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Metal Exchange Networks in Prehistoric Southeast Asia

Summary

Southeast Asian metal consumption in the form of copper-bronze artifacts begins on the mainland in the late 2nd millennium BC and in the islands in the form of bronze, iron and steel, gold, and silver in the mid to late 1st millennium BC. Regional copper production was initiated within mere decades of the medium's initial appearance on the mainland but is currently unknown for the islands. Likewise, mainland and island Southeast Asian iron production seems to have swiftly followed prehistoric consumption behaviors, but for silver, gold, tin, and lead, primary production (mining and smelting) remain unknown and secondary production (alloying and casting) is represented by occasional crucible and mold fragments.

Metals are often assumed to have been exchanged or traded, but there is a general regional assumption, probably wrong, that gold, silver, copper, bronze, and tin travel over long distances whereas lead, and especially iron and steel, move only over short distances or are produced locally. Analytical methodologies exist for determining the provenance or at least the geochemical characterization necessary for each of the metals listed here, but the application of those methodologies is extremely uneven in terms of metal type and chronospatially. At the time of writing, scholars have no data concerning the prehistoric exchange of silver, tin (except where alloyed with copper), and lead (except where alloyed with copper-bronze). Critically, scholars have no provenance studies for early iron, the appearance of which is coincident with huge regional cultural developments, which is hard to explain when historic period research on this topic is burgeoning. The determination of the provenance of gold has been attempted regionally,

and while promising in the elucidation of exchange networks connecting Bali as far as Rome, the approach has not proliferated. Indeed, the only metal to have seen any systematic research is that of copper-bronze, and that is focused heavily on mainland rather than island Southeast Asia. Nevertheless, the research accomplished thus far has revolutionized the understanding of late prehistoric Southeast Asia. Due to large and often inaccessible territories, low numbers of archaeologists with limited funding, linguistic differences, and a dearth of specialists, especially ceramicists, relatively little was known about interactions between the present-day nations that make up the region prior to the Iron Age and the applicability of the provenance of glass. Complementary to that, and applying to the Bronze Age as well, the provenance of copper and bronze has begun to expose a complex web of exchanges that link centers of production and consumption across thousands of kilometers of mountain, forest, river, and sea. Most importantly, some of those networks seem to have been active at the very outset of the Bronze Age, suggesting they may have had Neolithic or earlier precedents.

Keywords

mainland Southeast Asia, island Southeast Asia, Bronze Age, Iron Age, Metal Age, copper, bronze, tin, lead, gold, silver, iron and steel

Introduction

This article discusses the state of the art in prehistoric metal exchange networks in mainland and island Southeast Asia (hereafter MSEA and ISEA, respectively). This combined region, covering over 10,000 square kilometers of tectonically active territory, hosts an enormous quantity of metallogenic deposits, for which an extensive ethnohistoric and colonial-era metal production, exchange, and consumption literature exists.¹ However, as by definition no texts exist for

prehistory and extrapolating sociocultural and socioeconomic interpretations of metallurgy is problematic over mere centuries, let alone millennia, the present discussion is based entirely on holistic archaeological evidence, that is, the combination of morphostylistic, technological, and elemental and isotopic data.² Scholarly leanings toward the latter archaeometric traits tend to imply a lesser weighting to art historical approaches simply by virtue of competence and familiarity, but never the dismissal of these essential components. Likewise, art-historical arguments that entirely disregard physicochemical characteristics will not be entertained—archaeometallurgy is far too established and accessible a subdiscipline for its insights to be overlooked. Data complementarity and combination allow for unexpected permutations of iconographies, materials, and techniques to emerge, and therein lie the real gems of interpretative value.

It is important to note that at the time of writing, late 2020, researchers are at a brink of a paradigm shift in data availability for regional lead, copper, and bronze exchange networks. Research on this topic began on a small scale on Thai lead minerals in the mid-1980s with the Thailand Archaeometallurgy Project (TAP) site survey in Loei province. Here S. Natapintu, U. Theetiparivatra, and V. C. Pigott sampled various provincial lead outcrops and documented major historic period lead–zinc mining and smelting at Rong Khee Bao. <<<Pigott 1984, 1985>>> Subsequently, further research commenced in earnest on Thai and Cambodian consumption assemblages from the early 1990s and integrated Thai and Lao production assemblages with expanded MSEA and ISEA geographical consumption coverage from 2008 with the Southeast Asian Lead Isotope Project (SEALIP).³ Since 2016, SEALIP has been in a phase of massively increased sampling density and chronological coverage with the French *Agence National de la Recherche*-funded project, “Bronze and Glass as Cultural Catalysts and Tracers in Early

Southeast Asia” (BROGLASEA).⁴ This latter project will more than double the regional database for nonferrous and nonprecious metals, but due to intensive laboratory schedules and Covid-19-induced delays, more than half the isotopic data set is still awaited. Raw data cannot be provided here for analytical results that have not yet been copublished with principle BROGLASEA participants. Nevertheless, the currently available data set is more than sufficient for identifying general trends of significant interest.

Places

For those unfamiliar with the region, MSEA’s 5 million square kilometers comprise Cambodia, Laos, Myanmar, Thailand, and Vietnam. ISEA covers Brunei, Indonesia (with the exception of West Papua), the Philippines, Singapore, Timor Leste, and, to some extent, Taiwan. Malaysia straddles MSEA and ISEA, with territories on the Thai-Malay Peninsula and on the island of Borneo (Figure). In no case can the region be considered without relevant historical reference to its immediate present-day neighbors: Bangladesh, India, and Sri Lanka bordering the Bay of Bengal to the west, the Himalayan piedmont and China to the north and east, and Oceania (Australasia, Melanesia, Micronesia, and Polynesia) to the east. For this latter cardinal direction, it should be noted that the furthest east prehistoric metal has been reliably identified is on Lou Island, in the Admiralty Archipelago off the northeastern coast of Papua New Guinea, meaning Australasia, Micronesia, and Polynesia were apparently metal-free until European contact, despite Southeast Asian, via Taiwan, millennia of ongoing movements of peoples and materials.⁵

Timings

MSEA and ISEA are both regions characterized by extreme diversity in climate, ecology, and geology, as well as culture, ethnicity, and language.⁶ This inter- and intraregional variability is strongly reflected in the adoption and adaptation of various metal technologies, as well as their inaccessibility to and rejection by various populations—metallurgy is not a human universal, and evolutionary processes are contextual and multidirectional.⁷ Nevertheless, two broad chronological trends can be seen in prehistoric Southeast Asian metallurgy.⁸ First, MSEA experienced, in pure presence-of-metal terms, a Bronze Age from the late second millennium BC and an Iron Age from the mid-first millennium BC. There was no Chalcolithic or Copper Age in the European or Western Asian sense, nor any distinct experimental phase with arsenical copper or other exotic alloys, though these exist as rare exceptions. The earliest MSEA metal artifacts tend to be low-tin bronze axes and may be the result of extensive down-the-line recycling processes. Second, ISEA transitioned directly from Neolithic to the “Metal Age” from the mid-late first millennium BC, though of course with huge variation geographically (Indonesia, including West Papua, alone is over 5,000 km west to east) and in chronological-contextual resolution.⁹ There are regional scholars who propose the use of the term Metal Age for MSEA as well as ISEA, or the lower case terms bronze age and iron age for MSEA so as to disassociate regional terminology from what they perceive as Eurocentric normalizing interpretative constraints about metallurgy and social complexity.¹⁰ <<<White and Hamilton 2018: 89>>>

However, in this article, the standard practice is followed, that of recognizing the Three Age system for what it is, a widely applicable and useful means of dividing late prehistory on a material presence and absence basis, with any sociocultural associations being argued for on a case-by-case basis.

The end of the MSEA and ISEA prehistoric period, and thus the scope of this article, is traditionally considered to be the mid-first millennium AD, with the formation of fully fledged “Indianized” states.¹¹ However, this overlooks the much earlier passage of Han-occupied northern Vietnam, 111 BC , and Pyu Myanmar, c. 2000 BP, into what are certainly state-level societies, as well as late first millennium BC protostates, again in northern Vietnam and peninsular Thailand.¹² Furthermore, limited but pertinent archaeometallurgical data exist from pre-imperial mid-late first millennium AD Cambodia, which is the end point for the present article.

