



HAL
open science

A late 2nd/early 1st millennium BC interaction arc between Mainland Southeast Asia and Southwest China: archaeometallurgical data from Hebosuo and Shangxihe, Yunnan

T.O. Pryce, Wengcheong Lam, Mélissa Cadet, Zhilong Jiang, Wei Yang, Alice Yao

► To cite this version:

T.O. Pryce, Wengcheong Lam, Mélissa Cadet, Zhilong Jiang, Wei Yang, et al.. A late 2nd/early 1st millennium BC interaction arc between Mainland Southeast Asia and Southwest China: archaeometallurgical data from Hebosuo and Shangxihe, Yunnan. *Journal of Archaeological Science*, 2022, 143 (8), pp.105612. 10.1016/j.jas.2022.105612 . cea-03687100

HAL Id: cea-03687100

<https://cea.hal.science/cea-03687100v1>

Submitted on 22 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Title: A late 2nd/early 1st millennium BC interaction arc between Mainland Southeast Asia and Southwest China: Archaeometallurgical data from Hebosuo and Shangxihe, Yunnan

Authors: T. O. Pryce¹, Wengcheong Lam², Mélissa Cadet³, Zhilong Jiang⁴, Wei Yang⁵ & Alice Yao⁶

Affiliations: ¹Centre National de la Recherche Scientifique, LAPA, UMR5060 IRAMAT, UMR3685 NIMBE, CEA Saclay, 91190 Gif-sur-Yvette cedex, France, ²Chinese University of Hong Kong, Department of History, ³Institute of History and Philology, Academia Sinica, Taipei, ⁴Yunnan Provincial Institute of Cultural Relics and Archaeology, ⁵School of History and Archives, Yunnan University, ⁶University of Chicago, Department of Anthropology

Abstract:

In this paper we use archaeometallurgical data from the Yunnanese Bronze Age sites of Hebosuo and Shangxihi, to examine the nature of early exchange networks within Yunnan, across southern China and into Mainland Southeast Asia (MSEA). Traditional perspectives on relations between China and MSEA were viewed from a Core-Periphery (C-P) perspective, derived from World Systems Theory (WST) but this area, though now divided by national borders, has shared ecological and cultural characteristics that allow its definition as the Southeast Asian Massif (SAM).

The fourteen analysed samples were all unleaded copper or bronze, mostly as-cast and with some annealing. Their lead isotope signatures did not group at site level but showed broad consistency with the other, limited, signatures available from Yunnan, Sichuan and Guangxi. Critically, comparison with MSEA signatures revealed good isotopic consistency with key Bronze Age sites in Thailand, Myanmar and Vietnam, active within tight timeframes, and mostly lying on or near the path of major river systems that find their source in or via Yunnan. The picture we propose, based on current data, is one of a complex network of autochthonous SAM societies interacting at short (ca. 50 km), medium (ca. 300 km) and long (ca. 800-1600 km) ranges over mountainous and forested terrain.

1.0 Introduction

With this paper we hope to show how archaeometallurgy can contribute to a major shift in trans-regional late prehistoric research, in this instance between Mainland Southeast Asia (MSEA) and southwest China. Unveiling and unravelling past human interactions lies at the heart of the archaeological endeavour, at multiple chronological and spatial scales and between populations of varying social complexity. A major approach to understanding those relations since the 1970s has been World Systems Theory (WST) and the application of Core-Periphery (C-P) models to socio-politically/socio-economically dissimilar groups. Originally proposed for the origins of western capitalism (Wallerstein, 1978), core-periphery modelling has been widely applied to historic and prehistoric societies (e.g. Champion, 1995; Rowlands et al., 1987; Sherratt, 1993), but has received criticism for being diffusionist and excessively founded on economics, though it is still regarded as potentially useful in appropriate contexts (e.g. Harding, 2013; Kardulias and Hall, 2008; Kohl, 1989).

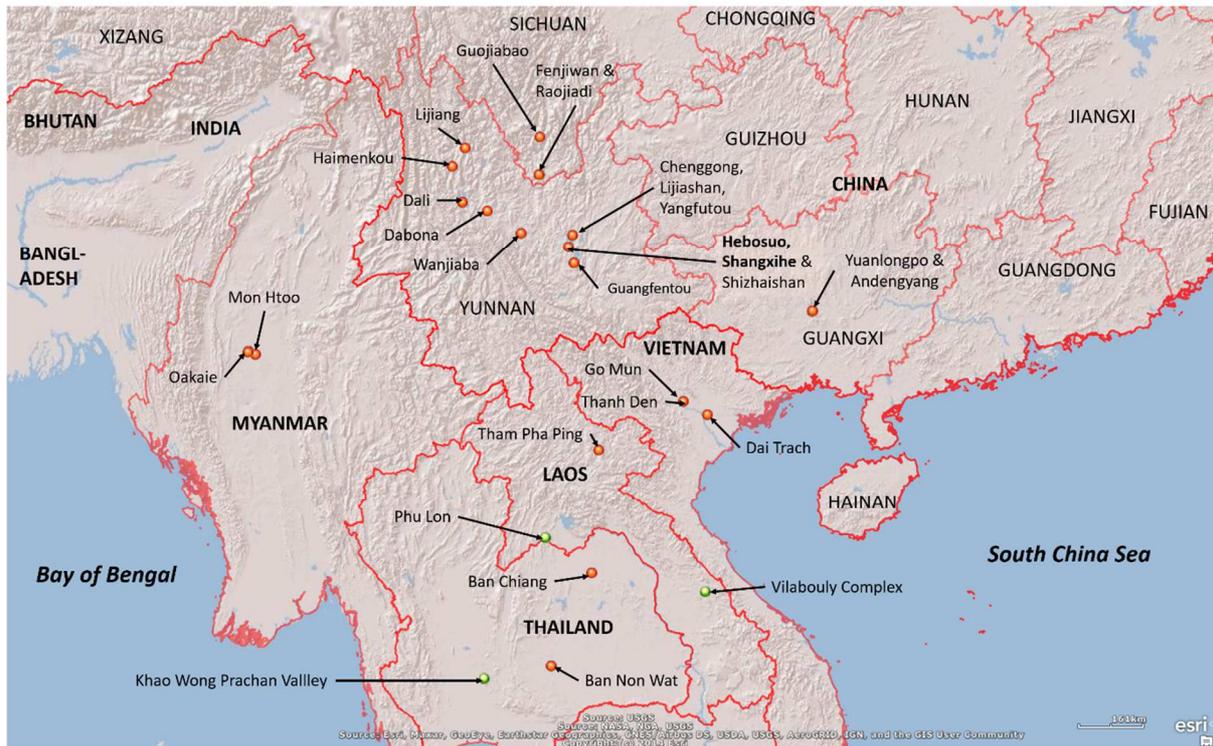


Figure 1: Principal regions and sites discussed in the text.

MSEA has been argued to be just such a context as, implied by its name, the region's geography and history have long been seen through the lens of relations with South and East Asia. Scholarly emphasis changed over the 20th century, from MSEA as an Indian colony (Majumdar, 1927), to heavy Indian cultural influence (Cœdès, 1944), to post-colonial MSEA rejections of historic foreign influence (Benda, 1962), to processual multicentric perspectives on the Chinese versus indigenous origins of the MSEA Neolithic (Gorman, 1969; Solheim, 1972) and Bronze Age (Bayard, 1972; Solheim, 1968), through to implicit and explicit regional applications of core-periphery models for Early Iron Age (post-4th c. BC) interactions with India (Glover, 1990) and Neolithic/Bronze Age interactions with China (Higham, 1989), respectively. Recent archaeological thinking emphasises the multilateralism in MSEA's extra-regional relations, in that foreign ideas, foodstuffs, material culture, technologies and *some* people did arrive from China and then India, but that these exogenous factors were generally adapted and integrated by pre-existing populations, whose own productions and/or peoples may have flowed in the opposite direction, albeit in lower numbers (e.g. Bellina, 2017; Higham, 2021). Thus, variably but systematically asymmetric long distance networks and exogenous influences have been invoked by MSEA archaeologists for several decades. Such perspectives also lend themselves when piecing together developments at the intra-regional level, given the composite nations' high energy-cost forested and mountainous landscapes (see below) and variable fieldwork/dataset densities, multiple language families and scripts, and academic traditions.

For over a decade, scholars have called for a renewed focus on the dynamic intra-regional exchange systems that linked the Southeast Asian Massif together into its own ecumene (von Schendel 2002, Michaud 2010). Instead of an emphasis on influences of the outside world, research is now needed to understand how exchange was conducted and coordinated at a variety of scales, from that between adjacent valleys and ecological zones, to more distant ones between different autochthonous societies. This is not to deny the importance of macro-scale questions like those posed by WST-informed research. It is rather a simple acknowledgement that mapping micro and

meso-scale exchange networks is pivotal to understanding how these long-range linkages were formed in the first place.

Interaction networks in the Southeast Asian Massif are likely to have a deep antiquity; not least as aDNA, archaeobotanical, linguistic and material culture evidence suggests early farmers migrated from centres of domestication in present-day central China (Bellwood, 2005; Charles F. W. Higham et al., 2011; Higham, 2021; McColl et al., 2018). Archaeometallurgical research can be used to identify or rule out potential exchange patterns and MSEA relationships with southern China from the late 2nd millennium BC onwards, subsequent to the generally-agreed introduction of copper metallurgy from more northerly metal-using populations (Higham, 2021; Pigott and Ciarla, 2007; Pryce et al., 2014a). A major development in recent years has been researchers working in southern China considering their region of interest's relationships with MSEA to the south, rather than focusing on links to the Chinese Central Plains in the north/northeast (e.g. Yao, 2016). This was most explicitly expressed with Yao *et al.*'s (2020) publication of 27 radiocarbon determinations from the well-stratified deposits of Hebosuo and Shangxihe, pushing the Early Bronze Age (EBA) for the Dian Lake area of Yunnan Province *backwards* to the early 12th c. BC. This sequence closely matches MSEA, mostly known from Thailand (Higham et al., 2015) and Myanmar (Pryce et al., 2018b), where the Bronze Age transition has been gradually pushed *forwards* by over two millennia over the last few decades (Bayard, 1972; Higham and Higham, 2009; Solheim, 1968; White, 2008, 1986). China's southernmost provinces, Yunnan, Guangxi and Guangdong, have long been suspected as potential metal-using donor/catalyst cultures by Southeast Asianists (Charles F.W. Higham et al., 2011; Pigott and Ciarla, 2007). Now, with broadly matching timelines and available metallurgical assemblages, we can begin to put the modelling to a preliminary test.

1.1 Physical geography of the Southeast Asia Massif

Although divided by political boundaries into East, South and Southeast Asia, the eastern terminus of the Himalayan Range shares a great many geological, ecological and cultural similarities. High mountains extend into northern Myanmar (Hkakabo Razi, 5881 m) and western Yunnan (Kawagarbo, 6740 m), whereafter they give way to the Hengduan Range, from 6000 to 1300 m in altitude. Indeed, much of MSEA is mountainous, with three main ranges running broadly north to south: the ca. 950 km long Arakan Range, dividing western Myanmar from northeast India and Bangladesh; the ca. 560 km by 330 km Shan Hills, demarking eastern Myanmar from western Yunnan and northern Laos and Thailand (this range is contiguous with the ca. 1670 km of the Tenasserim Hills, which run the length of western Thailand and to the tip of the Thai-Malay Peninsula); and the ca. 1100 km long Truong Son Cordillera, which constitutes most of Laos and the spine of Vietnam. The Tibetan Plateau is the ultimate source of the major rivers whose valleys radiate across the region: the 3848 km Brahmaputra into northeast India; the 2288 km Irrawaddy into Myanmar; the 3289 km Salween into Yunnan, Myanmar and bordering Thailand); and the 4909 km Mekong into Yunnan, Myanmar, Laos, Thailand, Vietnam and Cambodia. Also crucial to any consideration of upland - lowland exchanges across this landscape is the Red River, which rises in western Yunnan near Dali and empties into the Gulf of Tonkin 1149 km distant, and the upper reaches of the Yangtze River, which cuts east-west perpendicularly across the major mountain ranges of the Hengduan.

In addition to elevation and bisecting river systems, much of this region is heavily forested. Combined with the generally steep gradients and high humidity, and without even taking into account the fauna, moving across this landscape is often considered to be largely constrained to following river valleys, as the energy cost of moving otherwise is extremely high. Indeed, such are these shared

upland characteristics that Jean Michaud (2008) proposed the term 'Southeast Asian Massif' (SAM) to discuss regional populations living above 300 m altitude. As such, this is a human rather than a physical geographic term, and explicitly refers to MSEA nations as well as northeast India, Bangladesh, southwest China and Taiwan, and is highly pertinent for this study. The SAM should not be confused with Van Schendel's (2002) partly overlapping term, 'Zomia', which is more political in nature. Nevertheless, whilst the peoples of the SAM have a high genetic, linguistic and cultural diversity, and occupy a wide variety of ecological niches, there is also substantial geological variability at the meeting point of multiple tectonic plates. Metallogenic geology is of particular relevance here (Hutchison and Taylor, 1978; Khin Zaw et al., 2014; Takimoto, 1968), as non-ferrous metal deposits are chiefly located in upland regions and may represent a major economic output of local populations (Pryce, 2013; White and Hamilton, 2021). Our focus on the Lake Dian basin as a study region is due in part to its location in the highlands (above 1500 meters asl), as well as its special location at the geographical intersection of the Yangtze, Red, and Pearl river systems. Its distinctive position linking multiple riverine systems is crucial to understanding how ores and processed resources were exchanged between upland and lowland groups, thereby providing a preliminary description of the varying scales of interaction.

The SAM is best known for the Southeast Asian Tin Belt, which hosts the Old World's largest tin deposits, running ca. 3000 km from southwestern China to Sumatra (Schwartz et al., 1995). The exploitation of stanniferous resources is documented textually on the Thai-Malay Peninsula from the late 1st millennium AD (Tibbetts, 1978) and archaeologically from the mid-late 1st millennium BC (Pryce et al., 2017) but is likely to be more ancient still, especially to the northern end of this range where bronze usage is older. Sometimes coinciding with tin, particularly in upper-peninsular Thailand (Sitthithaworn, 1990), lead is another important regional product but one that remains understudied as the metal is disregarded by non-specialists (Pryce, 2012). Lead, especially argentiferous lead, is of special interest in northeastern Myanmar and Yunnan, with the famous Bawdwin mine in the former (LaTouche and Brown, 1909) and the association of upland groups with silver production in the latter (Fiskesjö, 2010; Yang, 2004). Gold is almost ubiquitous across the region, albeit in minor placer deposits, and often panned part-time by local people (Workman, 1977). The same could be said of iron, with regular instances of low-grade minerals and relatively rare rich deposits (Leroy et al., 2018; Pryce et al., 2014b; Pryce and Natapintu, 2009). Of course, the perennial interest of late prehistoric archaeologists is copper, and deposits of its ores are to be found across the SAM, though quite irregularly distributed. Modern maps (see Smith in Hamilton & White 2018) can give a misleading impression of proliferation, as many of the deposits are too low-grade or too deep for ancient exploitation, and thus geochemical (including lead isotope) data can be of variable relevance for historic metallurgy. Though there is little doubt protohistoric MSEA production centres remain to be discovered, in four decades of archaeometallurgical research only three such loci have been identified, despite the lead author's own extensive prospections in northern Laos, Myanmar and Vietnam. These are the Khao Wong Prachan Valley in central Thailand, Phu Lon in northern Thailand and the Vilabouly complex in central Laos (Pigott, 2019; Pigott and Natapintu, 1988; Pryce et al., 2014a). For a summary of MSEA metallurgy and metallogenic deposits please see Pryce (2014) and Hamilton & White (2018).



