and annealed microstructure with intergranular corrosion

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

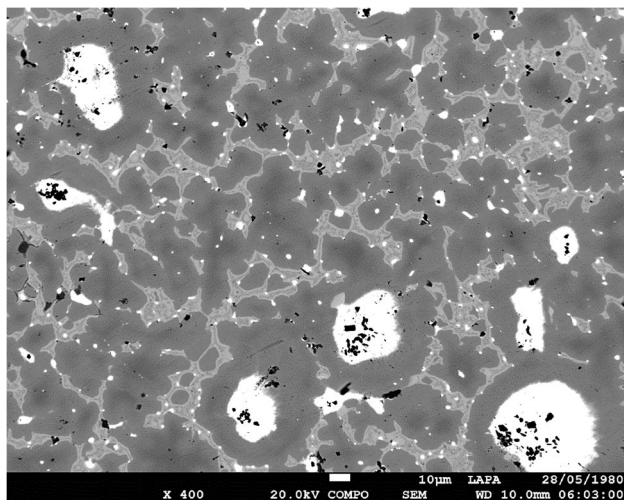


Fig. 8 BSE image showing as-cast (mid-grey and grey) microstructure to DTR/10, a leaded-bronze thap (bucket), with prills of immiscible lead (bright white) and intergranular tin-rich phase (light grey)

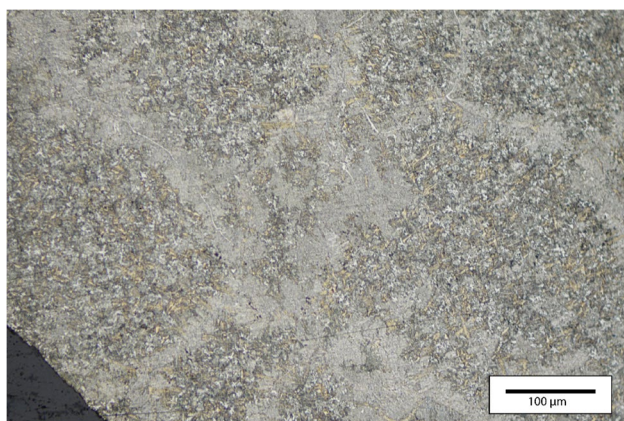


Fig. 9 Optical plane-polarised light micrograph of DTR/1: homogenised and annealed microstructure with intergranular corrosion, fragments of a scraper

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

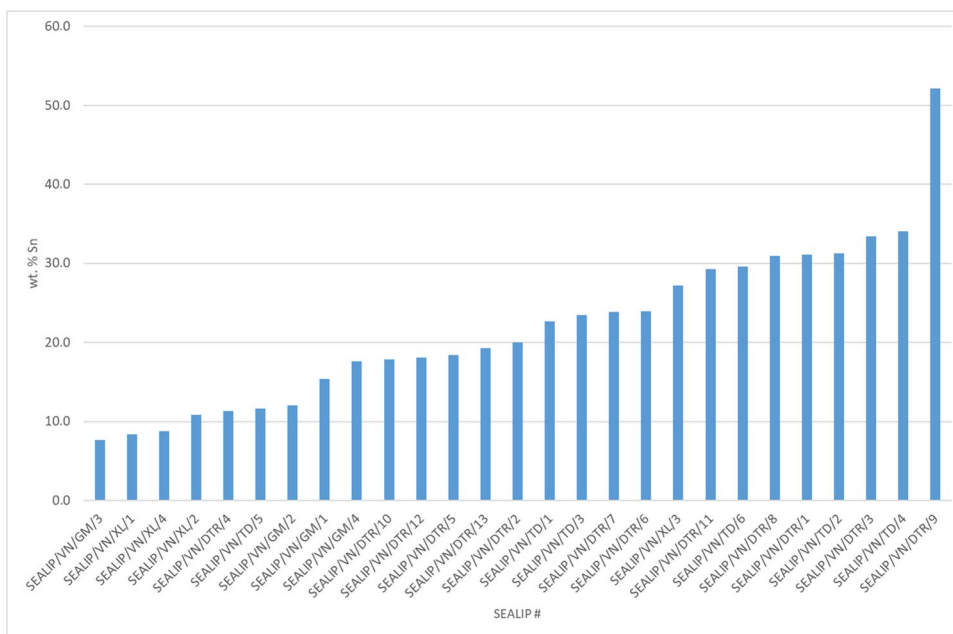
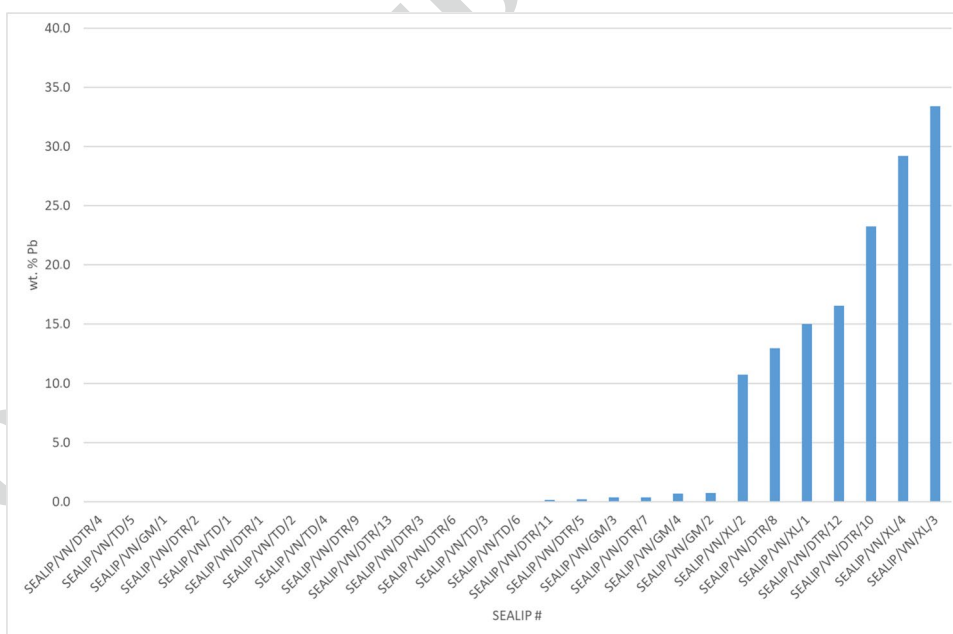