Metals

Approximately ninety five of the 118 elements in the periodic table are metals or metalloids but those that could be extracted, used, and were arguably known to prehistoric humankind were: copper (Cu), tin (Sn), lead (Pb), iron (Fe, and carburized to make steel), silver (Ag), and gold (Au). Many other metallic elements are present in prehistoric Southeast Asian alloys in minor or trace quantities, such as antimony (Sb), arsenic (As), bismuth (Bi), and zinc (Zn). While polymetallic minerals could have been selected for the mechanical and aesthetic characteristics resulting from their co-smelting, these elements would not have been produced as isolated metals and their individual exchange will not and cannot be discussed further.¹³

The metals of interest here: Cu, Sn, Pb, Fe, Ag, and Au, have substantially different physicochemical characteristics and thus potential thermodynamic extraction envelopes. Evidence of their production and consumption is present in the archaeological record in unequal proportions, partly due to historical reality, partly due to the priorities of archaeologists. Likewise, the analytical methods applied for their study differ considerably, resulting in data sets

of variable completeness and quality. Metallogenic maps show the distribution of known deposits for each of these metals but, while useful, the maps do not give a true reflection of potential prehistoric usage.¹⁴ Modern extractive metallurgy is a highly cyclical “leading” sector, with investment and production ramping up early in the economic cycle to meet expected demand from construction and hi-tech industry. Geological mapping is an expensive undertaking, typically undertaken by major industrial and state actors, who naturally focus on those mineral deposits that can be feasibly exploited using currently available or near-future expected technologies. It thus follows that metallogenic maps do not and cannot take into account the very small mineral deposits that may well have been high-grade and of interest for ancient miners and smelters but are now either too small to be worth exploiting or have indeed been completely exhausted over centuries or millennia of production activity.

The bulk of this article concentrates on current knowledge for prehistoric exchange networks for each of the historically pertinent metals, in reverse order of archaeological data density. The early sections are short, perhaps surprisingly so, but mention is made of contextually, radiometrically, and technologically reliable evidence for regional consumption and production behaviors, sites, and dates, also usually in reverse order of data density, as well as the methodologies employed or required for the reconstruction of exchange networks.

Iron-Steel

Iron, and its more common and useful alloy, steel, were long ago termed “democratic” in the late 2nd and early 1st millennium BC Near Eastern context.¹⁵ There is no doubting the relative abundance of iron oxide deposits in most areas as compared to those of copper, tin, and lead, but it is imperative to not overlook the need for high-grade iron ores for ancient smelting processes,

as well as the necessary confluence of fuel, clay and refractories, and, most importantly, skilled artisans.¹⁶ Iron and steel should not be assumed to be the products of local industry and could well have been acquired through exchange networks, particularly as might concern iron and steel of varying qualities, as per historical ISEA trade in prestigious kris blades.¹⁷

Consumption evidence for iron-steel is fairly widespread in Southeast Asia, though of low resolution in terms of technology and dating. The initial appearance of iron-steel in regional contexts marks the de facto debut of the Iron Age for MSEA and the Metal Age for ISEA. The dating varies widely across the region, with ISEA generally trending later, c. 200 BC, versus MSEA at c. 500 BC. Note, however, that robust radiometric chronologies across the region are scarce, and for the most commonly used technique, ¹⁴C dating, the mid-late 1st millennium BC corresponds to the Hallstatt Plateau, giving wider calibrated date ranges.¹⁸ The most reliably dated regional prehistoric site, in terms of a large number of radiocarbon dates as applied representatively to multiple materials from a wide range of periods and with Bayesian analysis of intersecting radiometric and stratigraphic data, is that of Ban Non Wat, in northeast Thailand.¹⁹ Here the excavators place the Late Bronze Age to Early Iron Age transition at 420 BC, which is in line with what regional archaeologists have suggested for decades.²⁰ These dates are supported by recent large-scale dating programs covering northeast, central, and peninsular Thailand, and comparable dates are available from western Thailand, Cambodia, Laos, Myanmar, and Vietnam.²¹ Early ISEA iron-steel consumption is also known from Indonesia, particularly Sumatra and Bali, Malaysia, and the Philippines.²²

The other major factors impacting regional iron-steel consumption data are the following: (1) the high levels of corrosion typical for these alloys, which hugely limits typological studies beyond identifying basic forms, obscures stylistic details, and impacts compositional analyses; (2) the relatively low interest shown by archaeologists excavating in the region due to the factors

just mentioned and their need to spend limited budgets effectively; and (3) the very few qualified regional archaeometallurgists who could actually perform the necessary in-depth studies. In summary, there are no prehistoric MSEA and ISEA iron-steel artifact typologies to give even the preliminary data needed for a regional comparison, though some individual site-level typologies have been proposed. Nevertheless, the general trend of mature iron-steel tool and weapon technologies replacing MSEA copper-bronze technologies and accompanying ISEA copper-bronze ornamental applications holds true for the most part.²³

Reliable production evidence for prehistoric MSEA and ISEA iron-steel is rarer than that for consumption. “Iron slag” is a widely recorded artifact class but is easily confused for other natural (rocks) or anthropogenic (e.g., vitrified ceramic) materials.²⁴ Without expert examination, iron slag should be considered as provisional evidence for secondary production, final product forging, and repair. Such a smithy operation may have been relatively common at the village or village cluster level but actual smithing sites, as opposed to smithing slag accumulations, are rare and so far only documented from Khao Sek in peninsular Thailand.²⁵ Primary production, converting mineral to metal, requires a different skill set and tends to produce very large quantities of waste material.²⁶ Regrettably, summarizing the evidence for prehistoric Southeast Asian primary iron-steel production is all too easily done. ISEA has none. In MSEA, only peninsular Malaysia and Thailand have furnished technologically confirmed and radiometrically dated smelted iron-steel smelting sites. Substantial production evidence, furnaces, tuyères, and slag were identified at Sungai Batu in the mid-late 2000s and have recently been corroborated by data from Kedah Tua, both of which commence activity in the mid-late 1st millennium BC.²⁷ The proven prehistoric Thai samples are located fairly close together in the northeastern province of Buriram: Ban Dong Phlong and Ban Kao Din Tai, <<<Venunan 2016>>> both dating from the

late 1st millennium BC.²⁸ There is very likely to have been Early-Mid Iron Age primary iron production in the Khao Wong Prachan Valley (KWPV) in central Thailand, but it has not yet been studied and the lead author has witnessed probable prehistoric smelting remains in central Myanmar, but these have been neither excavated, studied, nor dated.²⁹ Doubtless a great deal of work remains to be done in this field.

The situation is even worse for prehistoric regional iron-steel exchange networks. The methodology for verifying the provenance of iron-steel was first developed in Oxford in the 1970s and consists of matching the chemical fingerprint of smelting slag with remnant slag, called “stringers,” in iron ingots or final products.³⁰ Ban Don Tha Phet in west-central Thailand saw an early attempt at this “slag inclusion analysis” (SIA), identifying some chemical patterning among the iron-steel grave offerings but lacking production signatures with which to compare.³¹ The SIA approach was revisited by French and German researchers from the early 2000s and, with advances in ultratrace element analytical instrumentation and large and well-studied primary production signatures, have achieved remarkable results in western European iron-steel exchange spanning two millennia.³² This approach has now been applied extensively in Angkorian Khmer period Cambodia, with excellent results, but as it requires a very heavy investment in chronologically, geochemically, and technologically characterizing primary iron production loci, as well as extensive and destructive artifact analyses, it has yet to be applied to prehistoric assemblages.³³ The sole exception to this was a simplified methodology, based on major and minor oxide patterning rather than trace elements, which still achieved the differentiation of potentially South Asian, East Asian, and local iron products at Khao Sam Kaeo in peninsular Thailand.³⁴ This field of research is ripe for expansion, but the expertise and analytical and financial investment required is very high.