Figure 2: The study sites' location with respect to Lake Dian and the Shizhaishan cemetery.

The sites whose metal assemblages are the focus of this paper, Hebosuo and Shangxihe, are the same as those investigated by Yao *et al.* (2020) to define three phases of the Yunnan Bronze Age. There is thus a solid link between the new dating referred to and the artefacts being studied. Both Hebosuo and Shangxihe are located on the south-eastern fringes of Lake Dian, in Jinning District, Yunnan Province, just over 28 km south-south-west of the Yunnan Museum in Kunming city. This region, and Yunnan in general, has a complex geological history at the junction of the Eurasian, Indian and Pacific plates, and is rich in deposits of copper, gold, lead, silver and tin (e.g. Khin Zaw *et al.*, 2014). Hebosuo and Shangxihe were investigated as part of the “Dian Heartland Project”, which since 2008 has conducted site surveys, excavations and a multi-faceted analytical programme in order to better understand the impact of Han expansionism into south-western China upon pre-existing pastoral and state level societies. Of the latter, the Kingdom of Dian is the best known, centred around Lake Dian, and whose royal cemetery was located at Shizhaishan (Pirazzoli-t’Serstevens, 1974; Yunnan sheng bowuguan, 1959; Yunnansheng wenwu kaogu yanjiusuo *et al.*, [Yunnan provincial institute of cultural relics and archaeology, Kunming municipal museum, and Jinning district management office of cultural relics, 2009], less than one kilometre north-north-east from the present study’s sites. The founding of the Dian kingdom was attributed by the Han historian, Sima Qian, to Zhuang Qiao, a Chu general, in 279 BC (Watson, 1958), though the dense settlement patterning and rich material culture evidence Dian’s origins back to the Spring and Autumn period, 771-476 BC, if not earlier. The kingdom’s demise is more definitive, it having been annexed by the Han Emperor Wudi in 109 BC, but the Dian cultural and technological legacy was deep and widespread, it being a probable stimulus for the contemporary northern Vietnamese Đông Sơn culture known for its iconic drums (Calo, 2014; Han, 2004). Indeed, the highly decorated drums, weapons and myriad naturalistic sculptures of often impressive detail and scale mark the metallurgical prowess of the Lake Dian-centred population of the 1st millennium BC.

2.0 Archaeological sites and assemblages

Hebosuo is a 31 ha shell mound located 650 m east of the present-day Lake Dian shoreline and 1 km southwest of the Shizhaishan cemetery. Cultural deposits are 1.4-2.6 m thick and consist of seven distinctive anthropic layers including middens and building features. The underlying sterile layer is characterized by a silty clay soil that transitions into dark gley, whose inclusions of iron nodules suggests the mound was initially built on a flood or levee deposit. Nine samples of carbonised wheat and rice grains from layers 3 to 7 in 2014's 4.5 x 4.5 m testpit were submitted for AMS ¹⁴C determinations, with layers 7 and 6a dating to the 12th-10th c. BC, equivalent to the Central Plains' Late Shang to Early Western Zhou periods, and layers 6-3 to the 8th-6th c. BC Spring and Autumn period (Yao et al., 2020: Figure 5). The association of Han materials in layer 2 indicates occupations dating to the first century BC in Hebosuo's upper levels.

280 m east of Hebosuo, Shangxihe is a smaller settlement covering 1.6 ha in area, one of sixteen satellite similar sites along the shore of Lake Dian (Figure 2). The site's 13 culture layers are 3 m thick, with building structures found in layers 10, 8 and 6, as indicated by postholes and sunken clay floors. A total of 18 short-lived samples were submitted for AMS ¹⁴C from the 2016 10 x 10 m excavation unit. Layers 13 to 9 range from the 12th-8th c. BC, corresponding to the Late Shang and Early Western Zhou periods. Layers 8 to 5 date to the 8th-6th c. BC Spring and Autumn period and layer 4 to the 4th-3rd c. BC Warring States period (Yao et al., 2020: Figure 6).

Metallurgical finds from Hebosuo and Shangxihe comprised 17 copper-base artefacts, which are largely fragmentary but can be divided into points, flat shapes and amorphous (Table 1). Of the fourteen selected for study, based upon their apparent preservation and the reliability of their context, six Hebosuo samples come from layers 3 and 5 and date to the early-mid 1st millennium BC, whilst the eight samples from Shangxihe come from layers 8 and 10, dating to the late 2nd and early 1st millennia BC.

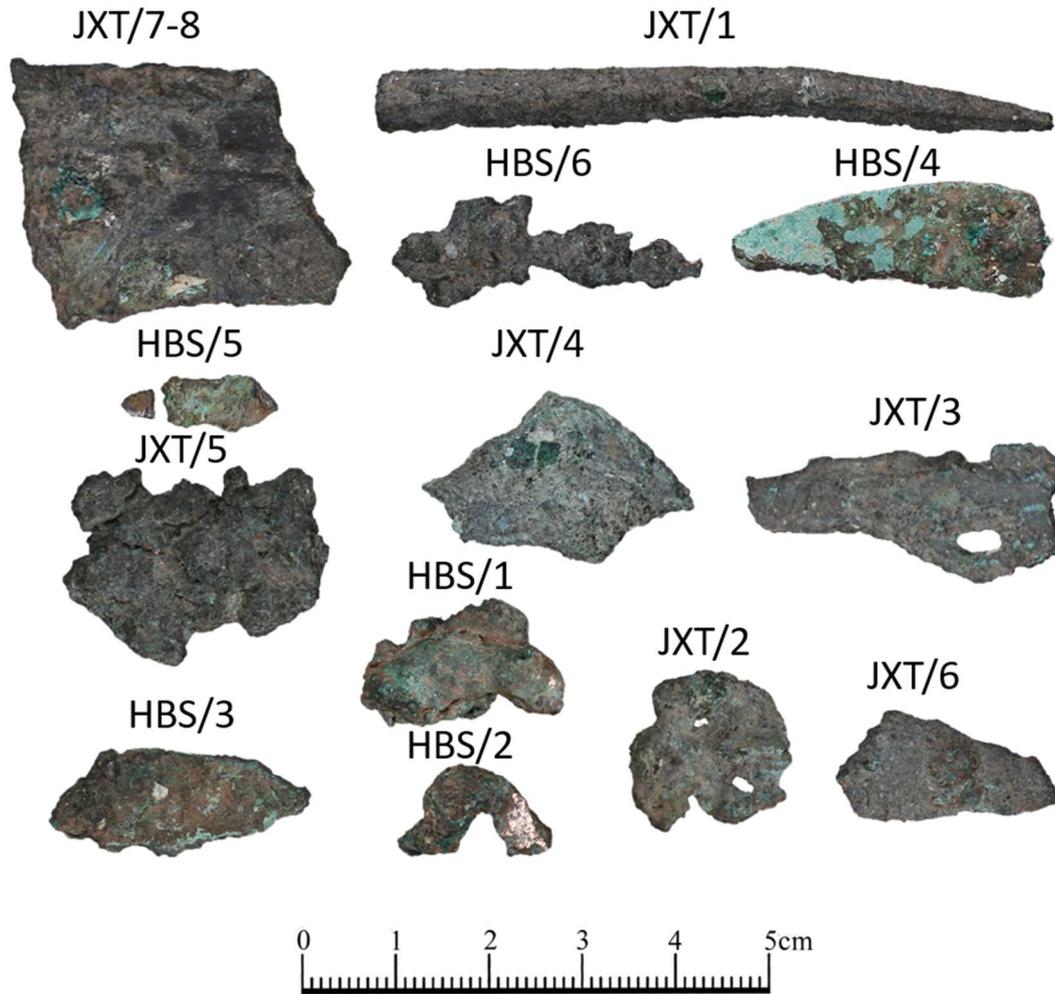


Figure 3: The study samples.

Table 1: Study sample context, type and corrosion levels.

SEALIP ID	Site	Context	Catalogue	Period	Date	Type	Morphology	Corrosion
SEALIP/CH/HBS/1	Hebosuo	HBS-SW-5:7	87202	Mid Bronze Age level 5	800-600 BC	Fragment	Amorphous	Medium
SEALIP/CH/HBS/2	Hebosuo	HBS-SW-SW5:7	87203	Mid Bronze Age level 5	800-600 BC	Copper	Amorphous	Medium
SEALIP/CH/HBS/3	Hebosuo	HBSW5-5:7	87204	Mid Bronze Age level 5	800-600 BC	Copper	Flat	Low
SEALIP/CH/HBS/4	Hebosuo	HBSW5-5:7	87205	Mid Bronze Age level 5	800-600 BC	Copper	Flat	Low
SEALIP/CH/HBS/5	Hebosuo	HBS-SW-5a:6	87207	Mid Bronze Age level 5	800-600 BC	Fragment	Amorphous	High
SEALIP/CH/HBS/6	Hebosuo	2014HBS-SW-3:6	87208	Mid Bronze Age level 3	675-550 BC	Copper	Flat	Low
SEALIP/CH/JXT/1	Shangxihe	2016JxT0401-10:6	87101	Early Bronze Age level 10	1100-800 BC	Needle	Point	Low
SEALIP/CH/JXT/2	Shangxihe	JxT0401-10a-F9-1	87102	Early Bronze Age level 10	1100-800 BC	Fragment	Flat	Low
SEALIP/CH/JXT/3	Shangxihe	2016JxT0401-8層下H38:4	87103	Early Bronze Age level 8	800-750 BC	Fragment	Flat	Low
SEALIP/CH/JXT/4	Shangxihe	2016JxT0401-F3:8	87105	Early Bronze Age level 8	800-750 BC	Fragment	Flat	Low
SEALIP/CH/JXT/5	Shangxihe	2016JxT0401-H38-1	87106	Early Bronze Age level 8	800-750 BC	Fragment	Amorphous	Low
SEALIP/CH/JXT/6	Shangxihe	2016JxT0401-H14:1	87107	Early Bronze Age level 8	800-750 BC	Fragment	Flat	Medium
SEALIP/CH/JXT/7	Shangxihe	2016JxT0401-H39-1:1	87108_(1)	Early Bronze Age level 8	800-750 BC	Fragment	Flat	Low
SEALIP/CH/JXT/8	Shangxihe	2016JxT0401-H39-1:1	87108_(2)	Early Bronze Age level 8	800-750 BC	Fragment	Flat	Low

3.0 Methodology

The studied artefacts were all cut using an ultra-fine jeweller's saw, taking into account areas of existing damage (preferred) and corrosion (avoided). The cut samples were 2-4 mm³, cut from exterior surfaces and may not be representative of object heterogeneity due to poor alloy mixing,

segregation during solidification, or any unidentified joints. The cut samples were then halved, for elemental/microstructural and isotopic analyses.

3.1 Optical Microscopy (OM)

The samples were mounted in epoxy resin, ground with silicon carbide paper (from 800 to 4000 grits) and then polished using diamond suspensions (1 and 0.5 μm). After etching with alcoholic ferric chloride, microstructural evidence for thermo-mechanical treatments was investigated using an optical microscope (Leica DLLM).

3.2 Scanning Electron Microscopy with Energy Dispersive Spectrometry (SEM-EDS)

The OM samples were then platinum coated for analysis using the Chinese University of Hong Kong's Department of Physics' JSM-7800f SEM with an Oxford X-Max EDS unit. Measurement was performed with an accelerating voltage of 20 kV, a spot size of 8 μm^2 , a working distance of 10 mm, and a 60 second acquisition time. Elemental data were processed by AZTEC software using the "standardless quantitative method". Certified Reference Materials were used to monitor accuracy and precision (Table 2).

Table 2: Certified Reference Materials published and analysed values, by the Chinese University of Hong Kong's Department of Physics' JSM-7800f SEM.

CRM	Cu wt%	Zn wt%	As wt%	Sn wt%	Pb wt%
BCR691_e SEM-EDS	90,6	0,3	0,3	8,5	0,5
BCR691_e certified value	92,5	0,2	0,2	7,0	0,2
diff.	102%	57%	73%	83%	44%
BCR691_d SEM-EDS	80,4	0,0	0,3	10,4	8,9
BCR691_d certified value	80,3	0,2	0,3	10,1	9,2
diff.	100%	375%	94%	98%	104%
BCR691_c SEM-EDS	92,8	0,2	5,9	0,1	1,0
BCR691_c certified value	95,0	0,1	4,6	0,2	0,2
diff.	102%	29%	78%	154%	18%
BCR691_b SEM-EDS	81,1	16,0	0,1	2,2	0,6
BCR691_b certified value	82,8	14,8	0,0	2,1	0,3
diff.	102%	93%	8%	97%	48%
below detection limit					

3.3 Multi Collector – Inductively Coupled Plasma – Mass Spectrometer (MC-ICP-MS)

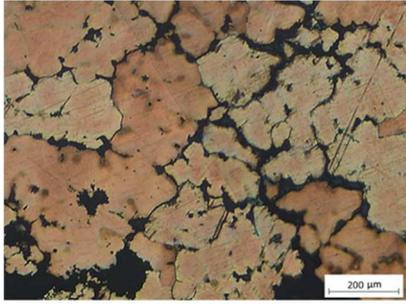
Lead isotope analysis (LIA) was conducted at the *Service d'Analyse des Roches et des Minéraux* of the Centre for Petrographic and Geochemical Research (SARM-CRPG) in Nancy, France, using MC-ICP-MS after lead extraction (Manhes et al., 1980). Thallium NIST SRM 997 was used to correct for instrumental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

As per the SEALIP/BROGLASEA programme, LIA was used to look for 'consistency' with known and characterised production systems, in recognition that there could be other, as yet uncharacterised, primary and/or secondary production systems, as well as mixing, alloying and recycling impacting interpretation (e.g. Budd et al., 1993; Pryce et al., 2014, 2011b; Wilson and Pollard, 2001).