Fig. 11 Lead content, with no doubt some corrosion influence but certainly a chronological difference as Iron Age artefacts are preferentially leaded alloys



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

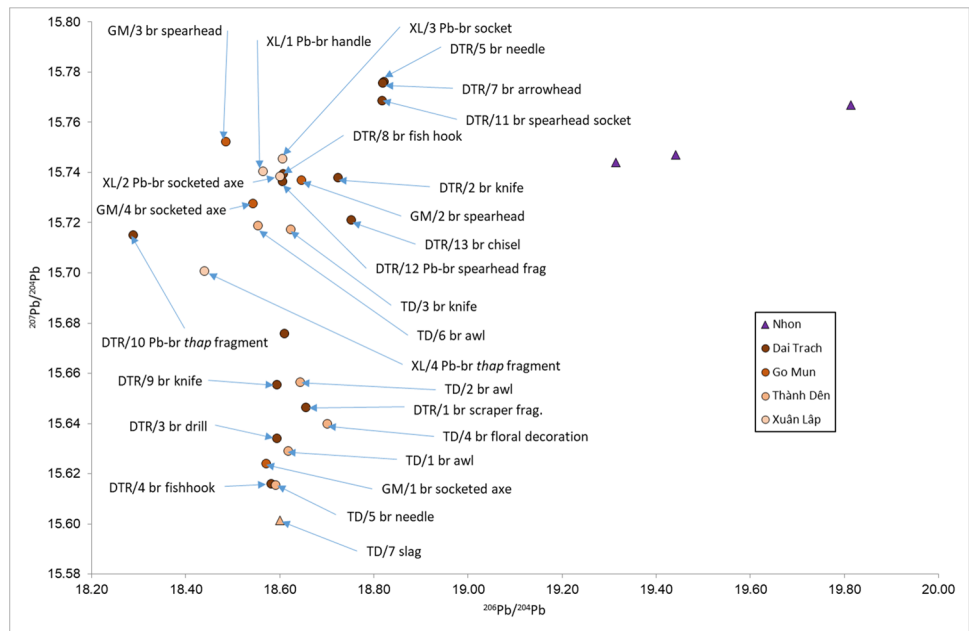
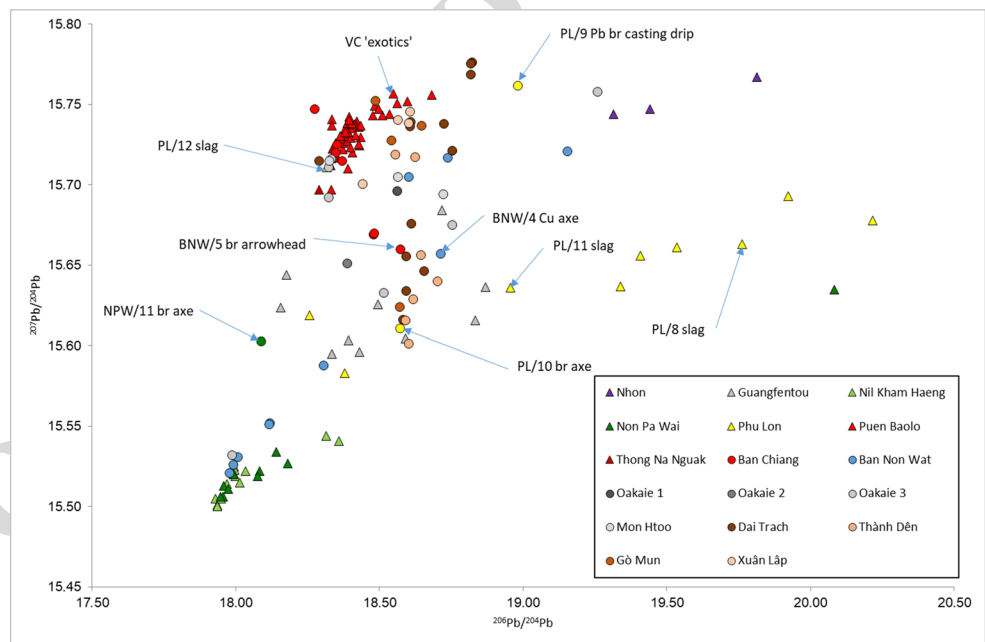


Fig. 13 Study and published SEALIP/BROGLASEA data for MSEA copper production and Bronze Age consumption. Nil Kham Haeng/Non Pa Wai represent central Thai production, Phu Lon northern Thai production, and Thong Na Nguak/Puen Baolo central Lao production. Production site artefacts/imports/exotics are marked;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