Silver

The production of silver is, with the very rare exception of native silver (natural silver metal), inextricably linked to the production of lead and, in fewer cases, copper rather than the smelting of silver ores directly.³⁵ The predominant method is that of cupellation, or the extraction of silver from argentiferous lead minerals by a process of reduction to lead metal, followed by the oxidization of the lead metal and the absorption of lead oxide into a calcareous cupel, which leaves a bead of silver.³⁶ The expected archaeological evidence for this would be fragmentary cupels, thought to have been the case at Khao Sam Kaeo but proven otherwise, or the presence of litharge (lead oxide).³⁷ Neither are currently known from prehistoric Southeast Asian contexts. While unproven for prehistoric or even 1st millennium AD production, the Bawdwin mine in Shan State, Myanmar was a major producer until recent decades, as were ethnic groups in upland neighboring Yunnan.³⁸

In terms of prehistoric consumption, silver is likewise virtually unknown regionally. The sole proven exception is the mid-Iron Age (2nd century BC to AD 1st century) cemetery of Prohear in the southeastern Prey Veng province of Cambodia.³⁹ A total of ninety-three gold and silver artifacts were excavated in three seasons between 2008 and 2011. Of the fifty-nine samples analyzed, only four were effectively unalloyed silver (*c.* 99 wt % Ag), with the remainder being gold–silver alloy variants (auriferous silver, electrum, and argentiferous gold) and other exotics. However, as discussed in the section “Timings,” the prehistoric and historic, Iron Age and protostate–state transition varies considerably across MSEA and ISEA. Silver, typically in the form of coinage, is a frequent artifact class in Pyu-period Myanmar (AD 1st to 9th centuries), Funan-period Cambodia and southern Vietnam (immediately postdating Prohear), and is widely attested in early trade-related texts, often involving China.⁴⁰

The methodological package for identifying the provenance of silver, and thus bringing to light prehistoric silver exchange networks, is identical to that of lead and copper: typology, technology, and elemental and lead isotopic composition. To the best of knowledge, no such study has been attempted with only one or two silver samples in the SEALIP and BROGLASEA database due to the rarity of the artifacts and the difficulties in obtaining permission to sample coinage.⁴¹ Only the Prohear study comes close, but regional exchange networks remain unreconstructed.

Gold

Gold, the metal of literal legend and often irrational fascination, and thus the bane of many an archaeological site director. There is no doubting the aesthetic characteristics of this noble metal, which was widely used in MSEA and ISEA by the mid-late 1st millennium BC for jewelry or clearly highly stylized iconic material culture, but the unfortunate side effect is looting and the general lack of archaeological context for ancient gold artifacts.⁴² The perceived value of gold is such that vast volumes of archaeological deposits are pillaged after the discovery of often minute fragments of gold foil of unknown purity weighing a fraction of a gram whose scrap market value lurks in the low tens of US dollars but is sold to middlemen for melting down. Finding gold during an excavation is thus very much a double-edged sword, as it is relatively easy to publish agreeable pictures of shiny pretty objects, but also it means night guards must immediately be posted and the looting risk continues long after the archaeologists have backfilled their trenches and left. This problem is of course by no means unique to Southeast Asia.

The association of Southeast Asia and gold dates back at least two millennia, with Ptolemy's reference to the "Golden Khersonese" in his *Geography*, as well as contemporary Han references

to the region's wealth of gold deposits.⁴³ Furthermore, there are the well-known South Asian literary clues of *Suvarnabhumi*, "Land of Gold," and *Suvarnadvipa* "Islands of Gold," which are thought to pertain to parts of MSEA and ISEA, respectively.⁴⁴ Geologically, there is little doubt that Southeast Asia is, relatively speaking, host to a geographically wide range of gold sources of varying size.⁴⁵ How does this mineral wealth translate into reliable archaeological data?

Generally, poorly.

Gold production in antiquity was almost exclusively by the panning of placer deposits, that is, the hydraulic density separation recovery of typically river-borne gold particles.⁴⁶ This method, still widely practiced at an artisanal level by villagers if the gold price makes it worth their while, requires next to no capital investment and, from an archaeological perspective, leaves no enduring trace. Thus, there is no primary production evidence for gold in Southeast Asia. Secondary production would require some sort of pyrotechnic structure (a hearth or furnace), crucibles to melt the gold, and molds to pour it. The furnaces necessary would likely be very small, and these structures are not known for their good preservation even where much larger and hotter iron smelting furnaces are concerned.⁴⁷ Likewise, gold crucibles were probably small, and even when likely typologies had their surfaces XRF scanned for trace gold, none remained, nor was gold detected in the case of molds for metal artifacts that could have been produced in precious or nonprecious alloys, with comparable molds known from Khlong Thom in western peninsula Thailand and Oc Eo in southern Vietnam.⁴⁸ Thus, no definite evidence exists for prehistoric Southeast Asian secondary gold production, but extant molds indicate it was highly likely

Moving on to consumption evidence, no gold artifacts have been reported from Bronze Age MSEA contexts, suggesting that despite regional geological abundance, gold was either unknown or not valued prior to the period of much increased interaction with East and South Asia.

Numerous Iron and Metal Age cemetery sites have furnished gold ornaments, typically foil *repoussé* plaques, filigree and foil beads of various typologies, and even as gold set within glass beads, as found at *c.* 2000 BP Bali.⁴⁹ Winnowing out the looted and noncontextualized artifacts is nevertheless a salutary exercise in realism about what is really known. Without precise find locations and dates, researchers cannot begin to seriate the types and make reliable interpretations, and without very detailed examination of those artifacts, often problematic in public or private collections of what are considered “treasures,” they cannot reconstruct the *chaînes opératoires* that might inform on the intricacies of producer–consumer relations, as per contemporary carnelian ornaments.⁵⁰

This discussion now leads to gold exchange data for prehistoric Southeast Asia. The methodologies regarding the provenance of gold are a work in progress and have generally relied on trace element patterning, which is obviously complicated when there are very numerous potential sources, as in MSEA and ISEA. Silver cupellated from lead can contain gold, which can be extracted by “parting” with salt cementation or dissolution in *aqua regia*. In theory, the trace lead in that gold could be subject to lead isotope analysis, as per the method for discovering the provenance of silver. However, as gold panning probably predominates in prehistory, it is not a widely applied approach. Gold tracing techniques, including isotopic analyses of, for example, osmium inclusions, have greatly advanced in recent years at the Curt-Engelhorn-Zentrum Archäometrie in Mannheim, Germany and it is from this laboratory that the only reliable attempts on regional gold networks are found. These *c.* 200 analyses have concentrated on the large and heavily looted cemetery of Prohear in Cambodia, as well as littoral sites in central Thailand, southern Thailand, and Bali.⁵¹ The first results, concerning as they do a number of sites related to the “Maritime Silk Road,” indicate a vast network of gold exchange, with gold–glass beads in particular potentially relating to assemblages produced in Roman-era Egypt and found in all

intervening Indian Ocean territories. The gold ornaments have no known source but fall into groups potentially representing South Asia, littoral MSEA, and parts of ISEA. Needless to say, a great deal more work needs to be done, including GIS-driven studies as per historical ISEA, and hopefully the increasing availability of portable laser-ablation (pLA) units will allow regional gold “treasures” to be microsampled in-country before fully quantitative inductively coupled plasma mass-spectrometry (ICP-MS) analyses can be conducted elsewhere.⁵²

Tin

For historical metallurgists rather than regional historians, Southeast Asia is best known for tin, as its deposits are the largest in the Old World. The “Southeast Asian Tin Belt” runs approximately north to south for *c.* 3,500 km from southwestern China, through eastern Myanmar, western Laos, western Thailand, peninsular Malaysia, and western Indonesia (Sumatra), with the greatest single concentration on Bangka Island.⁵³ In discussions of the Maritime Silk Road’s passage via Southeast Asia, the mostly widely cited possible regional contributions to that exchange system are spices and tin, stimulated in no small way by the AD 9th century writings of Ibn Khurdādhbih and other Arabic travelers and the critical importance of regional tin production until the mid-20th century.⁵⁴ As per gold, tin or rather its principal ore mineral, cassiterite (SnO₂), is generally recovered from riverine placer deposits or, nowadays, their offshore accumulations rather than hard-rock mining of plutonic intrusions in the granitic highlands. Cassiterite is a dense black mineral and can be concentrated by hydraulic separation methods. Indeed, it is the intensity and scale of recent historical tin production that must moderate researchers’ expectations in turning, inexorably, to the prehistoric archaeological data.