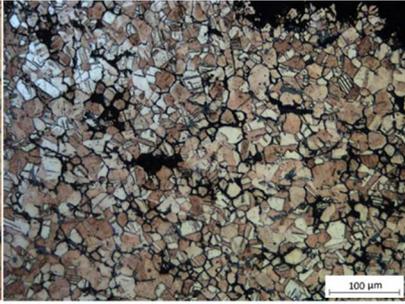
4.0 Results

4.1 Metallographic

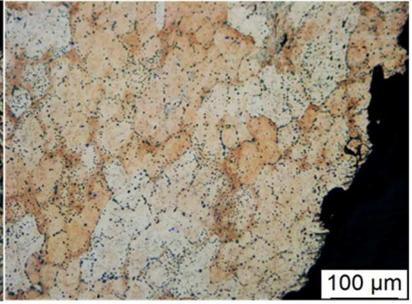
Of the fourteen samples, eleven were left as-cast, two (HBS/3 & JXT/4) were annealed and one (HBS/1) was too corroded to permit evaluation (Figure 4, Table 4). As all but JXT/1, an as-cast needle, are fragmentary, we cannot assess whether the thermo-mechanical treatments, or lack thereof, were adapted to form and use. JXT/1 was presumably either hard enough to do the task required, or that task, possibly ornamental, did not require hardness.



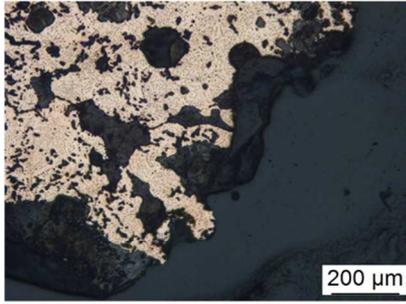
CH/HBS/2



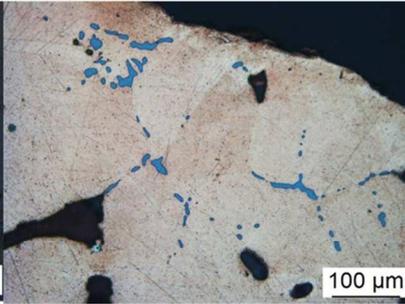
CH/HBS/3



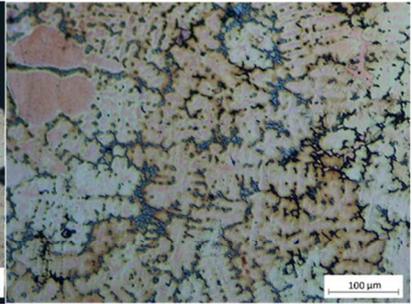
CH/HBS/4



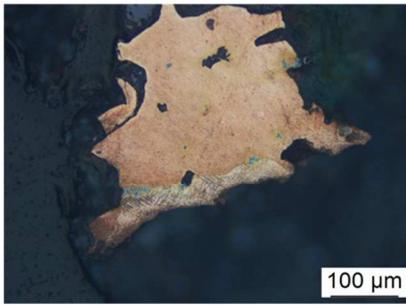
CH/HBS/5



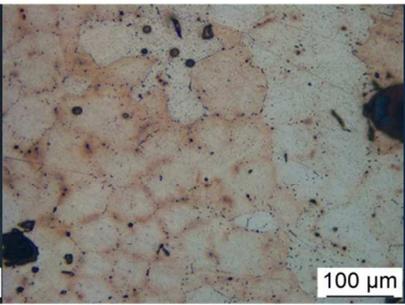
CH/HBS/6



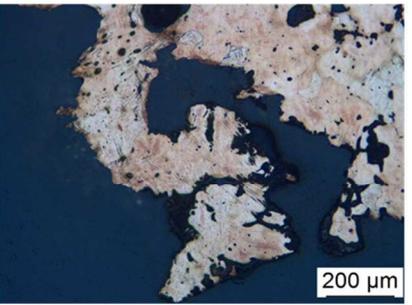
CH/JXT/1



CH/JXT/2



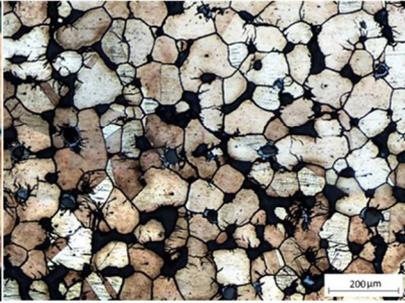
CH/JXT/3



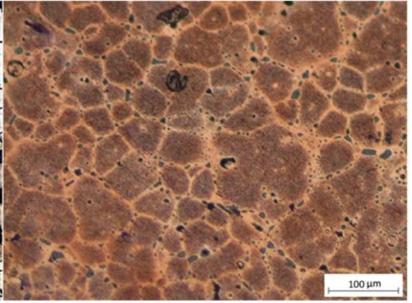
CH/JXT/4



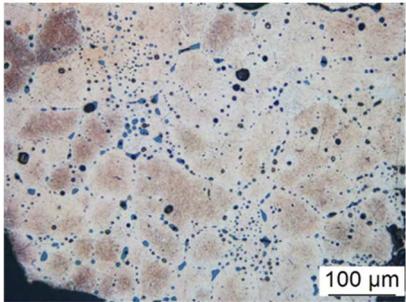
CH/JXT/5



CH/JXT/6



CH/JXT/7



CH/JXT/8

Figure 4: HBS/1, too corroded. HBS/2, Bronze. α phase solid solution with cored structure. Small amounts of non-metallic inclusions are present; HBS/3, Bronze. Recrystallized equiaxed and twin grains with slip bands and elongated inclusions; HBS/4, Copper. α phase solid solution with (α +Cu₂O) eutectic structure. Large quantities of non-metallic inclusions distributed along grain boundaries. Grains and inclusions were elongated; HBS/5, Bronze. α phase solid solution with (α +Cu₂O) eutectic structure; HBS/6, Copper. α phase solid solution with (α +Cu₂O) eutectic structure. Large-quantities of non-metallic inclusions and porosity is present; JXT/1, Bronze. Dendritic structure infilled of (α + δ) eutectoid and redeposited copper; JXT/2, Bronze. Equiaxed cored structure and slip bands; JXT/3, Copper. α phase solid solution with (α +Cu₂O) eutectic structure; JXT/4, Bronze. α phase solid solution with cored structure. Slip bands are present; JXT/5, Copper. α phase solid solution with (α +Cu₂O) eutectic structure. Large quantities of non-metallic inclusions distributed along grain boundaries; JXT/6, Bronze. Recrystallized equiaxed and twin grains; JXT/7, Copper. α phase solid solution with (α +Cu₂O) eutectic structure. Large quantities of non-metallic inclusions distributed along grain boundaries; JXT/8, Copper. α phase solid solution with (α +Cu₂O) eutectic structure. Large quantities of non-metallic inclusions distributed along grain boundaries.

Table 3: Elemental and metallographic data for the study samples, SEM-EDS detection limit is 0.1 wt.%.

SEALIP ID	Site	Catalogue	Sn	Pb	Cu	Fe	Al	S	Analytical total	Analysis	Corrosion	Alloy	Microstructure	Method
			wt. %											
SEALIP/CH/HBS/1	Hebosuo	87202	30,6%	0,0%	70,5%	0,2%	0,0%	0,0%	98,7	XRF	Medium	bronze	-	
SEALIP/CH/HBS/2	Hebosuo	87203	3,8%	0,9%	92,8%	0,0%	0,3%	0,4%	99,5	SEM-EDS	Medium	bronze	Alpha	As-cast
SEALIP/CH/HBS/3	Hebosuo	87204	5,7%	0,7%	91,1%	0,0%	0,3%	0,7%	99,7	SEM-EDS	Medium	bronze	Euhedral, regrown fine grains.	Heat-treated
SEALIP/CH/HBS/4	Hebosuo	87205	0,0%	0,1%	98,6%	0,0%	0,3%	0,8%	98,2	SEM-EDS	low	copper	Alpha. Sulphide grains concentrate along Cu grain boundaries.	As-cast
SEALIP/CH/HBS/5	Hebosuo	87207	1,2%	0,2%	98,2%	0,1%	0,8%	0,1%	97,8	SEM-EDS	high	bronze	Alpha	As-cast
SEALIP/CH/HBS/6	Hebosuo	87208	0,3%	0,9%	96,1%	0,1%	0,6%	0,7%	99,8	SEM-EDS	low	copper	Alpha	As-cast
SEALIP/CH/JXT/1	Shangxihe	87101	12,8%	1,0%	84,1%	0,2%	0,5%	0,6%	99,4	SEM-EDS	low	bronze	Alpha + Delta	As-cast
SEALIP/CH/JXT/2	Shangxihe	87102	4,1%	0,5%	94,5%	0,1%	0,5%	0,3%	99,6	SEM-EDS	low	bronze	Alpha	As-cast
SEALIP/CH/JXT/3	Shangxihe	87103	0,4%	0,7%	97,2%	0,0%	0,5%	0,3%	99,2	SEM-EDS	low	copper	Alpha	As-cast
SEALIP/CH/JXT/4	Shangxihe	87105	3,2%	0,6%	95,3%	0,1%	0,6%	0,1%	98,1	SEM-EDS	low	bronze	Alpha	As-cast
SEALIP/CH/JXT/5	Shangxihe	87106	0,1%	0,7%	99,1%	0,0%	0,6%	0,4%	97,6	SEM-EDS	low	copper	Alpha. Sulphide grains concentrate along Cu grain boundaries.	As-cast
SEALIP/CH/JXT/6	Shangxihe	87107	19,9%	0,7%	78,7%	0,2%	0,6%	0,3%	99,5	SEM-EDS	medium	bronze	Euhedral twinned grains	Heat-treated
SEALIP/CH/JXT/7	Shangxihe	87108_(1)	0,1%	0,5%	97,3%	0,0%	0,8%	0,8%	99,8	SEM-EDS	low	copper	Alpha	As-cast
SEALIP/CH/JXT/8	Shangxihe	87108_(2)	0,0%	0,5%	98,0%	0,0%	0,6%	0,8%	98,4	SEM-EDS	low	copper	Alpha	As-cast

4.2 Elemental

All but one of the samples has less than 1 wt. % Pb and should be considered unleaded alloys (Table 3). The exception is JXT/1, the needle, whose elemental composition lies on the threshold and it can also be considered unleaded given the normalised data. Eight of the samples are 'bronzes', with more than 1 wt. % Sn, and six samples have less, making them 'copper'. JXT/6 has relatively high tin levels, 19.8 wt. % Sn, and has been hot-worked and annealed (Figure 5), but it is not a 'high-tin' bronze in the sense of the South/Southeast Asian wrought and tempered tradition as the elevated tin content is at least partially due to corrosion (Bennett and Glover, 1992; Pryce et al., 2017; Srinivasan and Glover, 1995). Likewise, the very high tin content for HBS/1 is probably caused by post-depositional corrosion, which would have preferentially depleted the copper content and artificially inflated that of tin. It too should be considered a 'bronze'. Six of the samples have sulphur levels in excess of 0.5 wt. %, suggesting occasional unintentional use of S-bearing ores. Sulphur content would be reduced with prolonged heating, potentially over several cycles of use, so this minor alloying element may have been more prevalent in the raw smelted metal. Finally, the minor iron and aluminium contents (as oxides) of many samples, corroborate the macro and microscopically observed corrosion.

4.3 Lead isotopic

Table 4: Raw lead isotope data for the studied sites.

	206Pb/204Pb	err (2σ)	207Pb/204Pb	err (2σ)	208Pb/204Pb	err (2σ)	207Pb/206Pb	err (2σ)	206Pb/207Pb	err (2σ)	208Pb/206Pb	err (2σ)
SEALIP/CH/HBS/1	18,5802	0,0010	15,6544	0,0011	38,8535	0,0028	0,8430	0,0000	1,1862	0,0000	2,0912	0,0001
SEALIP/CH/HBS/2	18,5367	0,0024	15,6874	0,0022	38,8622	0,0059	0,8468	0,0000	1,1809	0,0000	2,0967	0,0001
SEALIP/CH/HBS/3	18,3957	0,0037	15,6474	0,0036	38,5618	0,0086	0,8510	0,0000	1,1750	0,0000	2,0961	0,0001
SEALIP/CH/HBS/4	18,5758	0,0029	15,5934	0,0023	38,8172	0,0058	0,8400	0,0000	1,1905	0,0000	2,0897	0,0001
SEALIP/CH/HBS/5	18,2684	0,0010	15,6837	0,0011	38,4563	0,0031	0,8590	0,0000	1,1641	0,0000	2,1051	0,0001
SEALIP/CH/HBS/6	18,5003	0,0007	15,6148	0,0008	38,6821	0,0026	0,8446	0,0000	1,1840	0,0000	2,0909	0,0001
SEALIP/CH/JXT/1	18,8000	0,0007	15,7537	0,0008	39,3322	0,0024	0,8385	0,0000	1,1926	0,0000	2,0922	0,0000
SEALIP/CH/JXT/2	18,4693	0,0011	15,6232	0,0011	38,6444	0,0029	0,8464	0,0000	1,1815	0,0000	2,0924	0,0001
SEALIP/CH/JXT/3	18,3446	0,0010	15,6738	0,0012	38,2168	0,0036	0,8550	0,0000	1,1696	0,0000	2,0833	0,0001
SEALIP/CH/JXT/4	18,5441	0,0007	15,6939	0,0009	38,8820	0,0025	0,8468	0,0000	1,1809	0,0000	2,0967	0,0001
SEALIP/CH/JXT/5	18,2059	0,0012	15,6395	0,0010	38,3081	0,0027	0,8595	0,0000	1,1634	0,0000	2,1042	0,0001
SEALIP/CH/JXT/6	18,3494	0,0016	15,6616	0,0015	38,5274	0,0040	0,8540	0,0000	1,1710	0,0000	2,0998	0,0001
SEALIP/CH/JXT/7	18,4218	0,0031	15,5998	0,0030	38,5461	0,0079	0,8472	0,0000	1,1803	0,0000	2,0924	0,0002
SEALIP/CH/JXT/8	18,3901	0,0006	15,5722	0,0188	38,4762	0,0156	0,8471	0,0002	1,1805	0,0002	2,0923	0,0000

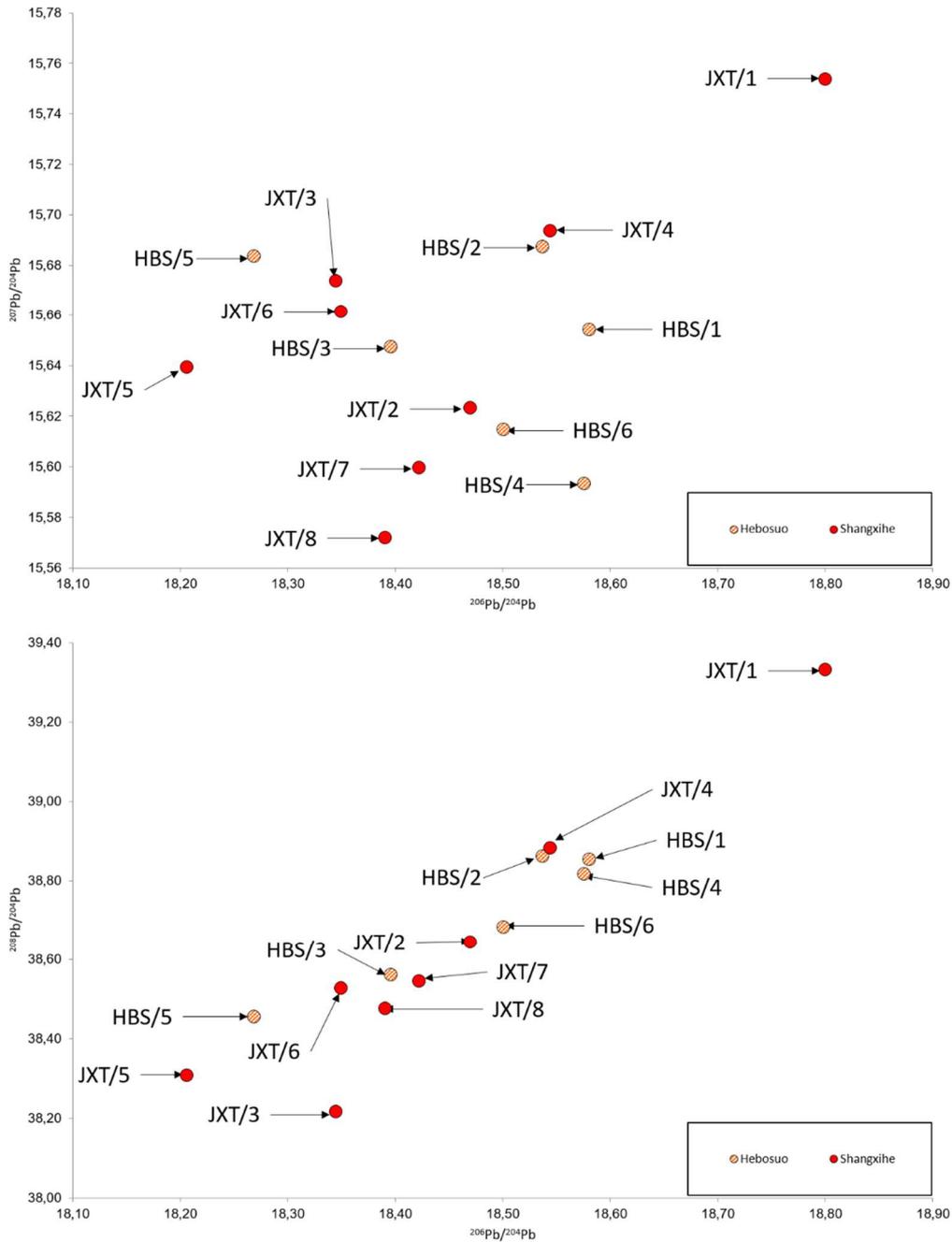


Figure 5: Lead isotope biplots for the study sites. Error bars are smaller than symbols.

All Hebosuo and Shangxihe samples produced lead isotope ratios with low and consistent instrumental errors (Table 4) and the data plot in one, largely intermixed, cluster (Figure 5). JXT/1, the borderline leaded/unleaded needle, is a possible outlier, and is a borderline ‘highly radiogenic lead’ sample, in the Chinese archaeometallurgical sense (Liu et al., 2018; Wang et al., 2020). JXT/1’s plot does not seem to be a function of its historical age as the other late 2nd millennium BC sample, JXT/2, plots in the middle of the main cloud. Any differences in ratios appear minor and are consistent with the study artefacts having been produced with copper from a similar geological environment, albeit from a range of mineralisations.

5.0 Discussion

As is often the case, the study data alone cannot be used to infer a great deal, beyond a general technological and geochemical homogeneity for an assemblage spanning up to six centuries. The study data are, however, more enlightening when compared with intra and inter-regional datasets. In this following sections we will use the terms ‘short’, ‘medium’ and ‘long-range’ to describe the various exchange networks we propose. These categories are somewhat arbitrary for the time being but we intend to give an impression of ‘frequent’, ‘occasional’ and ‘rare’ social interactions across the SAM, with riverine travel vastly reducing energy costs as opposed to overland routes.

5.1 Yunnan comparators

Before discussing archaeological datasets, it should be noted that a substantial geological lead isotope database exists for China, including Yunnan and its immediate neighbours (Hsu and Sabatini, 2019). These data evidence very considerable variation across the national territory, including ‘highly radiogenic lead’ (HRL) deposits, which have been the subject of much debate over their role in early Chinese metal supply (Liu et al., 2021, 2018; Wang et al., 2020). As general geological variation is beyond the scope of this paper, and the present study assemblage concerns copper exchange only, we have plotted only LI data from galenas and k-feldspars labelled as coming from copper and ‘polymetallic’ deposits, and excluded those labelled as gold, lead-zinc, mercury and tungsten deposits (Hsu and Sabatini, 2019). The copper mineral data for Yunnan (Figure 6) exhibit very high variation, including HRLs, and are poorly compatible with the Hebosuo and Shangxihe artefacts. However, the Yunnan polymetallic minerals, while not tightly clustered, certainly encompass the study artefact signatures and can be considered broadly compatible (Figure 6).

We apply the same rule to the Yunnan artefactual dataset, limiting our comparison to unleaded (<1 wt. % Pb) alloys. Commencing with production signatures, Guangfentou provides the only available dataset (Zou et al., 2019), located only ca. 50 km to the south-south-east of Hebosuo and Shangxihe, in the foothills south of Xingyun Lake (Figure 1). Guangfentou is a primary (smelting) and secondary (refining and casting) copper production site excavated in 2011-12, with ca. 600 m² exposed and deposits up to 5.2 m deep of the complete estimated site area of 170000 m². The stratigraphy presents two main phases with up to 17 layers, with the lower layer ranging from the Eastern Zhou to Western Han (770 BC – AD 25) and the upper layer from the Ming and Qing dynasties (AD 1368 – 1912). Slag and non-ferrous metal was found in both layers, with elemental and microstructural analysis of the slag demonstrating the likelihood of copper smelting, and the same analyses for metal samples identifying both unleaded copper and bronze, as well as possible cassiterite cementation. Although the earliest phase at Shangxihe is earlier than those attested at Guangfentou, we can nevertheless compare lead isotope signatures as these do not change in human timescales. As the authors note (Zou et al., 2019), their LI data for metal samples (no slag appears to have had LIA) do not cluster tightly, suggesting either variety of local mineral feedstock was used if the metals were

smelted on site (their LI values are compatible with Yunnan polymetallic minerals, Hsu and Sabatini, 2019), or the producer site also imported metal (as known in two cases in prehistoric MSEA, Pryce et al., 2014). Nevertheless, plotting Guangfentou, Hebosuo and Shangxihe data together reveals a reasonable level of consistency, and thus short-range metal exchange networks, as might be expected from sites located in such proximity (Figure 6).

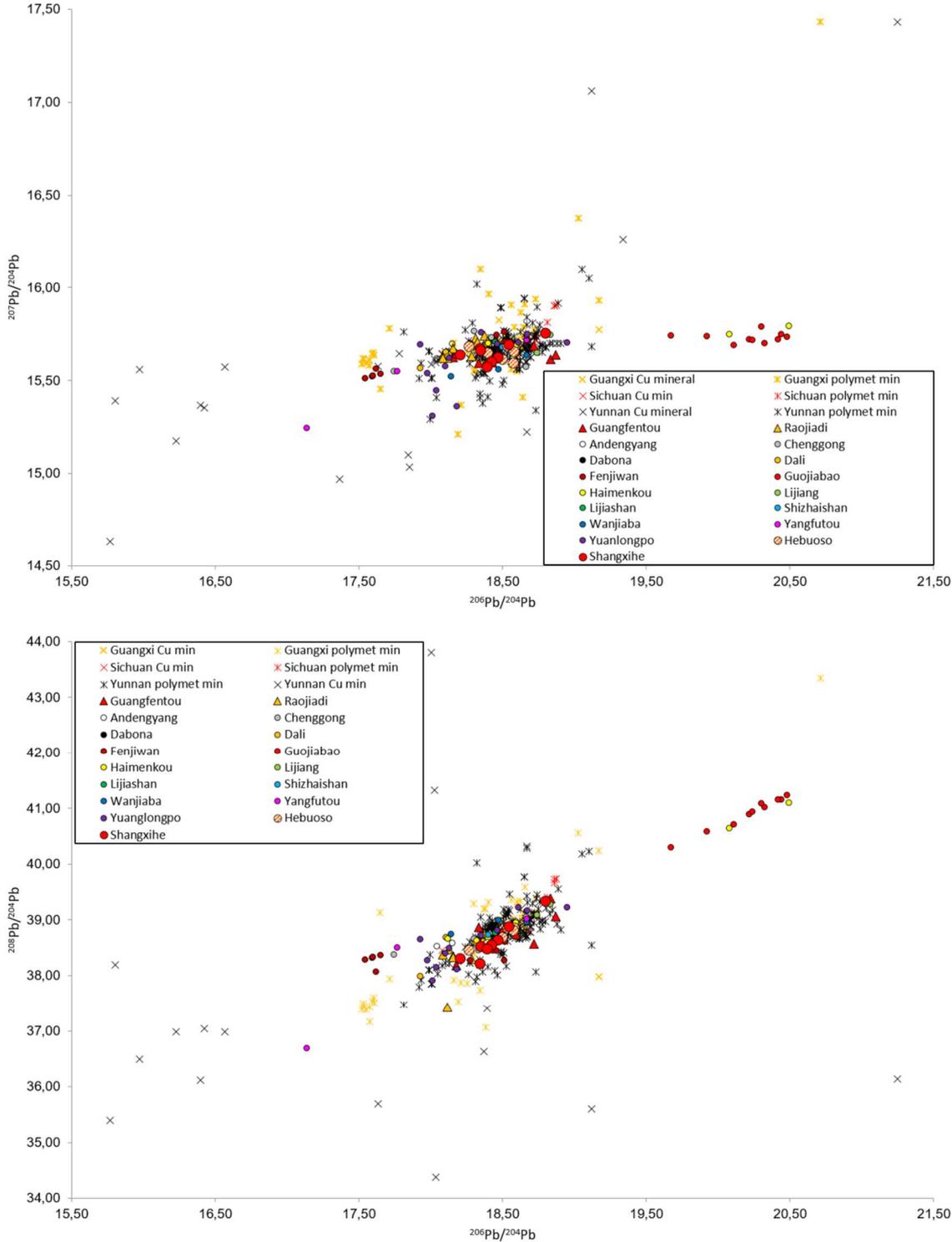


Figure 6: Lead isotope ratios plots for the study sites and available data for Guangfentou (Zou et al., 2019), Raojiadi and Fenjiwan (Chen et al., 2020), Guojiabao (Wang et al., 2020), Chenggong, Dabona, Dali, Haimenkou, Lijiang, Lijiashan, Shizhaishan, Wanjiaba and Yangfutou (Cui and Wu, 2008), Andengyang and Yuanlongpo (Anon., 2020), and

copper/polymetallic mineral signatures from Yunnan, Sichuan and Guangxi (collated by Hsu and Sabatini, 2019). Error bars are smaller than symbols, with the exception of the older Cui & Wu 2008 data, whose errors are at least an order of magnitude larger.

Closer still to the study sites, limited data are available from the royal tomb of Shizhaishan itself. The three unleaded samples are Dian period, thus several centuries younger than nearby Hebusuo and Shangxihe, but their LI data can still be used to consider local production and exchange networks. Figure 6 indeed shows excellent consistency with the study samples and Guangfentou. Similar can be said of the limited unleaded samples from the Dian cemeteries of Chenggong, Lijiashan and Yangfutou, all located in the environs of the Yunnan provincial capital, Kunming, and not more than 40 km from the study sites (Anon., 2002a, 2002b; Murowchick, 2001). All Lijiashan LI data plot closely within the study sample cloud but both Chenggong and Yangfutou have outliers, of which two are consistent with each other (Cui and Wu, 2008).

Moving further afield, the Wanjiaba cemetery lies ca. 120 km west-north-west from the study sites. Excavations in 1975-76 revealed 79 graves, which were dated to the 8th-4th c. BC and are thus of greater chronological compatibility with the study sites (Murowchick, 2001). The three unleaded samples plot within and immediately adjacent to the 'Kunming' cluster (Cui and Wu, 2008), and are strongly suggestive of the same or similar mineral resources being exploited to supply sites within a substantial radius.

This pattern appears to hold for the 6th-4th c. BC cemetery of Dabona, located ca. 215 km west-north-west of the study sites. Two graves contained a number of bronzes, stylistically comparable to those from Wanjiaba (Anon., 2016; Murowchick, 2001). Only one unleaded sample has LI data, which likewise plots with the aforementioned sites (Cui and Wu, 2008). Three unleaded samples were also available from 'Dali', and refer to two sites, Xiangyun and Yongping, of Warring States to Western Han date in the environs of Dali city, which is ca. 260 km west-south-west of the study sites. These data plot adjacent to the 'Kunming cluster' but not within it, suggesting other, nevertheless geologically similar, copper sources may have been active in Yunnan supply.

The presence of other copper sources become more apparent once we push out to ca. 340 km north-west of Hebusuo and Shangxihe, where the site of Haimenkou is located just south of Jianhu Lake in Jianchuan County (Figure 1). Excavated in 1957 and 1978, Haimenkou was formerly claimed to have the earliest Bronze Age phase in Yunnan but its radiocarbon chronology is now understood to have been complicated by potentially intrusive old wood (Li Xiaocen et al., 2015). Excavations since 2008 have improved contextual resolution but copper/bronze and iron appear simultaneously from layer VI, which is now argued to be dated from c. 1200 BC (late Shang/early Western Zhou periods, Liu et al., 2021); with probably intrusive iron but also highly compatible dating with both the present study sites and the earliest MSEA metallurgy. Seven lead isotope results for Haimenkou unleaded copper-base artefacts are available (Cui and Wu, 2008: 144-145; Xiaocen et al., 2015: Table 1 indicates sample 9915 had 1.3 wt. % Pb and 9916 had 5.3 wt. Sb). Five of the samples are generally consistent with those for Guangfentou, Yunnan polymetallic minerals and the 'Kunming cluster', and we note particular compatibility between: bracelet '4' and HBS/1, copper adze '28' with JXT/6, and bracelet '33' with HBS/2 and JXT/4. (Figure 6). However, two samples, '30' and '32', are more radiogenic, possibly indicating the exploitation of regional HRL mineralisations (Hsu and Sabatini, 2019).