There are as yet no proven primary tin production data from MSEA or ISEA. Given the generally more modest scale of ancient production and the complete landscape remodeling capacity of 19th- and 20th-century extractions methods, this lack of evidence is unfortunately to be expected. Given the relatively low efficiency of ancient smelting techniques, prehistoric tin slag concentrations could have been economically reprocessed during later periods. The only known prehistoric site with possible, though as yet undemonstrated, tin smelting remains is that of Khuan Luk Pat in western peninsular Thailand, but looting for beads (*luk pat*) has left the ground surface resembling that of the Moon.⁵⁵

While the slag and associated technical ceramics (furnaces, crucibles, tuyères, and molds) for the smelting of metallic tin may be unknown from the prehistoric regional archaeological record, there is a single instance of indirect primary production evidence. The site in question, Khao Sam Kaeo in eastern peninsular Thailand, was a major settlement and multi-industry center from the 4th to 1st centuries BC and was located close to known cassiterite deposits.⁵⁶ The evidence at Khao Sam Kaeo concerns two fragmentary crucibles, with adhering cupriferous slag containing residual cassiterite minerals. This has been interpreted as cassiterite co-smelting—introducing cassiterite into molten copper or bronze to make either bronze or an enriched tin bronze.⁵⁷ Regarding secondary tin production, there is no evidence for the refining of metallic tin, but there is relatively plentiful evidence for alloying copper and tin to make bronze, and the recycling thereof, in crucibles and molds. This is attested at Khao Sam Kaeo, Ban Chiang, Ban Phak Top Ban Na Di, Ban Non Wat, Ban Tong, Don Klang, Nil Kham Haeng (trace tin in some slag), Non Nok Tha, and Phu Lon (PL) in Thailand, Oakaie in Myanmar, the Vilabouly Complex (VC) in Laos, as well as northern Bali, some of which are major production centers and others village communities, which suggests that the casting of small bronze tools and artifacts was relatively widespread.⁵⁸

In terms of tin consumption, there is no prehistoric regional evidence for the use of metallic tin to make a final artifact, though it should be noted artifacts have sometimes been claimed to be lead without analytical proof, and the two silvery white metals can be confused by those unfamiliar with the technology. The consumption of tin as an alloy component is dealt with in the section “Copper-Bronze.”

As there are no extant prehistoric Southeast Asian metallic tin artifacts, it follows there are no data for tin exchange networks. Such a study could, in theory, be done with lead isotope analysis, as cassiterite often contains trace amounts of lead. However, as copper minerals generally contain far more trace lead than cassiterite, the geochemical fingerprint of the latter will be swamped by the former, although it could cause the overall patterning to “drift” somewhat.⁵⁹ There is a methodological solution to this, once again developed at the Curt-Engelhorn-Zentrum Archäometrie in Mannheim, Germany, with the development of tin isotopy.⁶⁰ As tin has ten stable isotopes, the highest number in the natural world, it follows that their determination requires a custom-built mass-spectrometer, which was no small undertaking. As such, addressing the “tin question” has been focused on traditional regions of archaeometallurgical concern, the Bronze Age tin supply to Europe and the Near and Middle East.⁶¹ Given the known historical and likely prehistoric importance of tin in Southeast Asia’s local, regional, and interregional interactions, the application of this methodology could be extremely fruitful as individual peninsular city-state production could be characterized relative to their respective river drainages and placer deposits.

Lead

Lead is a metal that does not attract a great deal of attention from nonarchaeometallurgists who presumably consider it to be of low value and with a low skill requirement for extraction. The latter is true to an extent relative to metals with more demanding thermodynamic envelopes but overlooks the frequent association with silver and, more importantly, the advantages of leaded alloys for making detailed copper-base castings. Examples of lead–tin alloys, commonly known as pewter, are extremely rare. It is important, then, at this juncture to define what is discussed in this section and what is dealt with in the section “Copper-Bronze.” Common archaeometallurgical practice is for a copper-base alloy to be considered “leaded” when it contains more than 1 wt % Pb, though some use 2 wt % Pb.⁶² In either case, lead is very much a minor alloying component but can have an important impact on lowering the *liquidus*, or melting range, of the alloy and thus allowing the molten metal to reach the constricted extremities of a complex mold before freezing. What archaeometallurgists are broaching is whether the alloy was *intentionally* produced, the deliberate combination of copper-bronze metal, with lead metal versus the presence of elevated levels of lead in copper ore minerals or the natural combination of lead and copper ore minerals. Beyond 1–2 wt % Pb, copper-base alloys are generally considered intentional, with some leaded copper or leaded bronze alloys containing far greater proportions of lead metal. This is seen quite frequently in the SEALIP and BROGLASEA and Hirao et al.’s databases such that the sheer quantity of lead metal represented in, for example, a large drum represents a substantial labor input from lead smelters, the exchange networks required to get the lead metal to the secondary production workshops, the artisanal contribution of founders, and further social interaction systems to deliver the final product to consumers, who may then have exchanged or traded this material culture with other down-the-line consumers, before even recycling potential is mentioned. In brief, lead matters.⁶³

Once again, archaeological evidence for prehistoric lead production is extremely limited despite the proliferation of plumbiferous geology. In the early to mid-1980s, the Thailand Archaeometallurgy Project (TAP), under the codirection of Vincent C. Pigott and Surapol Natapintu, conducted an archaeometallurgical survey for evidence of premodern mining, including possible lead mines in ore-rich northeastern Loei Province, led by Department of Mineral Resources geologist Udom Theethiparivattra. A probable historic period lead–zinc mine at Rong Khee Bao, with an associated slag field, <<<Pigott 1984, 1985>>> was sampled, with lead isotope analyses conducted by Tom Chase at the Smithsonian. Likewise, late 1980s surveys in the west-central Thai province of Kanchanaburi by Ian Glover and Anna Bennett identified numerous possible lead mineralizations, some with signs of exploitation, but investigations went no further. Further prospections were made in the early 2010s, but as yet no excavations, dating, or technological studies of primary lead production have been made in west-central Thailand or anywhere else in MSEA or ISEA.⁶⁴ As such, there is no geochemically (elemental and lead isotope) defined prehistoric primary production signature to compare consumption assemblages against, but along with the Loei mine found by TAP, the west-central Thai mine of Song Toh has provided another historical example and is likely to have been exploited in earlier periods.⁶⁵

Leaded copper-base alloy consumption is discussed separately, as although lead heavily modifies the characteristics, prehistoric producers and consumers were likely to have appreciated these artifacts as red-gold colored metal artifacts with usable strength and hardness rather than silver-white artifacts of very low strength and hardness. As such, the number of “pure” or near-pure lead artifacts is very low. There are potential examples of Iron Age lead spindle whorls from Tha Kae in central Thailand as well as the curious possibility of a “lost-lead,” as opposed to “lost-wax,” casting process evidenced at Ban Na Di and Ban Non Wat in northeast Thailand.⁶⁶

Rare lead ornaments, bangles, and earrings have been reported from Ban Non Wat and Non Ban Jak in northeast Thailand and Ban Khu Muang in central Thailand.⁶⁷ SEALIP and BROGLASEA have also identified >90 wt % Pb artifacts: two socketed and one chopped decorated lead fragments from late 1st millennium BC Đông Xá in northern Vietnam, a further lead fragment from mid-1st millennium BC Ban Non Wat, and a lead strip from AD mid-1st millennium Prei Khmeng in northern Cambodia, plus a lead strip from mid-1st millennium BC Phromtin Tai in central Thailand (Figure).⁶⁸ Further such occasional instances should probably be expected as analytical study of regional metal assemblages becomes more widespread.

Copper-Bronze

If lead, tin, and, to a lesser extent, iron-steel are generally not viewed as significant by nonarchaeometallurgists, the production, exchange, and consumption of copper-bronze most certainly are due to long-standing associations with early metallurgy, technological prowess (both in the past and as reflected upon the present nation), “civilization,” and social complexity.⁶⁹ Southeast Asia is no exception, but discussion over the sociocultural impact of early regional copper-bronze metallurgy has stretched over half a century and there is insufficient space here to go into detail about it.⁷⁰ Suffice to say, the advent of scientific archaeology in MSEA coincided with the new archaeology revolution in Anglo-Saxon archaeology and the growing application of radiocarbon dating. This confluence led to highly erroneous chronologies being developed for Bronze Age sites excavated in northeastern Thailand in the 1960s and 1970s, which evolved into spurious claims for MSEA being a center for the independent invention of metallurgy.⁷¹ The decadal effort to refute this mistaken paradigm has now been achieved on the chronological front, with a late 2nd millennium BC technological transfer from present-day China being almost

universally accepted.⁷² In terms of social complexity, the outlook is regionally variable but with a tendency toward copper-bronze being at least somewhat elite-associated during the Early Bronze Age.⁷³ How this association evolved over the coming centuries and the general role of copper and bronze in MSEA social groups can now be evaluated with some cautious confidence with an increasingly dense data set, albeit weaker in ISEA.