The final unleaded bronze LI data come from Lijiang in Ninglang county, a Warring States to Western Han dated cemetery ca. 345 km northwest of the study sites. These samples plot within the 'Kunming cluster' and, combined with the other Yunnan unleaded bronze data suggest there may have been a shared copper source whose produce was distributed over hundreds of kilometres, in addition to the presence of other more radiogenic copper producers. The Yunnan dataset strongly attests the

presence of both short and medium-range metal exchange networks, and our study data fit well within that trend.

5.2 Sichuan comparators

Sichuan is the province to the north of Yunnan but the sites discussed below are actually closer to our study area than Dabona, Haimenkou and Lijiang (Figure 1). Located in Huili County, Liangshan Prefecture, ca. 190 km north-north-west of our study area, the 15th c. AD site of Raojiadi furnished copper slag, nine samples of which were analysed by Chen *et al.* (2020) to give an impression of local mineral geochemistry. We are not evaluating historical exchange systems between sites up to 2500 years distant in time but rather comparing and contrasting geological data expressed in lead isotope ratios that might indicate the possibility of concurrent metal networks. The slag samples' lead isotope signature partially overlaps that of Guangfentou slag signature, as well as that of the sole Sichuan copper mineral data point, from a mine located ca. 160 km northwest of Raojiadi. The Sichuan polymetallic mineral data are not compatible but the mineralisation is ca. 525 km northwest of the archaeological site, suggesting closer 'Yunnan' minerals may have been smelted (Figure 6). As the available Yunnan (Guangfentou) and Sichuan (Raojiadi) copper production sites do not seem to have very tight lead isotope signatures, all we can say at present is that the Hebosuo and Shangxihe artefacts are broadly consistent with both Guangfentou and Raojiadi, which is a positive step given the wide variation of regional mineral LI data.

Situated ca. 1 km to the east of Raojiadi, the cemetery site of Fenjiwan contains approximately 150 supine burials, with predominantly re-used domestic pottery grave goods and relatively few metal artefacts (spears, knives, bracelets and ornaments), typologically-dated to the Warring States period (476-221 BC) (Chen *et al.*, 2020). The analysis of ten simple copper-base bracelets revealed six were leaded bronze (2.1-3.0 wt. % Pb), and are thus not directly comparable to the present study data, but four contain c. 0.5 wt. % Pb and can be considered with respect to Hebosuo and Shangxihe samples. The six leaded bronze bracelets form an outlying (less radiogenic) cluster but the four unleaded bronze bracelets are broadly consistent with the Raojiadi copper slags and most of the present study samples. We note particular compatibility between samples HL/9 and HBS/5, as well as HL/10 with JXT/4 and HBS/2 (Figure 6).

The Guojibao cemetery, also in Huili County and ca. 350 km from the study sites, has shaft and cyst graves with pottery and copper-base spearheads, dagger-axes and swords typologically attributed to the Warring States period (Wang *et al.*, 2020: 4). The ten socketed spearheads analysed by Wang *et al.* were almost pure copper, >99 wt. % Cu, and with low lead contents <0.3 wt. % Pb, and can thus be compared directly to the Hebosuo and Shangxihe data. Figure 6 clearly shows there is no compatibility at all with the present study data or regional copper and polymetallic mineral data but good compatibility with the two radiogenic Haimenkou samples, suggesting the presence of multiple medium-range metal exchange networks being supplied by as yet uncharacterised regions.

Guizhou province lies to the northeast of Yunnan but we were unable to find either copper/polymetallic mineral or archaeological LI data in regional databases (Hsu and Sabatini, 2019).

5.3 Guangxi comparators

To the east of Yunnan lies the province of Guangxi, which completes the border with northern Vietnam and borders the Gulf of Tonkin (Figure 1). Guangxi, together with neighbouring Guangdong,

and sometimes including Hainan province and parts of northern Vietnam, were formerly referred to as Lingnan. This region, south of the Nanling Mountains, constitutes a geographic frontier with the Yangtze Valley of the Central Plains, and also was the historical territory of the Nanyue kingdom, conquered by the Han in the 2nd c. BC (Allard, 2018). Lingnan, whose EBA chronology is compatible with Yunnan's, has been hypothesised as being populated by 2nd-1st millennium BC metal-using cultures likely to have transmitted filtered forms of sophisticated Central Plains metal technologies to Mainland Southeast Asia (Ciarla, 2007; Higham, 1996; Pigott and Ciarla, 2007)¹.

Given the limited archaeometallurgical data available, we will limit our Lingnan discussion to Yunnan's immediate neighbour, Guangxi. The bulk of these data concern bronze drums dated 2nd c. BC to 9th c. AD (Lu et al., 2020), but, being uniformly heavily-leaded, they fall out of our copper-exchange remit. However, we have located LI data from the sites of Andengyang and Yuanlongpo, located in Wuming district immediately north of Nanning city (Figure 1). The Yuanlongpo cemetery is dated to the early-mid 1st millennium BC and was specifically cited by Roberto Ciarla (2007) as having potential technological links to MSEA metallurgy. The Andenyang cemetery dates to the Warring States period but, as per the non-contemporary sites above, can be usefully compared for regional consumption signatures. What we have not been able to establish from the Wuming report (Anon., 2020) is whether these artefacts are leaded or unleaded. On the basis that late 2nd/early 1st millennium BC alloys tend to be unleaded, and for Andenyang we will just take the chance, Figure 6 shows Yuanlongpo has three slight outliers from the 'Kunming cluster' but these are still within the range of values for Guangxi copper and polymetallic mineral signatures. Overall, the available Guangxi unleaded bronze artefact LI data offer good compatibility with the study sites, which lie ca. 600 km to the west-north-west but most of those could be covered by travel on the Yong and You tributaries of the Pearl River.

Whilst these archaeological LI data from Yunnan, Sichuan and Guangxi fulfil the requirements of the provenance methodology, in that they appear to plot more tightly than regional LI data for mineral deposits, we nevertheless remain cautious as to labelling the 'Kunming cluster' as a real historical exchange network. Reaching a 'burden of proof' will take the substantial accumulation of archaeometallurgical data, from assemblages with detailed context, morphological and chronological information but we believe it reasonable, at the present state of research, to propose the possibility of metal exchange networks linking Hebuoso and Shangxihe with sites across southwest and southern China.

5.4 Mainland Southeast Asian comparators

¹ Not necessarily to the exclusion of potential transmissions from Yunnan.

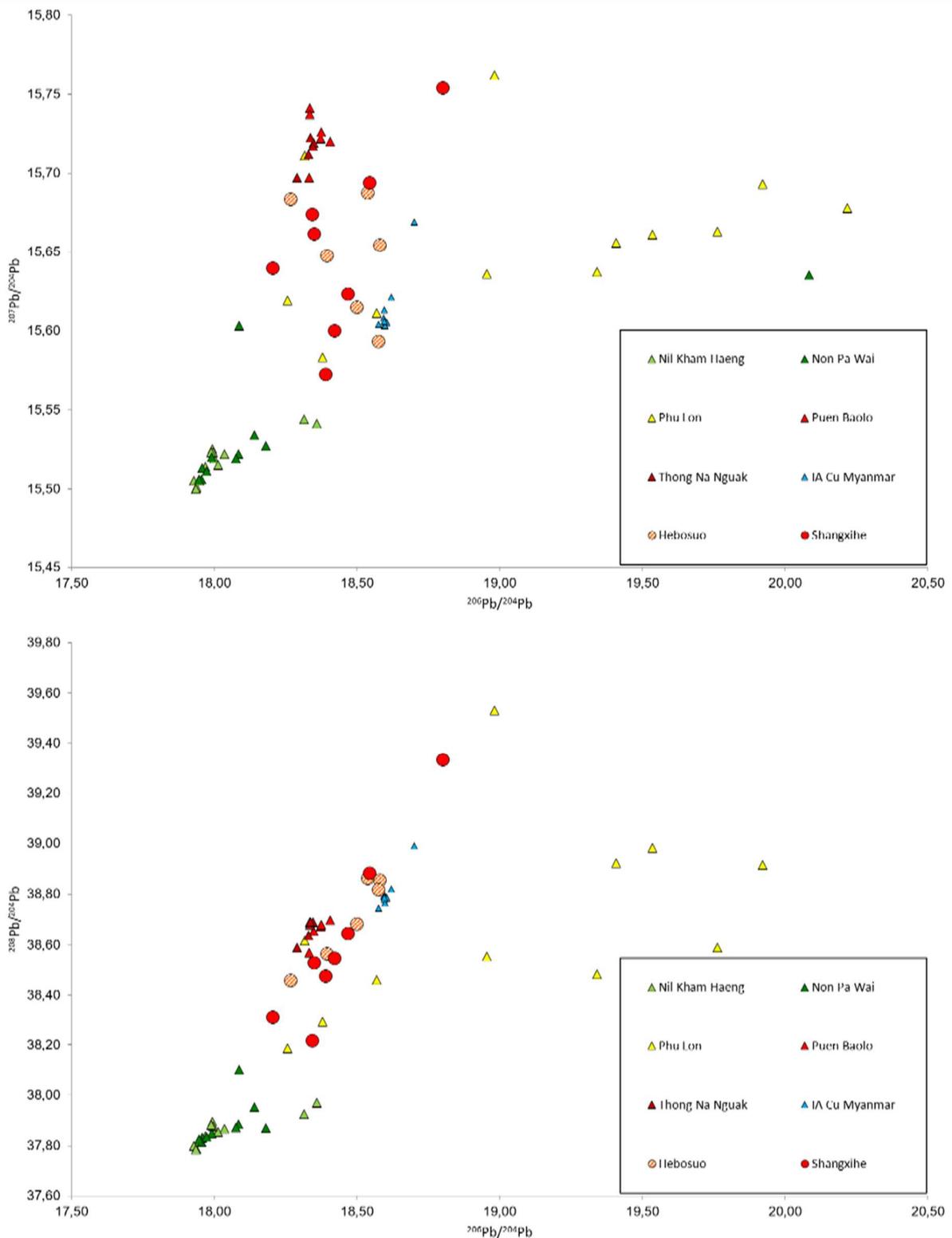


Figure 7: Raw lead isotope data for Hebosuo and Shangxihe plotted against the three known MSEA prehistoric primary copper production sites: Non Pa Wai and Nil Kham Haeng in the Khao Wong Prachan Valley of central Thailand, Phu Lon in northeast Thailand, and Puen Baolo and Thong Na Nguak in the Vilabouly Complex of central Laos (Pryce, 2014). Error bars are smaller than symbols.

Above we discussed Chinese comparators 50-600 km distant from Hebosuo and Shangxihe, and thus there is no reason to exclude MSEA, when the Vietnamese border is 215 km away and that of Myanmar 360 km and no geological discontinuity between the two regions (Cheng et al., 2016; Khin

Zaw et al., 2014; Liu et al., 2021). To date, MSEA has little to no available lead isotope data (they are proprietary or inexistent) for its complex metallogenic geology, with which we might compare the study samples. However, MSEA does benefit from having an archaeological copper-base production and consumption database approaching 1000 samples. As such, we will limit our comparison to broadly contemporary, late 2nd/early-mid-1st millennium BC 'Bronze Age', artefacts, which are a distinct minority in the SEALIP/BROGLASEA dataset (and absent from Prof. Hirao's, 2013). Firstly, by way of thoroughness, we compare the study samples' LI signatures against those of the known prehistoric MSEA copper production systems, all of which are proven (Cadet et al., 2019; Higham et al., 2020; Pigott et al., 1997; Pryce et al., 2011a for the Khao Wong Prachan Valley of central Thailand and the Vilabouly Complex in central Laos) or reasonably surmised (for Phu Lon in northern Thailand Pigott and Weisgerber, 1998) to have been active in the MSEA Bronze Age. We also include a probable primary production signature, which is tightly defined by Iron Age (IA) unalloyed copper wire bundles (possibly money) found in central Myanmar, rather than a physical mining/smelting site (Dussubieux and Pryce, 2016; Pryce et al., 2018a). Figure 7 clearly shows the Hebosuo and Shangxihe samples do not have any compatibility with the Thai and Lao signatures, and that their clustering is indeed loose as compared to the Vilabouly Complex and Khao Wong Prachan Valley data (Figure 7). However, HBS/4 has good consistency with the 'Myanmar' copper signature, suggesting there may be a shared raw material source for these sites, quite possibly in Yunnan itself given the proximity. With regards to consumption comparanda, MSEA Bronze Age sites with reliable dating are few in number but luckily their metal assemblages have mostly been integrated within SEALIP/BROGLASEA.

Vietnam is the closest MSEA nation to our study sites, and it is from Đại Trách, a Đồng Dâu culture site (ca. 1300 – 1000 BC, though admittedly less securely dated) in Bắc Ninh Province (Figure 1) that we observe some compatibility and evidence for medium-range exchanges, namely between HBS/1 (a bronze fragment) and DTR/9 (a bronze knife), and to a lesser extent between JXT/1 (a bronze needle) and DTR/5 (a needle), DTR/7 (a fishhook), and DTR/11 (a spearhead socket, Figure 8). The two other Bronze Age Vietnamese sites for which we have lead isotope data, Thành Dên and Gò Mun, do not offer any close consistency but we recognise that there may be contemporary north Vietnamese production sites, and the border with Guangxi is only ca. 130 km to the north (Pryce et al., 2021).

Moving further south, we see compatibility between HBS/1 and BC/5, an early-mid 1st millennium BC bronze tanged arrowhead from Ban Chiang in northeast Thailand (Figure 8). This is the same cluster in which we previously noted DTR/9, suggesting a shared metal network spanning 750+ geodesic kilometres, 'long-distance' by any reasonable definition. No further Thai Bronze Age samples have high consistency and the sole available Bronze Age sample from Laos, TPT/1, a bronze axe from Tam Pà Ping in Houaphan province (Pryce and Cadet, 2018), offers no compatibility.

Looking west from Yunnan the situation becomes more interesting still. Until recently the very few Myanmar sites attributed to the EBA lacked any radiometric dating but this changed radically with the excavation of Oakaie and the re-excavation of Nyaung'gan by the *Mission Archéologique Française au Myanmar*. This investigation identified a solid Neolithic to Bronze Age transition at ca. 1000 BC (Pryce et al., 2018b), only slightly later than Thailand (Higham et al., 2015) and almost identical to Yunnan (Yao et al., 2020). Previous analyses showed that some of the Oakaie and Nyaung'gan metal artefacts presented good consistency with copper production in central Thailand and central Laos but most of the assemblage had lead isotope signatures incompatible with MSEA copper production and only weakly compatible with MSEA copper/bronze consumption. Whilst it is unclear whether the compatible samples arrived in Myanmar as raw/scrap metal or finished objects, it is noticeable that they appeared from the outset of the local Bronze Age (Pryce et al., 2018a).

When compared with the present study data we note high consistency between OAI2/1, an early 1st millennium BC bronze rod, and HBS/3, a bronze fragment. Likewise, there is strong consistency between OAI/1, a late 2nd/early 1st millennium BC bronze axe, and MHT/1, a bronze fragment from nearby Mon Htoo, with HBS/4, a copper fragment, and JXT/4, a bronze fragment. Finally, there is good consistency between OAI3/6, a bronze ring fragment, and HBS/6, a copper fragment, and JXT/2, a bronze fragment, all of which are broadly compatible with Guangfentou copper production. Thus it is possible we have long-distance metal networks extending 800+ geodesic kilometres west from Hebusuo and Shangxihe, most of which would be potentially riverine via the Nanting, Irrawaddy and Chindwin. Potential compatibility between northern Myanmar IA and northern Vietnamese BA copper-base artefacts has previously been noted but the direct path between them is logistically improbable (Pryce et al., 2021). What the addition of the current 14 Yunnan samples adds is a hint of the apex of these relationships, with the full arc of metallurgical interaction possibly exceeding 1500 km.

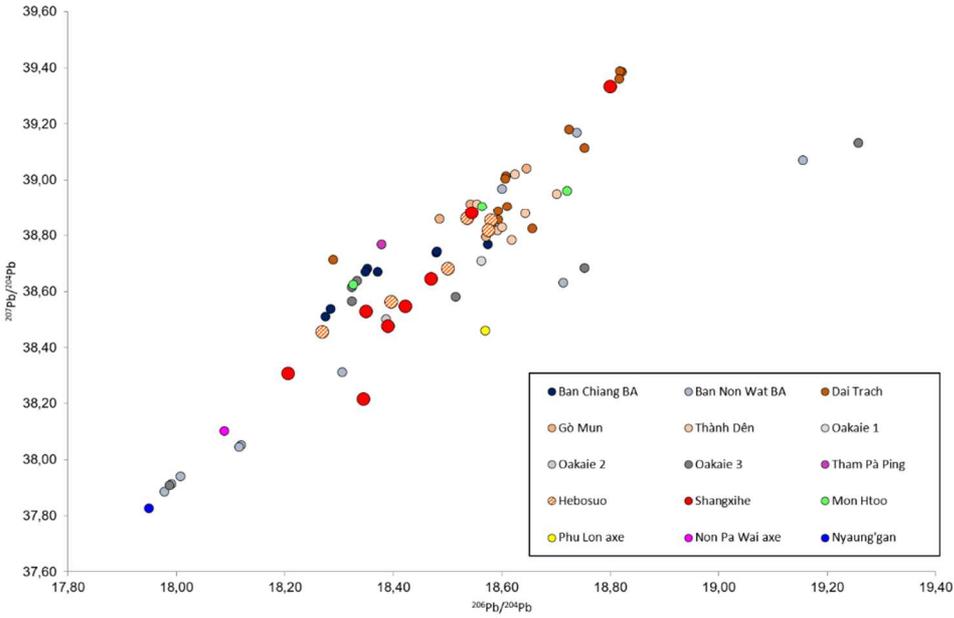
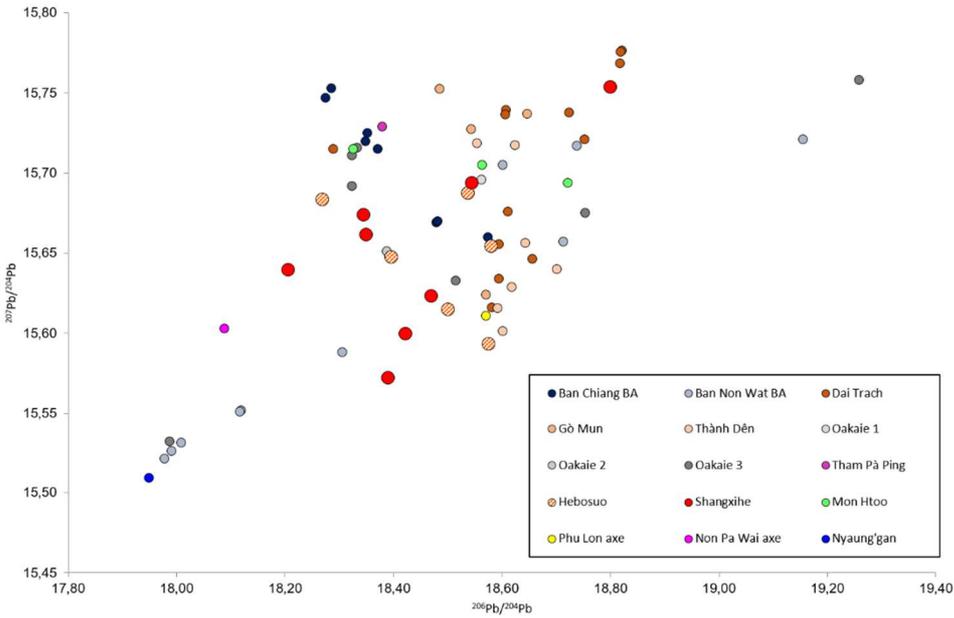


Figure 8: Raw lead isotope data for Hebosuo and Shangxihe plotted against BROGLASEA's MSEA Bronze Age consumption dataset: Ban Chiang, Ban Non Wat, Non Pa Wai (single axe), and Phu Lon (single axe) in Thailand, Dai Trach, Go Mun and Thanh Den in Vietnam, and Mon Htoo, Nyaung'gan (leaded spearhead) and Oakaie 1-3 in Myanmar, and Tam Pà Ping in Laos (Pryce, 2019; Pryce et al., 2021, 2018a, 2014a). Error bars are smaller than symbols.

5.4 A Centre-Periphery relationship?

In addition to Hebosuo and Shangxihe offering support for hypothesised short (ca. 50 km) and medium (ca. 300 km) relationships with sites in Yunnan and Sichuan, the combined datasets above suggest there may have been long (ca. 750-1500 km) range networks extending as far as Myanmar, Thailand and Vietnam. We are not suggesting a single producer or producing-population was directly responsible for this exchange patterning, 'down-the-line' relationships (*sensu* Renfrew et al., 1969) being more likely, but the networks appear to have been present from the outset of the EBA in the late 2nd millennium BC. The very similar dates for the Neolithic to Bronze Age transition across northern MSEA implies long-range interactions were not only present but active, resulting in rapid disseminations of relatively complex technologies (Pryce et al., 2018b).

A tone of caution cannot be avoided. The existence of such networks was predicted (Higham, 2021, 1996; Pigott and Ciarla, 2007; White, 1988; White and Hamilton, 2009) and they are, to some extent, obvious, but they are not yet irrefutably evidenced. The number of well-contextualised, dated and analysed Bronze Age metal artefacts remains low across the SAM, and many of the MSEA signatures we have plot in an 'isoscape' densely occupied by IA and later artefacts. Ergo, in addition to unknown and overlapping production signatures, there could be many isotopically-intersecting but historically-irrelevant signature compatibilities. As much as lead isotope archaeometallurgy is 'scientific', the interpretation of results still requires archaeologists' subjective judgement, which is often rendered difficult by a lack of clear artefact typology and poor dating. It is also noteworthy that whilst Myanmar's currently earliest metal artefact, OAI1/1, is consistent with Hebosuo and Shangxihe signatures, Thailand's oldest bronzes, BNW/1-3 (Pryce, 2011) and NPW/1 (Pryce et al., 2011b) do not yet have any comparanda. Given Thailand lies to the east of Myanmar, maybe the source of these artefacts was to the east of Yunnan, i.e. Guangxi or Guangdong, or even further north.

As regards the nature of late 2nd-early 1st millennium BC interactions between Yunnan and MSEA, a core-periphery relationship does not seem to fit the available data. Were this the case we might expect to identify: a relatively consistent presence of Yunnanese lead isotope signatures at MSEA EBA sites, representing exports from a metal-rich core being exchanged against an archaeologically poorly-visible MSEA product; and/or MSEA lead isotope signatures in Yunnan, representing imports as payment for other goods or services, or indeed as tribute. This is not what the current picture shows. Instead we see a complex web of metal exchanges with, indeed, some Yunnan metal present in both north-central Myanmar and northern Vietnam, but also a criss-crossing of supply in central Thai and central Lao copper to north-central and southern Myanmar, southern Thailand but not to northern Vietnam, and an apparently shared copper source in what might well be Myanmar's Shan State or southern Yunnan. Many of these putative links do not make much sense when plotted on a map in terms of geodesic distance, as they often cut perpendicularly across substantial mountain ranges and river systems. Whilst not impossible to traverse, these routes would have a considerable energy cost. The distribution of producer and consumer populations appears more logical when viewed from the perspective of major river systems. The study sites on Dian lake are connected to the Red and Yangtze rivers by tributaries. The Red River connects directly downstream to the aforementioned lowland sites in north Vietnamese sites (Pryce et al., 2021), while interactions with upland sites such as Haimenkou in Lake Jianhu and Erhai are reached via tributaries of the Yangtze

River. Our admittedly preliminary findings suggest the existence of at least two medium-range networks that facilitated intra-regional exchanges between highland-highland and highland-lowland groups from the late second millennium BC (Figure 9). From western Yunnan, numerous rivers like the Shweli and Nanting cross the present-day Myanmar border and reach the Irrawaddy basin, which flows to the confluence with the Chindwin and thence the Myanmar sites mentioned above (Pryce et al., 2018a). Likewise, the identification of the central Lao copper production signature in EBA and IA contexts from peninsular Myanmar and Thai sites (Pryce, 2018 and unpublished data) is suggestive that metal and metal products were moving by sea from the late 2nd-early 1st millennium BC – this potentially being part of the route by which Thai and Lao metal reached north-central Myanmar (Pryce et al., 2018a). Such a tangled web does not hint at a core and its peripheries but rather an extended network of disparate metal-producing and metal-consuming communities interacting over considerable distances for a considerable period of time. Indeed, the two scenarios highlighted above could well be imagined as presaging the Southwest (Yang, 2004) and Maritime (Bellina et al., 2019) Silk Roads, both attested to be active by the late 1st millennium BC, as well as following the ‘paths of Neolithization’ (*sensu* Rispoli, 2007) thought to have been taken by southern Chinese farmers from the end of the 3rd millennium BC (Charles F. W. Higham et al., 2011; Higham, 2021).

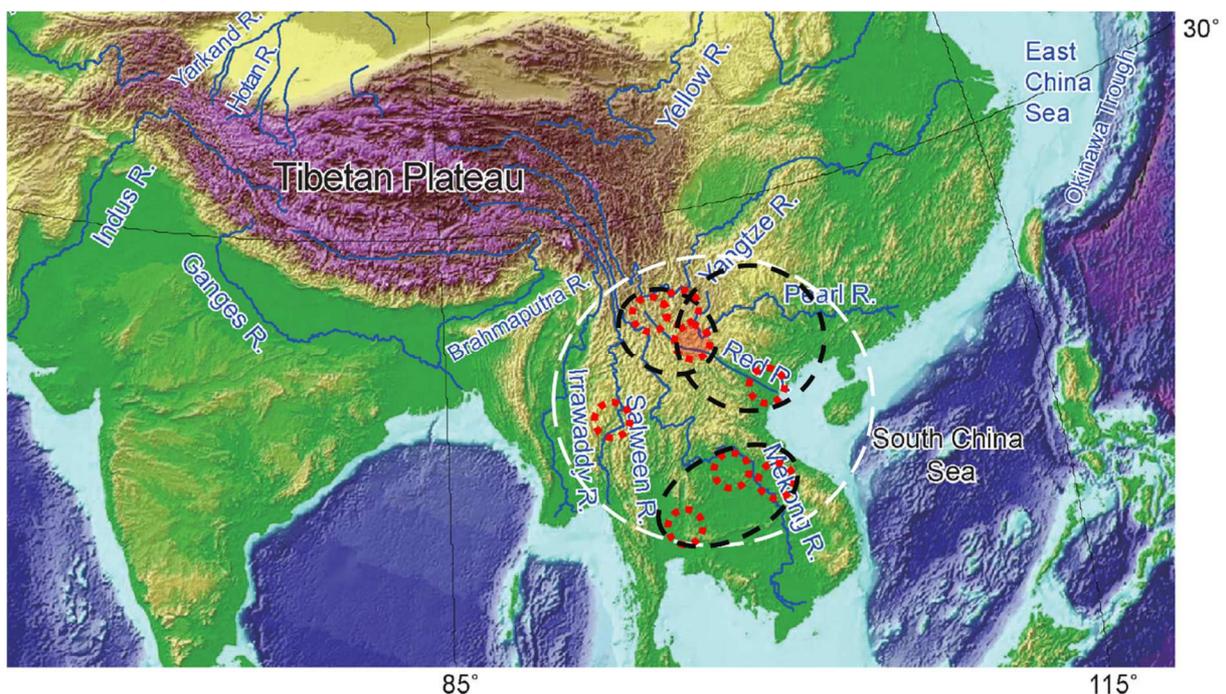


Figure 9: Topographic and major river map adapted from Zheng et al. (2015: Figure 1). The present study sites and their short-range interactions are located within the shaded red ellipse with red dotted outline. The other red dotted ellipses likewise represent, schematically, short range interaction zones of the metal producing and consuming loci mentioned in the text: north-central Myanmar, western Yunnan, southern Sichuan, the Red River delta, central Thailand, northeast Thailand and central Laos. The black dashed ellipses represent medium range interaction zones, linking the present study area with western Yunnan and southern Sichuan, and the Red River delta, respectively. Finally, the white dashed ellipse represents, very broadly, the full extent of the Southeast Asian Massif long range metallurgical interaction zone.

6.0 Conclusion

With this paper we demonstrate that fourteen copper-base artefacts from the Early-Mid Bronze Age (11th-6th c. BC) sites of Hebosuo and Shangxihe in the southwestern Chinese province of Yunnan were all unleaded bronzes, mostly left as-cast but with occasional thermo-mechanical treatments. The lead isotope signatures of these bronzes were not tightly clustered but were nevertheless broadly

consistent with metal production and consumption sites in western, central and southern Yunnan and southern Sichuan and Guangxi. When compared to the Mainland Southeast Asian non-ferrous/non-precious metallurgical datasets, we observe some compatibility with Bronze Age sites in Myanmar, Thailand and Vietnam. Whilst the west-east geographical distribution of these sites might appear to represent a horizon of Early Bronze Age cultures moving south from China's much older metal-using societies, the lead isotope data give an impression of the complex mountainous and riverine networks responsible for the distinctly radial dissemination of metals and metal technologies among disparate late 2nd/early 1st millennium BC populations.