In terms of primary copper production evidence, for mining and smelting, ISEA has none as yet. Given the presence of copper-bronze artifacts in ISEA, the abundance of copper deposits in Indonesia and the Philippines, and the presence of some ethnohistorical accounts, it is likely this situation represents archaeological prospection bias in very large territories rather than historical reality.⁷⁴ For MSEA, three main prehistoric primary copper production loci are known and have been extensively studied, though the presence of others is suspected on reliable archaeometric reasoning.⁷⁵ An exhaustive review of this topic has recently been published but can be summarized as the PL and KWPV complexes excavated by the Thailand Archaeometallurgy Project in Loei Province and Lopburi Province, northeast and central Thailand, respectively, during 1984–1994, and the VC of Savannakhet Province in central Laos, excavated from 2008 to 2017.⁷⁶ As per ISEA, given the scale and mineral wealth of MSEA, it is almost certain other primary copper production loci remain to be discovered but the region's mountainous and heavily vegetated landscape militate against archaeometallurgical prospection.⁷⁷

The dating of these primary production sites is a critical issue for understanding regional copper consumption patterning during the Bronze and Iron Ages of MSEA and not just the tired and largely redundant “origins of metallurgy” debate, as becomes clear in the exchange discussion later in this section. The least well-dated of the three loci would arguably be PL, which is located on the Thai bank of the Mekong, c. 60 km upstream from Vientiane. The reasons for the low-resolution dating are severalfold: (1) PL was the first prehistoric primary metal

production site ever investigated in Southeast Asia, during 1984–1985, and as such there was a potential learning curve for those experienced in other areas and those new to the subdiscipline; (2) PL is the only locale of the three known to not present evidence for permanent habitation, which generally offers better sampling opportunities for dating; (3) the shallow pottery flat PL matrix was pulverized into an admixture of mineral, slag, technical ceramic, and pottery, not conducive to good context preservation; and (4) at some point, PL suffered a near-complete collapse of the mined-out mountain, which would have destroyed extant timber supports that could have been radiocarbon or dendrochronologically dated. The available radiocarbon dates place PL broadly in the 1st millennium BC, with a single 2nd millennium BC outlier which, while not unreasonable, cannot be considered reliable evidence of early Bronze Age exploitation.⁷⁸

The second best-dated primary copper production site is that of the VC, located at a natural crossing point of the Annamite Range in central Laos. The two main sites, Puen Baolo and Thong Na Nguak, present cemetery as well as industrial evidence, and the Tengkham and Khanong shaft mines had intact organic and bamboo reinforcing structures, both of which allow for improved dating opportunities.⁷⁹ Of the radiocarbon dates available for the VC, all but one fall into the mid- to late-1st millennium BC Iron Age. The single Bronze Age date, *c.* 1000 BC, is nevertheless reinforced by the presence of grave features at Puen Baolo, with an upper layer containing glass ornaments, a regional Iron Age artifact class, and a lower layer without glass but with copper-base ingots of a different typology.⁸⁰ A principal characteristic of the VC is unfortunately one of quasi-certain massive data loss in regard to the Lane Xang Minerals Limited (LXML) mining concession. LXML has been exploited for copper and gold since the mid-2000s, was subject to preproduction surveys, and has integrated rescue archaeology and unexploded ordnance (UXO)-related artifact recording since then. Nevertheless, the total quantity of metallurgical waste material recovered from Puen Baolo and Thong Na Nguak is 142 kg, and it is safe to hypothesize

that major prehistoric slag concentrations at the VC have either been destroyed over the centuries or, more likely, reprocessed to recover more base and precious metals.⁸¹

By far the best-dated primary copper production complex is that of the KWPV in central Thailand, excavated in five seasons between 1986 and 1994, with the main smelting sites being Non Pa Wai (NPW) and Nil Kham Haeng (NKH).⁸² The relative abundance of geochemical data for consumption of copper is examined here, but by way of contrast with the VC and its 142 kg of metallurgical waste; most of the NPW main mound trenches produced *c.* 1,000 kg each. The chronological attribution of KWPV copper production has changed drastically over the past four decades, up to the order of a millennium with the application of strict “chronometric hygiene” criteria to the original dates, but has now come full circle with respect to the earliest metallurgy at NPW, *c.* 1200–1300 BC.⁸³ The technological analysis of KWPV prehistoric copper production was initially carried out by Anna Bennett in the 1980s and then updated by the first author in the 2000s, with the benefit of the NKH excavations being completed, as well as some minor methodological developments.⁸⁴ A key aspect of the latter technological reconstruction is that an evolutionary sequence was identified from inefficient and nonstandardized copper smelting practice at Bronze Age NPW (no greater chronological resolution was available) to more efficient, intensified, and standardized behaviors at NKH, which at the time was attributed exclusively to the Iron Age. This shift in “metallurgical ethos” was interpreted as the supply response to rocketing demand for copper-base metals during the MSEA Iron Age and potentially the ISEA Metal Age. This reading of the archaeometallurgical data can no longer hold true as NKH dates are concentrated in the 8th–6th centuries BC (mid- to late Bronze Age) and tail off rapidly in the 5th century BC early Iron Age.⁸⁵ This point is discussed again in the copper exchange discussion.

In addition to the large (*c.* 5 ha) and deep (3–6 m) metal production deposits at NPW and NKH, three smaller scale sites with copper smelting evidence are known in the vicinity of the KWPV: Khao Sai On, Noen Din, Phromtin Tai, and Tha Kae, samples of which are all under study within the BROGLASEA program.⁸⁶ Khao Sai On itself has been subject to an intensive field survey of the type developed in Mesoamerica and the Aegean, which revealed a range of microproduction sites within a 2 km² area, probably representing the production of individual households.⁸⁷ The site has also been the subject of a preliminary soil analysis project aimed at detecting levels of concentrations of heavy metals, in particular copper within the site matrix.

<<<<Rogan et al. 2018; Tighe et al. 2018>>>>

As secondary copper production, mixing, alloying, casting, and recycling have already been discussed in the section “Tin,” the article now proceeds directly to copper-bronze consumption. As compared to previous metal sections, copper-bronze artifacts have been excavated in substantial quantities across the region, so much so that it would be impossible to give details here (see [Hamilton and White 2019](#) for Upper Thailand, which has the greatest data density in [MSEA](#)). Nevertheless, there is significant variation in the quantity and nature of copper-bronze finds, depending on the chronology, location, and type of site.

First, as most prehistoric MSEA and ISEA excavations have focused on cemeteries, funerary assemblages dominate, usually composed of complete artifacts, and those evidently selected by the deceased’s survivors. These artifacts may have been produced intentionally for burial purposes, as might be interpreted by inappropriate alloys and thermomechanical treatments for the supposed use of the type class, and a lack of use wear.⁸⁸ Funerary assemblages might also not represent the typical array of typologies that would be found on contemporary settlement sites, the few excavated examples of which tend to produce, as expected, artifacts or fragments thereof

that were probably lost, as worn or damaged copper and bronze objects could be repaired or recycled. <<<<Hamilton and White 2019>>>>⁸⁹ Given this bias in the available archaeological record, the uneven distribution of metal artifacts and other grave goods between individual tombs within cemeteries, whether assessed by strata, date, age, sex, diet, or health, has been the primary means for arguing for or against the sociocultural impact of metallurgy in prehistoric Southeast Asia.⁹⁰ <<<Higham et al. 2014b>>>>

Second, excavated MSEA funerary sites tend to be located on plateaus, where their typically mounded topography aided identification. Upland MSEA archaeology remains underdeveloped due to the difficulties of the terrain and cost-effectiveness of such prospection.⁹¹ There is also a distinct difference between northern Vietnam, where huge numbers and quantities (mass) of copper-base funerary artifacts are found, versus the rest of MSEA, even when no prehistoric primary copper production sites are known for the former.⁹² Furthermore, a significant difference can be seen between the quantity of metal excavated from ISEA Metal Age sites as compared to MSEA Iron Age, with the former tending to have much less in addition to the approximately minimum three centuries later dating.⁹³ <<<AU: Pryce et al. 2018a not in refs>>>>

Third, far more copper and bronze, both artifact numbers and mass of metal, are found from MSEA Iron Age than Bronze Age contexts. To put this difference in context, MSEA sites with an Iron Age phase tend to be more visible on the landscape than Bronze Age-only sites due to the frequent presence of earthworks from the mid-late 1st millennium BC, as wet rice agriculture took off in an increasingly dry environment (for northeast Thailand at least) as well as increased conflict and fortification.⁹⁴ These factors indicate the MSEA Iron Age probably saw a significant rise in population density in lowland areas and thus more sites with copper-bronze are perhaps to be expected, with concomitant demand for metal for tools, ornaments, and funerary offerings.

The preceding discussion summarizes the structure of the regional copper-bronze consumption data set, predominantly MSEA Iron Age lowland funerary assemblages. What is singularly lacking, however, is any attempt at a comprehensive regional prehistoric metal artifact typology, which is also the case for prehistoric pottery. Certain artifact classes under copper-bronze exchange systems are now examined but, suffice to say, MSEA Bronze Age assemblages are primarily comprised of suspended core, deep socketed adzes, axes, and spearheads cast in bivalve molds, as well as occasional potentially lost-wax cast bells and ingots as known from the VC and NKH.⁹⁵ MSEA Iron Age and ISEA Metal Age copper-bronze assemblages are dominated by ornaments: bangles, anklets, bells, belts, bowls, bracelets, rings, seals, and other iconic types like drums and mirrors, as seemingly mature iron-steel technologies replaced copper-base tools and weapons, with the exception of cast-on copper-bronze sockets on some iron-steel spearheads and arrowheads, particularly of the prismatic tanged Han type.⁹⁶

Moving to the regional copper-base exchange database, it is essential to recap the laboratory-based provenance, or rather potential provenance, methodology, that is, techniques in addition to typo-stylistic studies. Major (1–100 wt %), minor (1–0.1 wt %), and trace (<1000 ppm [0.1 wt %]) elemental analysis of metal artifacts in attempts to identify their provenance has been practiced for centuries but reached a climax in the 1960s with a number of major European-focused projects.⁹⁷ However, it is now universally accepted in archaeometallurgical circles that an elemental-only approach does not work for provenance research due to differential partitioning of lithophile (e.g., uranium) and cuprophile (e.g., lead) elements between slag and metal during smelting, the impact of mixing copper from different primary production centers, the alloying of other metals like tin or lead with copper, and repeated recycling episodes, including the depletion of volatile elements like arsenic and sulfur with extended and repeated heating (which conversely artificially enriches the remnant copper, nickel, and other contents).

That said, archaeometallurgically nuanced elemental compositional analysis, approaches that take into account extensive corrosion and general heterogeneity, can give reliable identification of original alloys, which can be evaluated for suitability to type, as well as fine-tuning the principal method of copper-base metal provenance, lead isotope analysis (LIA).⁹⁸ It should also be noted that technological (ways of making) analyses, namely, using macro-observation of extant casting and finishing stigmata, and metallography to evaluate crystallographic evidence for mold seams and thermos-mechanical treatments are required to identify technological styles and communities of practices, as well as confirming that the microstructure is compatible with the elemental results, especially in the case of high tin alloys.⁹⁹

LIA was developed in the 1930s as a means of characterizing and dating geological deposits. Its potential application to archaeology was first explored in the 1960s, just as elemental-only limitations were being realized.¹⁰⁰ The fundamental difference of the lead isotope approach as opposed to an elemental one is that the ratio of stable isotopes (^{204}Pb , ^{206}Pb , ^{207}Pb , ^{208}Pb) in the trace lead content of copper ores is not modified (fractionated) by the smelting process and matches that of the trace lead in the raw copper product. In other words, LIA can theoretically provide a link from the artifact to the mineral source. However, this link can be disrupted by the aforementioned processes of mixing, alloying (especially by the addition of lead metal, which completely overwhelms the signature of the lead), and recycling, and one must also allow for the possibility of a single mining location having internal heterogeneity and multiple mineralizations, and thus signatures, or multiple mining locations having overlapping signatures. Thus, LIA is not a silver bullet and alternate data sources are essential as opposed to complementary.¹⁰¹

LIA-based sourcing commences with satisfying the “provenance hypothesis,” that variation between sources is greater than that within them.¹⁰² Ideally, archaeometallurgists achieve this as a desk-based study of the available geological literature for the region in question, but for MSEA

and ISEA, this was not possible due to the absence or unavailability of such data sets, nor can archaeometallurgists, with social science budgets be expected to conduct comprehensive studies of a region's metallogenic geological isotopic variability. Therefore, SEALIP began at the beginning with the technological, elemental, and lead isotope characterization of the three known prehistoric MSEA primary copper producers: PL, the KWPV, and the VC in Thailand and Laos, respectively. Critically, these analyses were focused on slag samples, which, being anthropogenic, represent the signature of minerals (and potential smelting system contaminants like fuel, ceramic, gangue, and flux) rather than minerals that may have been inaccessible, ignored, or rejected by ancient metallurgists. This initial phase was a success, with clear differentiation of the three loci (Figure), albeit with high variability at PL due to the predominance of mineral rather than slag samples and the presence of multiple mineralizations.¹⁰³

With viable primary copper production signatures in hand, the discussion turns to the consumption signatures, and thus evidence of exchange networks. But before blithely doing so, the nature of the regional copper-bronze consumption assemblage must be recalled—predominantly MSEA Iron Age funerary and ornamental in location, date, nature, and type. Of the approximately 860 Southeast Asian archaeometallurgical lead isotope determinations currently available, roughly half are for leaded copper or leaded bronze (>1 wt % Pb). For these artifacts it cannot be known where their constituent copper comes from, as its trace lead signature will have been swamped by several orders by that of the added lead metal, for which there is no regional primary production signature. Furthermore, most of the artifacts suffer from varying degrees of corrosion, which must impact the confidence of attempted attributions and interpretations, as lead is an element highly mobile within groundwater and thus the burial environment.¹⁰⁴ This is not to be unrelentingly negative. The strength of the lead isotope methodology is that it has been tried, tested, probed, critiqued, and refined for almost six decades.

Its weaknesses are for the most part Rumsfeldian “known unknowns,” which is a real improvement over the “finger in the wind” reliability of many archaeological approaches toward provenance of other materials.

These caveats in hand, plotting the combined MSEA and ISEA unleaded copper-bronze lead isotope signatures clearly demonstrates (these are raw data with no statistical manipulations) that the vast majority *cannot* be considered compatible with any of the known primary copper production signatures. This is not a methodological failure. In addition to the real likelihood of as yet undiscovered primary copper production centers, these data show that the late prehistoric Southeast Asian economy and social interaction networks were dynamic—most copper-bronze did not move directly from smelter and founder to grave, neither as direct-to-death production nor as the interment of long-husbanded heirlooms nor the result of unmodified gift-giving networks.¹⁰⁵ Many regional copper-bronze artifact life histories seem to have involved at least one former incarnation prior to being recycled into the form they were excavated as. If these geochemical signatures cluster and make geographical, chronological, and cultural sense, then that patterning should represent subregional recycling pools or the metallurgical manifestation of economic and political boundaries. Such identifications can be reinforced by the analysis of waste materials from secondary copper-bronze production centers, which may highlight the center of political power, or economic output at least, for each pool.¹⁰⁷

In this article, a reasonable solution is offered to an issue that has perplexed researchers ever since SEALIP data first came rolling out of the mass spectrometer in 2008. Despite the KWPV having produced the greatest quantity of primary copper production waste in Southeast Asia by many orders of magnitude, its lead isotope signature has been almost invisible in the regional consumption database. Naturally, this led to the question, “where is all the KWPV copper going?” Mixing, alloying, and recycling could have been partly responsible but unlikely to the

extent seen.¹⁰⁸ That is not to say there were no copper and bronze artifacts consistent with the KWPV signature, with Ban Non Wat only 180 km ENE providing convincing data as well as, more surprisingly, Oakaie, some 1,000 km NNW, and that distance assuming a relatively unlikely direct mountainous overland route.¹⁰⁹ What these consumption samples had in common was being early 1st millennium BC Early- and Mid-Bronze Age in date, a period during which the KWPV has always been thought to have been producing copper. However, the previous mindset was based upon the understanding that NKH at least was an Iron Age copper producer.¹¹⁰ The revelation now is NKH was primarily, if not entirely, mid- to late Bronze Age in date, and thus it is perfectly understandable that the KWPV copper production signature is not to be seen in the predominantly Iron Age and Metal Age regional consumption data set.¹¹¹ There may well have been Bronze Age KWPV copper circulating into the Iron Age but mixing, alloying, and recycling would eliminate the original signature. It is also possible that the satellite sites of Khao Sai On, Phromtin Tai, and Tha Kae did carry on producing into the Iron Age, albeit at a much lower scale. And therein lies the most pressing question for prehistoric MSEA nonferrous archaeometallurgy: “why did the KWPV, the region’s largest smelting sites, stop or massively reduce copper production at the cusp of the Iron Age?”