Acknowledgements:

The isotopic analyses presented here were conducted within the frame of the French *Agence Nationale de Recherche* project "BROGLASEA" (ANR-16-CE27-0011). The archaeological investigations from which the samples were acquired was funded by the US National Science Foundation "Dian Heartland Archaeology Project" (BCS-1357347). The metallurgical analysis at CUHK was funded by CUHK Direct grant (#4051151) and Hong Kong government RGC-GRF (#14621718). We would like to thank E. Foy (UPS, CEA, CNRS, NIMBE-LAPA, France) for complementary XRF analyses, using a RU-200HB generator (Rigaku) equipped with a monochromatized Mo-Ka micro-beam, to confirm the SEM-EDS spectra. Permissions for excavations and analyses were kindly given by the Yunnan Provincial Institute of Cultural Relics and Archaeology. We thank three anonymous reviewers for their constructive comments, though all errors remain our own.

Bibliography

- Aebischer, S., Cloquet, C., Carignan, J., Maurice, C., Pienitz, R., 2015. Disruption of the geochemical metal cycle during mining: Multiple isotope studies of lake sediments from Schefferville, subarctic Québec. *Chemical Geology* 412, 167–178. <https://doi.org/10.1016/j.chemgeo.2015.07.028>
- Allard, F., 2018. The Lives of Shovels, Vessels, and Bells in Early South China: Memory, Ritual, and the Power of Destination, in: Allard, F., Linduff, K.M., Sun, Y. (Eds.), *Memory and Agency in Ancient China: Shaping the Life History of Objects*. Cambridge University Press, Cambridge, pp. 50–71. <https://doi.org/10.1017/9781108560726.004>
- Anon., 2020. Guangxi Wenwu Baohu Yangjiusuo & Nanningshi Bowuguan [The Pre-Qin tombs in Matou, Wuming]. *Wenwu chubanshe*, Beijing.
- Anon., 2016. The Dabona Cemetery in Xiangyun County, Yunnan: Yunnan Provincial Institute of Cultural Relics and Archaeology, Dali Bai Autonomous Prefectural Commission for Preservation of Ancient Monuments and Xiangyun County Commission for Preservation of Ancient Monuments. *Chinese Archaeology* 16, 13–26. <https://doi.org/10.1515/char-2016-0002>
- Anon., 2002a. The Ancient Burials at Lijiashan in Jiangchuan, Yunnan. *Chinese Archaeology* 2, 201–211. <https://doi.org/10.1515/char.2002.2.1.201>
- Anon., 2002b. The Yangfutou Cemetery in Kunming, Yunnan Province. *Chinese Archaeology* 2, 212–221. <https://doi.org/10.1515/char.2002.2.1.212>
- Bayard, D.T., 1972. Early Thai bronze: analysis and new dates. *Science* 176, 1411–1412.
- Bellina, B., 2017. *Khao Sam Kaeo: An Early Port-City between the Indian Ocean and the South China Sea*. Ecole française d'Extrême-orient, Paris.

- Bellina, B., Favereau, A., Dussubieux, L., 2019. Southeast Asian early Maritime Silk Road trading polities' hinterland and the sea-nomads of the Isthmus of Kra. *Journal of Anthropological Archaeology* 54, 102–120. <https://doi.org/10.1016/j.jaa.2019.02.005>
- Bellwood, P., 2005. *First Farmers: The Origins of Agricultural Societies*. Wiley-Blackwell, Oxford.
- Benda, H.J., 1962. The structure of Southeast Asian History. *Journal of Southeast Asian History* 3, 106–138.
- Bennett, A., Glover, I.C., 1992. Decorated high-tin bronzes from Thailand's prehistory, in: Glover, I. (Ed.), *Southeast Asian Archaeology 1990*. Centre for Southeast Asian Studies, Hull University, pp. 187–208.
- Cadet, M., Sayavongkhamdy, T., Souksavatdy, V., Luangkhoth, T., Dillmann, P., Cloquet, C., Vernet, J., Piccardo, P., Chang, N., Edgar, J., Foy, E., Pryce, T.O., 2019. Laos' central role in Southeast Asian copper exchange networks: A multi-method study of bronzes from the Vilabouly Complex. *Journal of Archaeological Science* 109, 104988. <https://doi.org/10.1016/j.jas.2019.104988>
- Calo, A., 2014. *Trails of Bronze Drums Across Early Southeast Asia: Exchange Routes and Connected Cultural Spheres*. Institute of Southeast Asian Studies, Singapore.
- Champion, T.C. (Ed.), 1995. *Centre and Periphery: Comparative Studies in Archaeology*. Routledge, London & New York.
- Chen, D., Yang, Y., Du, J., Tang, X., Luo, W., 2020. Alloy ratio and raw material sourcing of Warring States Period bronze bracelets in Huili County, Southwest China by pXRF and MC-ICP-MS. *Heritage Science* 8, 69. <https://doi.org/10.1186/s40494-020-00413-z>
- Cheng, Y., Mao, J., Liu, P., 2016. Geodynamic setting of Late Cretaceous Sn–W mineralization in southeastern Yunnan and northeastern Vietnam. *Solid Earth Sciences* 1, 79–88. <https://doi.org/10.1016/j.sesci.2016.12.001>
- Ciarla, R., 2007. Rethinking Yuanlongpo: The Case for Technological Links between the Lingnan (PRC) and Central Thailand in the Bronze Age. *East and West* 57, 305–328.
- Cloquet, C., Carignan, J., Libourel, G., 2006. Atmospheric pollutant dispersion around an urban area using trace metal concentrations and Pb isotopic compositions in epiphytic lichens. *Atmospheric Environment* 40, 574–587. <https://doi.org/10.1016/j.atmosenv.2005.09.073>
- Cœdès, G., 1944. *Histoire ancienne des états hindouisés d'Extrême-Orient*. Ecole française d'Extrême-orient, Hanoi.
- Cui, J., Wu, X., 2008. The archaeological research of lead isotopes: examples of bronzes from Yunnan, China, and Vietnam. *Wenwu*.
- Dussubieux, L., Pryce, T.O., 2016. Myanmar's role in Iron Age interaction networks linking Southeast Asia and India: Recent glass and copper-base metal exchange research from the Mission Archéologique Française au Myanmar. *Journal of Archaeological Science Reports* 5, 598–614.
- Fiskesjö, M., 2010. Mining, history, and the anti-state Wa: the politics of autonomy between Burma and China. *Journal of Global History* 5, 241–264.
- Glover, I.C., 1990. *Early Trade Between India and Southeast Asia - a Link in the Development of a World Trading System*. Centre for Southeast Asian Studies, University of Hull.
- Gorman, C.F., 1969. Hoabinhian: a pebble-tool complex with early plant associations in Southeast Asia. *S* 163, 671–3.
- Han, X., 2004. Who Invented the Bronze Drum? Nationalism, Politics, and a Sino-Vietnamese Archaeological Debate of the 1970s and 1980s. *Asian Perspectives* 43, 7–33.
- Harding, A., 2013. World Systems, Cores, and Peripheries in Prehistoric Europe. *European Journal of Archaeology* 16, 378–400. <https://doi.org/10.1179/1461957113Y.0000000032>
- Higham, C., Higham, T., 2009. A new chronological framework for prehistoric Southeast Asia, based on a Bayesian model from Ban Non Wat. *Antiquity* 83, 125–144. <https://doi.org/10.1017/S0003598X00098136>
- Higham, C.F.W., 2021. The later prehistory of Southeast Asia and southern China: the impact of exchange, farming and metallurgy. *asian archaeol* 4, 63–93. <https://doi.org/10.1007/s41826-021-00040-y>

- Higham, C.F.W., 1996. *The Bronze Age of Southeast Asia*. Cambridge University Press, Cambridge.
- Higham, C.F.W., 1989. *The Archaeology of Mainland Southeast Asia - from 10,000 BC to the Fall of Angkor*. Cambridge University Press, Cambridge.
- Higham, C.F.W., Douka, K., Higham, T.F.G., 2015. A New Chronology for the Bronze Age of Northeastern Thailand and Its Implications for Southeast Asian Prehistory. *PLOS ONE* 10, e0137542. <https://doi.org/10.1371/journal.pone.0137542>
- Higham, Charles F. W., Guangmao, X., Qiang, L., 2011. The prehistory of a Friction Zone: first farmers and hunters-gatherers in Southeast Asia. *Antiquity* 85, 529–543.
- Higham, Charles F.W., Higham, T., Ciarla, R., Douka, K., Kijngam, A., Rispoli, F., 2011. The Origins of the Bronze Age of Southeast Asia. *Journal of World Prehistory* 24, 227–274.
- Higham, T.F.G., Weiss, A.D., Higham, C.F.W., Ramsey, C.B., Guedes, J. d’Alpoim, Hanson, S., Weber, S.A., Rispoli, F., Ciarla, R., Pryce, T.O., Pigott, V.C., 2020. A prehistoric copper-production centre in central Thailand: its dating and wider implications. *Antiquity* 94, 948–965. <https://doi.org/10.15184/aqy.2020.120>
- Hirao, Y., Ro, J.-H., 2013. Water Civilisation: From Yangtze to Khmer civilisations, in: Yasuda, Y. (Ed.), *Chemical Composition and Lead Isotope Ratios of Bronze Artifacts Excavated in Cambodia and Thailand*. Springer, Tokyo, pp. 247–312.
- Hsu, Y.-K., Sabatini, B.J., 2019. A geochemical characterization of lead ores in China: An isotope database for provenancing archaeological materials. *PLOS ONE* 14, e0215973. <https://doi.org/10.1371/journal.pone.0215973>
- Hutchison, C.S., Taylor, D., 1978. Metallogenesis in SE Asia. *Journal of the Geological Society* 135, 407–428.
- Kardulias, P.N., Hall, T.D., 2008. Archaeology and world-systems analysis. *World Archaeology* 40, 572–583. <https://doi.org/10.1080/00438240802453252>
- Khin Zaw, Meffre, S., Lai, C.-K., Burrett, C., Santosh, M., Graham, I., Manaka, T., Salam, A., Kamvong, T., Cromie, P., 2014. Tectonics and metallogeny of mainland Southeast Asia — A review and contribution. *Gondwana Research* 26, 5–30. <https://doi.org/10.1016/j.gr.2013.10.010>
- Kohl, P.L., 1989. The use and abuse of world systems theory: the case of the “pristine” West Asian state, in: Lamberg-Karlovsky, C.C. (Ed.), *Archaeological Thought in America*. Cambridge University Press, Cambridge, pp. 218–240.
- LaTouche, T.D., Brown, J.C., 1909. The Silver-Lead Mines of Bawdwin, Northern Shan States. *Records of the Geological Survey of India* 27, 235–63.
- Leroy, S., Hendrickson, M., Bauvais, S., Vega, E., Blanchet, T., Disser, A., Delque-Kolic, E., 2018. The ties that bind: archaeometallurgical typology of architectural crampons as a method for reconstructing the iron economy of Angkor, Cambodia (tenth to thirteenth c.). *Archaeol Anthropol Sci* 10, 2137–2157. <https://doi.org/10.1007/s12520-017-0524-3>
- Liu, R., Pollard, A.M., Lv, F., Huan, L., Zhang, S., Ma, M., 2021. Two Sides of the Same Coin: A Combination of Archaeometallurgy and Environmental Archaeology to Re-Examine the Hypothesis of Yunnan as the Source of Highly Radiogenic Lead in Early Dynastic China. *Front. Earth Sci.* 0. <https://doi.org/10.3389/feart.2021.662172>
- Liu, R., Rawson, J., Pollard, A.M., 2018. Beyond ritual bronzes: identifying multiple sources of highly radiogenic lead across Chinese history. *Scientific Reports* 8, 11770. <https://doi.org/10.1038/s41598-018-30275-2>
- Lu, Q., Zou, G., Li, Y., Zheng, L., Wang, W., 2020. Provenance study on ‘Big bronze drums’: a method to investigate the ancient bronze industry of Guangxi, Southwest China from Han to Tang dynasty (around 200 BC–900 AC). *Journal of Cultural Heritage* 44, 15–26. <https://doi.org/10.1016/j.culher.2020.02.002>
- Majumdar, R.C., 1927. *Ancient Indian Colonies in the Far East*, Vol. I, Champa, Greater India Society Publication No.1. Punjab Sanskrit Book Depot, Lahore.
- Manhes, G., Allègre, C.J., Dupré, B., Hamelin, B., 1980. Lead isotope study of basic-ultrabasic layered complexes: Speculations about the age of the earth and primitive mantle characteristics. *Earth and Planetary Science Letters* 47, 370–382.