A definitive answer cannot be given, but it could be as simple as the penultimate word of the last paragraph: the KWPV switched to iron production, high-quality ore minerals for which were available nearby at Khao Thab Kwai at least. While there is possible evidence for apparently late, historic period iron smelting at Non Mak La <<<Weiss 1989>>>, this is not considered a satisfactory answer. MSEA Iron Age funerary data suggest copper and bronze were being consumed in significant quantities for personal ornaments, so why would KWPV copper producers with unexhausted (to this day) copper ore minerals and with no archaeobotanical and

anthropological evidence for a lack of fuel abandon the central technological tradition of their locality of at least 500 years standing?

The authors consider the historical reality to have been economic or political or a combination of those factors. VC Iron Age copper smelting indicates a slightly higher degree of technical competence than that seen in the KWPV despite substantial improvements in the latter over time.¹¹² This could have led to VC supply undercutting that of the KWPV; however, that might be expressed in prehistoric terms: more copper per unit of cost per labor. Furthermore, increasing mid-first millennium BC populations and potentially interaction density, combined with reducing communication and transport costs, may have meant the Iron Age copper and bronze metal market was more liquid than in the Bronze Age. VC and KWPV signatures have already been seen in early Bronze Age 10th-century BC north central Myanmar <<<Pryce et al. 2018c>>>, the Iron and Metal Age's higher "velocity" of metal could have rendered less efficient production uncompetitive.¹¹³ Finally, there is the possibility of political actions and constraints on KWPV copper production. Already seen and continuing to be seen in fresh BROGLASEA data is an overwhelming dominance of VC signature copper at sites equidistant from the KWPV, or even located right next to it during the Iron Age, where transport or contact cannot have been an issue.¹¹⁴ Maybe the prevalence of VC copper in the Iron Age is an indicator of an emergent political complex that could control the production and exchange of raw materials. Of course, this only accounts for the samples considered "consistent" with the known signatures. There remains a huge cloud of data that might correspond to other primary production systems, in particular in China, where economies of scale could certainly have knocked KWPV copper out of viability. In general MSEA and ISEA archaeological terms, rather than the specific interests of archaeometallurgists, some of the most exciting data to emerge from the study of copper and

bronze exchange concern the simple provision of reliable evidence for prehistoric interaction networks, and especially the dating of those same. As previously mentioned, no methodologically robust and widely accepted regional pottery typologies exist for Bronze and Iron Age Southeast Asia,¹¹⁵ largely due to the low density of researchers in the area, the lack of appropriate methodologies for covering very large areas, and the mutually unintelligible languages and scripts of almost all ASEAN nations (English being the common language). Although contact between late prehistoric Cambodia and Laos, Myanmar and Thailand, and so on, was obvious, there was typically no reliable archaeometric evidence for those exchanges before the application of ultra-trace element glass analyses for Iron Age assemblages and nothing for the Bronze Age prior to SEALIP and Hirao et al.'s work.¹¹⁶ The reconstruction of copper and bronze exchange systems provided the first geologically anchored evidence for the movement of raw materials in late prehistoric MSEA, with the implicit association of social interaction systems. What archaeometallurgy can thus offer is cross-dating opportunities of unparalleled reliability.

These cross dates have been of huge utility at the primary copper production sites themselves. Based upon the chronology available for the KWPV in 2009, post the work of [Pigott et al. in 1997](#) and prior to that of [Higham et al. in 2020](#), it was not certain that copper was being smelted during the Bronze Age based upon Non Pa Wai's dating, though foundry and consumption evidence was present in funerary contexts.¹¹⁷ That early metal, a single low tin bronze axe discovered in a founder's burial, transpired to be not made from KWPV copper and was likely an import, suggesting an absence of local smelting in 13th–12th centuries BC.¹¹⁸ However, the analysis of copper-base artifacts dated 1000–900 BC (BA2) at Ban Non Wat established a high degree of lead isotope consistency with the KWPV production signature.¹¹⁹ Thus, a high probability copper was being smelted by the turn of the 2nd–1st millennium BC at

Non Pa Wai or its environs, an identification subsequently reinforced by 10th-century BC copper-base artifacts from north-central Myanmar (Oakaie) also being consistent.¹²⁰ The same is also true for the VC, which only recently produced an in situ Bronze Age date, with the remaining ¹⁴C determinations falling inexorably into the mid-late 1st millennium BC Iron Age.¹²¹ Once again, the identification of reliably dated early 1st millennium BC Bronze Age copper-base artifacts at Ban Chiang, Oakaie, and more tentatively at Tham Than Nam Lot Yai in peninsular Thailand, with good VC copper production signature compatibility, gave great weight to the proposition that central Lao copper production was active several centuries before the direct archaeological evidence could demonstrate.¹²² For the PL copper production locale, there are very few geochemically consistent consumption assemblages due to a dispersed signature, but those that could be compatible are exclusively from Iron Age central Myanmar contexts, <<<Pryce et al. 2018c>>> though overlapping production signatures in Myanmar or Yunnan are also a possibility.¹²³ It is also of great interest to note the existence of KWPV slag with a PL signature, as well as a PL slag with a VC signature.¹²⁴ This is not an instance of mislabeling, as these samples were submitted in batches many months apart. It is evidence that the permanent or visiting (PL) populations of primary copper production loci were for some reason exchanging minerals and slag between themselves.¹²⁵ This could be indicative of an at least partially nonmarket economy and that while copper ingots and copper-base artifacts may have served as a means of exchange, there was a noncommodity value above and beyond that, for some populations at least.¹²⁶

With these techno-chronological foundations in place for the VC and the KWPV at least, the presence or absence of copper consistent from these production centers can help to date consumption sites without reliable radiometric sequences. Many data still need to be processed

but so far there is no well-dated MSEA Iron Age context that has copper-base artifacts consistent with the KWPV signature, which reinforces the new chronology.¹²⁷ There are some central Thai sites (Khao Sai On, Phromtin Tai, Tha Kae) that have the “cordiform” copper-base artifacts that are typologically similar to those seen from NKH in what are strongly argued to be Iron Age contexts, but it could well be (subject to ongoing or future analyses) that these artifacts are either inconsistent geochemically or represent the tail end of NKH production, with some ingots lingering into nearby early Iron Age contexts or potentially still being produced there on a small scale.¹²⁸ Notably, the three potentially cordiform artifacts from Iron Age 1 (420–200 BC) Ban Non Wat were either highly leaded or made of near pure lead and thus cannot have been made in the KWPV anyway.¹²⁹