- McColl, H., Racimo, F., Vinner, L., Demeter, F., Gakuhari, T., Moreno-Mayar, J.V., Driem, G. van, Wilken, U.G., Seguin-Orlando, A., Castro, C. de la F., Wasef, S., Shoocongdej, R., Souksavatdy, V., Sayavongkhamdy, T., Saidin, M.M., Allentoft, M.E., Sato, T., Malaspinas, A.-S., Aghakhanian, F.A., Korneliussen, T., Prohaska, A., Margaryan, A., Damgaard, P. de B., Kaewsutthi, S., Lertrit, P., Nguyen, T.M.H., Hung, H., Tran, T.M., Truong, H.N., Nguyen, G.H., Shahidan, S., Wiradnyana, K., Matsumae, H., Shigehara, N., Yoneda, M., Ishida, H., Masuyama, T., Yamada, Y., Tajima, A., Shibata, H., Toyoda, A., Hanihara, T., Nakagome, S., Deviese, T., Bacon, A.-M., Durringer, P., Ponche, J.-L., Shackelford, L., Patole-Edoumba, E., Nguyen, A.T., Bellina-Pryce, B., Galipaud, J.-C., Kinaston, R., Buckley, H., Pottier, C., Rasmussen, S., Higham, T., Foley, R.A., Lahr, M.M., Orlando, L., Sikora, M., Phipps, M.E., Oota, H., Higham, C., Lambert, D.M., Willerslev, E., 2018. The prehistoric peopling of Southeast Asia. *Science* 361, 88–92. <https://doi.org/10.1126/science.aat3628>
- Michaud, J., 2008. Economic Transformation in a Hmong Village of Thailand. *Human Organization* 56, 222–232. <https://doi.org/10.17730/humo.56.2.nkj35278227n0172>
- Murowchick, R.E., 2001. The Political and Ritual Significance of Bronze Production and Use in Ancient Yunnan. *Journal of East Asian Archaeology* 3, 133–192.
- Pigott, V.C., 2019. Prehistoric copper mining and smelting in Southeast Asia: evidence from Thailand and Laos, in: White, J.C., Hamilton, E.G. (Eds.), *Ban Chiang, Northeast Thailand, Volume 2C: The Metal Remains in Regional Context*. University of Pennsylvania Press, Philadelphia, P.A., pp. 5–53.
- Pigott, V.C., Ciarla, R., 2007. On the origins of metallurgy in prehistoric Southeast Asia: The View from Thailand, in: *Metals and Mining: Studies in Archaeometallurgy*. Archetype, London, pp. 76–88.
- Pigott, V.C., Natapintu, S., 1988. Archaeological investigations into prehistoric copper production: the Thailand Archaeometallurgy Project, 1984-86, in: Maddin, R. (Ed.), *The Beginning of the Use of Metals and Alloys: Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21-26 October, 1986*. MIT Press., pp. 156–162, Cambridge, MA, pp. 156–162.
- Pigott, V.C., Weisgerber, G., 1998. Mining archaeology in geological context. The prehistoric copper mining complex at Phu Lon, Nong Khai Province, northeast Thailand, in: Rehren, T., Hauptmann, A., Muhly, J.D. (Eds.), *Metallurgica Antiqua: In Honour of Hans-Gert Bachmann and Robert Maddin*. Deutsches Bergbau-Museum Bochum, pp. 135-161, Bochum, pp. 135–161.
- Pigott, V.C., Weiss, A., Natapintu, S., 1997. Archaeology of copper production: Excavations in the Khao Wong Prachan Valley, central Thailand, in: Ciarla, R., Rispoli, F. (Eds.), *South-East Asian Archaeology 1992. Proceedings of the Fourth International Conference of the European Association of South-East Asian Archaeologists. Rome, 28th September - 4th October 1992*. Istituto Italiano per l’Africa e l’Oriente, pp 119-157, Rome, pp. 119–157.
- Pirazzoli-t’Serstevens, M., 1974. *La Civilisation du royaume de Dian à l’époque du Han d’après le matériel exhumé a Shizhaishan*, Publications de l’Ecole française d’Extrême Orient. Ecole française d’Extrême-orient, Paris.
- Pryce, T.O., 2019. Lead Isotope Characterization and Provenance of Copper-Base Artifacts from Ban Chiang and Don Klang, in: White, J.C., Hamilton, E.G. (Eds.), *Ban Chiang, Northeast Thailand, Volume 2C: The Metal Remains in Regional Context*. University of Pennsylvania Press, Philadelphia, P.A., pp. 57–64.
- Pryce, T.O., 2018. Initiating discourse on the (multi?) directionality of the Mainland Southeast Asian Bronze Age transition, in: Choi, J.-Y., Park, J.-S. (Eds.), *Proceedings of The Ninth International Conference on the Beginning of the Use of Metals and Alloys (BUMA-IX), 16-19 October 2017 International Center, Dong-A University, Busan, Korea*. The Korean Institute of Metals and Materials, Seoul, pp. 160–175.
- Pryce, T.O., 2014. Metallurgy in Southeast Asia. *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*.

- Pryce, T.O., 2013. Mobility and heritage in Northern Thailand and Laos: past and present, in: Evrard, O., Vaddhanaphuti, C., Guillaud, D. (Eds.), *Sedentism, Social Complexity, and Metallurgy in Upland Southeast Asian Populations*. Chiang Mai University, Chiang Mai, pp. 27–45.
- Pryce, T.O., 2012. Proceedings of the 5th Forbes Symposium on ancient Asian bronzes, in: Jett, P., Douglas, J. (Eds.), *A Flux That Binds? The Southeast Asian Lead Isotope Project*. Smithsonian, Washington D.C., pp. 113–121.
- Pryce, T.O., 2011. The excavation of Ban Non Wat: The Bronze Age, in: Higham, C.F.W., Kijngam, A. (Eds.), *XIX Technical Analysis of Bronze Age Ban Non Wat Copper-Base Artefacts*. The Fine Arts Department, Bangkok, pp. 489–498.
- Pryce, T.O., Baron, S., Bellina, B.H.M., Bellwood, P.S., Chang, N., Chattopadhyay, P., Dizon, E., Glover, I.C., Hamilton, E., Higham, C.F.W., Kyaw, A.A., Laychour, V., Natapintu, S., Nguyen, V., Pautreau, J.-P., Pernicka, E., Pigott, V.C., Pollard, M., Pottier, C., Reinecke, A., Sayavongkhamdy, T., Souksavatdy, V., White, J., 2014a. More questions than answers: the Southeast Asian Lead Isotope Project 2009–2012. *Journal of Archaeological Science* 42, 273–294. <https://doi.org/10.1016/j.jas.2013.08.024>
- Pryce, T.O., Brauns, M., Chang, N., Pernicka, E., Pollard, M., Ramsey, C., Rehren, T., Souksavatdy, V., Sayavongkhamdy, T., 2011a. Isotopic and technological variation in prehistoric primary Southeast Asian copper production. *Journal of Archaeological Science* 38, 3309–3322.
- Pryce, T.O., Cadet, M., 2018. Ancient copper-base metallurgy in the Lao PDR, in: Patole-Edoumba, E., Demeter, F. (Eds.), *Pà Hang: La Montagne Habitée. 100000 Ans d’histoire de La Biodiversité et de l’occupation Humaine Au Nord Du Laos*. La Rochelle, pp. 196–207.
- Pryce, T.O., Cadet, M., Allard, F., Kim, N.C., Hiep, T.H., Dung, L.T.M., Lam, W., Foy, E., 2021. 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 Lấp. *Archaeol Anthropol Sci* 14, 16. <https://doi.org/10.1007/s12520-021-01489-9>
- Pryce, T.O., Hendrickson, M., Phon, K., Chan, S., Charlton, M.F., Leroy, S., Dillmann, P., Hua, Q., 2014b. The Iron Kuay of Cambodia: Tracing the role of peripheral populations in Angkorian to Colonial Cambodia via a 1200 year old industrial landscape. *Journal of Archaeological Science* 47, 142–163.
- Pryce, T.O., Htwe, K.M.M., Georgakopoulou, M., Martin, T., Vega, E., Rehren, T., Win, Tin Tin, Win, Thu Thu, Petchey, P., Innanchai, J., Pradier, B., 2018a. Metallurgical traditions and metal exchange networks in late prehistoric central Myanmar, c. 1000 BC to c. AD 500. *Archaeological and Anthropological Sciences* 10, 1087–1109. <https://doi.org/10.1007/s12520-016-0436-7>
- Pryce, T.O., Kyaw, A.A., Kyaw, M.M., Win, Tin Tin, Win, Thu Thu, Win, K.H., Mon, M.M., Aye, M.M., Htay, S.H., Mar, A.A., Bellina, B., Bentley, R.A., Champion, L., Colonna, C., Cook, A.J., Favereau, A., Fuller, D.Q., Georjon, C., Higham, C.F.W., Htwe, K.M.M., Iizuka, Y., Innanchai, J., Le Meur, C., Peixoto, X., Petchey, P., Pinhasi, R., Pradier, B., Valentin, F., Willis, A., Zazzo, A., 2018b. A first absolute chronology for Late Neolithic to Early Bronze Age Myanmar: New data from the 2014–2016 seasons of the Mission Archéologique Française au Myanmar at Nyaung’gan and Oakaie. *Antiquity* 690–708.
- Pryce, T.O., Murillo-Barroso, M., Martinon-Torres, M., Biggs, L., Bellina, B., 2017. The Metallurgical Industries, in: *Khao Sam Kaeo: An Early Port-City between the Indian Ocean and the South China Sea*. Ecole française d’Extrême-orient, Paris.
- Pryce, T.O., Natapintu, S., 2009. Smelting iron from laterite: Technical possibility or ethnographic aberration? *Asian Perspectives* 48, 249–264.
- Pryce, T.O., Pollard, M., Martinon-Torres, M., Pigott, V.C., Pernicka, E., 2011b. Southeast Asia’s first isotopically-defined prehistoric copper production system: When did extractive metallurgy begin in the Khao Wong Prachan Valley of central Thailand? *Archaeometry* 53, 146–163.
- Renfrew, C., Dixon, J.E., Cann, J.R., 1969. Further Analysis of Near Eastern Obsidians. *Proceedings of the Prehistoric Society* 34, 319–331. <https://doi.org/10.1017/S0079497X0001392X>

- Rispoli, F., 2007. The Incised & Impressed Pottery Style of Mainland Southeast Asia: Following the Paths of Neolithization. *East and West* 57, 235–304.
- Rowlands, M.J., Larsen, M., Kristiansen, K. (Eds.), 1987. *Centre and Periphery in the Ancient World*. Cambridge University Press, Cambridge.
- Schwartz, M.O., Rajah, S.S., Askury, A.K., Putthapiban, P., Djaswadi, S., 1995. The Southeast Asian Tin Belt. *Earth-Science Reviews* 38, 95–293.
- Sherratt, A., 1993. What Would a Bronze-Age World System Look Like? Relations Between Temperate Europe and the Mediterranean in Later Prehistory. *Journal of European Archaeology* 1, 1–58. <https://doi.org/10.1179/096576693800719293>
- Sitthithaworn, E., 1990. Metallogenic Map of Thailand.
- Solheim, W.G., 1972. An earlier agricultural revolution. *SA CCVI*, 34–41.
- Solheim, W.G., 1968. Early bronze in Northeastern Thailand. *CA* 9, 59–62.
- Srinivasan, S., Glover, I.C., 1995. Wrought and quenched, and cast high-tin bronzes in Kerala State, India. *JHM* 29, 69–88.
- Takimoto, K. (ed) (Ed.), 1968. *Geology and Mineral Resources in Thailand and Malaya*. Dobosha Co. Ltd., Kyoto.
- Thirlwall, M.F., 2002. Multicollector ICP-MS analysis of Pb isotopes using a 207Pb - 204Pb double spike demonstrates up to 400 ppm/amu systematic errors in TI-normalization. *Chemical Geology* 184, 255–279.
- Tibbetts, G.R., 1978. *A Study of the Arabic Texts Containing Material on South-East Asia*. Royal Asiatic Society Books, London.
- van Schendel, W., 2002. Geographies of Knowing, Geographies of Ignorance: Jumping Scale in Southeast Asia. *Environ Plan D* 20, 647–668. <https://doi.org/10.1068/d16s>
- Wallerstein, I., 1978. *The Modern World-System, vol. I: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century*. Academic Press, New York & London.
- Wang, X., Luo, W., Yang, Y., Chen, D., Du, J., Tang, X., 2020. Preliminary Discussion on the Highly Radiogenic Lead in Unalloyed Copper Artifacts of the Eastern Zhou Dynasty: Starting from the Huili Copper Spearheads. *Metals* 10, 1252. <https://doi.org/10.3390/met10091252>
- Watson, B., 1958. *Ssu-ma Ch'ien: Grand Historian of China*. Columbia University Press, New York.
- White, J.C., 2008. Archaeology in Southeast Asia: From Homo Erectus to the Living Traditions, Choice of Papers from the 11th EurASEAA Conference, Bougon 2006, in: Pautreau, J.-P., Coupey, A., Zeitoun, V., Rambault, E. (Eds.), *Dating Early Bronze at Ban Chiang, Thailand*. European Association of Southeast Asian Archaeologists, Chiang-Mai, pp. 91–104.
- White, J.C., 1988. Early East Asian Metallurgy: The Southern Tradition, in: Maddin, R. (Ed.), *The Beginning of the Use of Metals and Alloys: Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21-26 October, 1986*. MIT Press., Cambridge, Mass., pp. 175–181.
- White, J.C., 1986. *A Revision of the Chronology at Ban Chiang and its implications for the prehistory of Northeast Thailand (Ph.D.)*. University of Pennsylvania, Philadelphia.
- White, J.C., Hamilton, E.G., 2021. The metal age of Thailand and Ricardo's Law of Comparative Advantage. *Archaeological Research in Asia* 27, 100305. <https://doi.org/10.1016/j.ara.2021.100305>
- White, J.C., Hamilton, E.G., 2009. The Transmission of Early Bronze Technology to Thailand: New Perspectives. *Journal of World Prehistory* 22, 357–397.
- Workman, D.R., 1977. *Geology of Laos, Cambodia, South Vietnam and the eastern part of Thailand*. Overseas Geological and Mineral Resources 50, Institute of Geological Sciences.
- Xiaocen, L., Yun, Y., Han, R., 2015. Scientific examination of metal objects from the third excavation of Haimenkou site, Western Yunnan, in: *Metals and Civilizations: Proceedings of the Seventh International Conference on the Beginnings and the Use of Metals and Alloys (BUMA VII)*. National Institute of Advanced Studies, Bangalore, pp. 123–128.
- Yang, B., 2004. Horses, Silver, and Cowries: Yunnan in Global Perspective. *Journal of World History* 15, 281–322.

- Yao, A., 2016. *The Ancient Highlands of Southwest China: An Archaeological History from the Bronze Age to the Han Empire*. Oxford University Press, Oxford.
- Yao, A., Darré, V., Zhilong, J., Lam, W., Wei, Y., 2020. Bridging the time gap in the Bronze Age of Southeast Asia and Southwest China. *Archaeological Research in Asia* 22, 100189. <https://doi.org/10.1016/j.ara.2020.100189>
- Yunnan sheng bowuguan, [Yunnan Provincial Museum], 1959. *Yunnan Jinning Shizhaishan gumu qun fajue baogao* [Report on the excavation of ancient tombs at Shizhaishan, Jinning, Yunnan]. Wenwu Chubanshe, Beijing.
- Yunnansheng wenwu kaogu yanjiusuo et al., [Yunnan provincial institute of cultural relics and archaeology, Kunming municipal museum, and Jinning district management office of cultural relics, 2009. *Jinning Shizhaishan: diwuci fajue baogao* [Jinning Shizhaishan: the report on the fifth excavation]. Wenwu Chubanshe, Beijing.
- Zheng, H., 2015. Birth of the Yangtze River: age and tectonic-geomorphic implications. *National Science Review* 2, 438–453. <https://doi.org/10.1093/nsr/nwv063>
- Zou, G., Cui, J., Liu, X., Li, X., Min, R., 2019. Investigation of early Bronze Age civilizations in Yunnan: a scientific analysis of metallurgical relics found at the Guangfentou ruins in Jiangchuan. *Archaeol Anthropol Sci* 11, 15–31. <https://doi.org/10.1007/s12520-017-0530-5>