There is insufficient space here to cover all the copper-base exchange patterning that might be of interest to general regional archaeologists. This would also be a futile exercise as the completion of BROGLASEA’s full data interpretation is awaited, which will require monograph-length treatment. This article ends with a final example of the necessity to analyze metal artifacts “in the round”—that is, for their morphostylistic, technological, elemental, and isotopic characteristics. The case study in point is that of the so-called Đông Sơn drums, one of the most iconic classes of prehistoric metallurgical material culture for all Southeast Asia and the subject of intense scholarly interest for over a century.¹³⁰ They are also known as “Heger drums” after their first eponymous (1902) classification into four main types, with “Is” being the oldest and “IVs” still being used by some ethnic upland minority groups.¹³¹ Heger Is are the main prehistoric type, and thus the focus here. They are generally divided into Dian or Đông Sơn styles, corresponding to the mid-late 1st millennium BC Yunnanese kingdom and Red River Delta culture regions, respectively. Needless to say, there has been considerable ink spilt on which is the earliest and thus original type, with nationalist sentiment coming into play over what are

considered to be prestige objects symbolizing princely civilization and artisanship.¹³² There are in excess of 400 Heger “Is” known from across MSEA and ISEA, ranging in accessibility and legitimacy from those officially excavated and held in public museums to those looted and held in private collections, and a range of intermediate situations.¹³³ The drums range in size from 200 to 1,000 mm in diameter across the tympanum and similarly in height, corresponding to a mass range of low single digits to several hundred kilograms of metal.¹³⁴ The alloy used, when analyses have been conducted and are of acceptable quality, are generally leaded bronzes but both copper-bronze examples are known.¹³⁵ A case in point can be seen from Dong Xa near Hanoi, a site of Đông Sơn period and general style, which nevertheless furnished a large drum of Dian style.¹³⁶ Subsequent analyses demonstrated this artifact was made from bronze rather than the typical leaded bronze alloy and whose lead isotope signature was dissimilar to most analyzed Dong Son drums.¹³⁷ Discussion of the fabrication method for Đông Sơn and Dian styles has ranged over lost-wax, bivalve, and multipiece mold casting techniques but with none of the advocates having ever carried out an exhaustive study due in part to the aforementioned wide distribution and inaccessibility of some examples.¹³⁸ The end result is that general archaeologists working in Southeast Asia, when confronted with a copper-base artifact of drum-like shape and with geometric or naturalistic cast decoration, tend to immediately identify the object as Dong Son (diacritics deliberately excluded) and assume some form of exchange system linking the find location to the lower Red River area.¹³⁹ This might have been acceptable and understandable once, but trained archaeometallurgists have been present in the region since the 1960s, had the methodological means to do a proper job since the 1980s, and have been actively doing so since the 1990s.

Through BROGLASEA analyses, two situations have been able to be identified where an uncritical attribution of Dong Son contact would have been factually wrong. The first concerns a

fragmentary but relatively large drum found at Khao Sek in peninsular Thailand, recovered out of context but with the rest of the site comfortably dating to the 4th to 1st centuries BC.¹⁴⁰ The main extant element for this drum was the tympanum, also broken, but which had cast decoration in classic Đông Sơn geometric style of a blazing sun (see Figure 2).

<COMP: INSERT FIGURE 2 NEAR HERE>

However, macroanalysis of the section cut for export revealed the well-preserved metal to be extremely red-pink in tone, and highly porous. Even prior to laboratory analysis, this was indicative of a low tin and low lead alloy, which would have produced a more yellow color and a better-quality casting. These initial impressions were indeed confirmed by metallographic and elemental analysis, showing that while the Khao Sek drum was stylistically Dong Son, the alloy was used atypically and the execution poor. Finally, lead isotope analysis showed high consistency with the VC copper production signature rather than the putative north Vietnamese and Yunnanese source expected of a Đông Sơn drum. Thus, the Khao Sek drum appears to be an ancient imitation of exotic material culture using a third-party raw material source, though it is not known where this example was actually cast.¹⁴¹

This neatly brings us to the evidence from the Iron Age site of Non Nong Hor in northeastern Thailand, where ceramic molds with Dong Son-style decoration were found along with conical copper-base ingots of a type similar to that from the VC in Laos, directly east across the Mekong River.¹⁴² While these finds have not yet been analyzed, the typology and geographical proximity strongly suggest Dong Son drums were being produced outside of the Đông Sơn culture area. Why the drums were replicated is open to speculation, but it seems reasonable to say that subregions of Iron Age MSEA saw it worth their while or fulfilling their needs to imitate north Vietnamese material culture, even while the genuine articles may also have been available.

This Dong Son drum story is not limited to MSEA. Calo's extensive regional drum study covered a large proportion of the known examples and identified many potential examples located in ISEA of Đông Sơn style.¹⁴³ It is perfectly possible, likely even, that some of these drums are of Đông Sơn culture origin, but the requisite technological and geochemical tests have not yet been conducted. In Calo's subsequent excavations of Metal Age sites, including Manikliyu on the north coast of Bali, a stylistically different drum type was encountered, known as "Pejang," examples of which are also known from Java.¹⁴⁴ It had been suggested that Bali Pejang drums were produced by attaching the separate tympanum to the body, as per the side handles, but the authors' metallographic studies of the available samples showed the drums were cast in one piece, as per most Đông Sơn drums. Furthermore, elemental and lead isotopic analysis showed that the Bali Pejang drums were made from the same type of alloy, leaded bronze, just like the majority of analyzed Đông Sơn examples, and that they had compatible lead isotope signatures. While plenty of evidence exists for long-range exchange networks at c. 2000 BP Bali, and taking into account that nothing is known of ISEA prehistoric primary metal production, the authors' interpretation for the Pejang drum is that it may have been recast from melted down Đông Sơn imports—thus, the "drumness" was maintained but completely reinterpreted for local ideological needs <<Calo et al. 2020; Pryce et al. 2018a>>>.

These examples, which will surely be complemented by others once comprehensive analytical programs proliferate, demonstrate that relying on any single strand of evidence is likely to be misleading at best, or just plain wrong. Important human information lies in the triangulation of morpho-stylistic, technological, and geochemical characteristics, and the minor repairable damage caused by sampling is ultimately essential if researchers are to extract holistic historical meaning from metallurgical material culture. Artifacts corroding in museum cases with

informationless labels are interesting neither for scholars nor the public. Scholars can, are, and will continue to do better.

Discussion of the Literature

As in many areas of the world, the literature concerning prehistoric Southeast Asian metallurgy has been largely focused on its origins. This is a common issue as metallurgy, particularly copper metallurgy, has long been associated with the “rise of civilization” due to its apparent association in the ancient Near East, noted in the early 20th century.¹⁴⁵

Primary Sources

As this article is concerned with prehistory, there are no written primary sources for early Southeast Asian exchange networks. In terms of artifact assemblages, there are three main possibilities: museum, excavation, and private collections, with subdivisions according to location.

Most prehistoric metal artifacts are found in museums, predominantly in the country of origin at the national (capital) and regional (provincial) levels, but with some major overseas collections. Visiting these museums gives an initial impression of assemblages but many of the artifacts are likely to be in storage rather than on display. Actually handling the assemblages likely requires extensive prearranged permission, if it is possible at all; this counts equally for photography, drawing, measuring, and weighing. Sampling is another matter altogether, as it permanently modifies the artifact—typically museums do not permit this, especially those in the country of origin where the finds are considered national treasures.

Excavation collections are also to be found both in and out of regions, stored in both museum and research institute and university contexts. In the past, it was common to export large assemblages, like those of the Thailand Archaeometallurgy Project held at the University of Pennsylvania Museum, but in recent decades this is far less prevalent as regional analytical capacity has increased. Having not been accessioned, there is a better chance of studying these assemblages, but those stored in museums may be subject to similar restrictions as those artifacts on display.

The final possibility is that of private collections, both in-country and overseas. There are, of course, a great many museum artifacts that do not have formal provenance and that may have uncertain life histories. However, the proportion of not formally excavated (looted) material in private collections is likely to be much higher. Not only does studying these assemblages lend support to what is sometimes illegal, in addition to unethical activity, the lack of contextual information is often crippling for interpretative purposes.

Links to Digital Materials

The Ban Chiang Project—Metals Database <https://db.iseaarchaeology.org/metals-database/>.

Professor Charles F.W. Higham's excavation archives <https://drive.google.com/drive/folders/0BwyPRRjONdiFYmpuZzduWVBKQ0k?resourcekey=0-PEesF7C7WEI-b9ijnFAE9g1>.

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Figure 2. Copper-base drum found at 4th–2nd centuries BC Khao Sek in peninsular Thailand, showing (left) the tympanum of clear “Dong Son” decorative style, (top right) the pinkness and porosity of the sectioned rim in hand specimen, and (bottom right) the porous and as-cast microstructure (the latter courtesy of Pi Venunan).

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