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Bronze Metallurgy in Southeast Asia with Particular Reference to Northeast Thailand

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Abstract

The long-awaited definitive chronology for the period from the initial use of bronze metallurgy to the end of the Iron Age on the Khorat Plateau of Northeast Thailand has received near universal acceptance. In this review, we trace how bronze was deployed, and assess its social impact from the late Neolithic communities that first encountered metal to the civilization of Angkor. We identify eight phases that, for the prehistoric period, centred on the anchor site of Ban Non Wat, beginning in the eleventh century BC with imported copper axes and the opening of the first mines and associated smelting sites. This was followed in the second and third phases of the Bronze Age by a dramatic increase in mortuary wealth in the graves of social aggrandizers. After about eight generations, bronzes were locally cast in bivalve moulds. However, no further elite burials were found and bronze mortuary offerings were very rare. From about 400 BC, the opening of seaborne exchange networks, the establishment of dynastic China and climatic change then stimulated marked regionality. On the Khorat Plateau, many more bronzes were interred with the dead, but casting activity in the consumer sites declined. In the early centuries AD, increased aridity stimulated an agricultural revolution as sites were ringed by reservoirs and wet rice was grown in ploughed fields. This was accompanied by a surge in the range and number of bronzes with the new social elite that within a century led to the formation of early states. The new royalty now sponsored bronze statues, leading directly on to the dynastic foundries of Angkor, when massive bronzes reflected royal divinity.

Keywords Bronze Age · Southeast Asia · Technology transfer · Social change · Bronze metallurgy

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Introduction

Evaluating the impact of copper-base metallurgy on prehistoric societies in mainland Southeast Asia has been handicapped by controversies over chronology, how the necessary expertise was transmitted, how to identify evidence for the first use of metal, and the interpretation of evidence for social change.

The current literature presents two incompatible chronologies (Pryce 2014). The 'long chronology', by White and Hamilton, places their initial 'bronze period' at the site of Ban Chiang between c. 2000 and 1800 BC, with direct transmission of the necessary technical knowledge from the Seima-Turbino cultural phenomenon proximally located in the Siberian Altai (White 2008; White and Hamilton 2009, 2014, 2018, 2019). The seven radiocarbon dates that they present in support come from the organic fraction of crushed potsherds found as mortuary offerings, and in one sample, from rice phytoliths found in a pottery vessel. The short chronology is based on c. 350 new radiocarbon determinations from multiple sites on the basis of charcoal, human bone collagen, rice and millet grains, *Spilanthes* seeds and freshwater shells. The results of these and all other available radiocarbon determinations from Southeast Asian and Chinese sites from the Neolithic and Bronze Ages date the earliest evidence for copper-base metallurgy in the late 2nd millennium BC, and are illustrated in Fig. 1, together with three dates cited by White in support of her long chronology. Judging the plausibility of either the long or the short chronology has generated a lively discussion (White and Hamilton 2018; Higham et al. 2015, 2019a; Higham 2015; Pryce 2015; Bellwood 2015; Oxenham 2015). We leave it to interested readers to make their own judgement. We adopt the short chronology, since it is supported by every available set of radiocarbon determinations save the seven from Ban Chiang, which employed a technique widely regarded on multiple grounds as unreliable (Hedges 1992; Bonsall 2002; Berstan 2008).

There are four consumer sites on the Khorat Plateau in which there is a sequence from Neolithic into early Bronze Age occupation. All were subject to disturbance of early layers by bioturbation and the digging of graves, pits and postholes. All present a difficult issue of interpretation when fragments of bronze or crucible are found

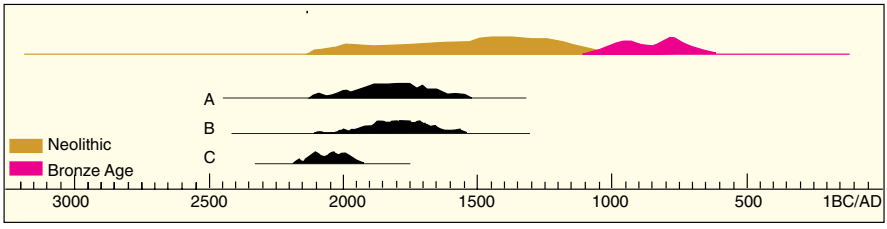

Fig. 1 Plot of all available Neolithic and Bronze Age contexts from Southeast Asia and southern China, compared with three ^{14}C determinations from crushed potsherds claimed by White and Hamilton (2018) to place initial bronze contexts at Ban Chiang between 2000 and 1800 BC. White (2008, p. 97) describes these dates as denoting: (A) *terminus ante quem* for bronze spear point in BCES burial 76; (B) and (C) no bronze grave goods in lower EP BC locale but bronze in lower EP occupation deposits contemporaneous with these Phase EPII graves (graphics program: freehand mx)

in basal and disturbed occupation contexts ascribed to Neolithic occupation. At the site of Ban Non Wat, for example, elite Bronze Age graves were excavated through Neolithic occupation and mortuary remains. Not only fragments of bronze, but also iron and even a couple of glass beads, found their way down into places where they clearly do not belong. The same is true at the site of Ban Chiang. There are two ways of dealing with this important problem. White and Hamilton (2019) readily accept that these fragments of bronze are *in situ*, thereby lengthening the duration of the Bronze Age by many centuries, and identifying a long period of acquaintance of metallurgy before it was, for example, found as a mortuary offering or being cast within the settlement in question. The basal Neolithic occupation and mortuary contexts do, in fact, contain undisturbed midden deposits that contain incised and impressed ceramics, hallmark of the initial farmer settlement of Southeast Asia. None contained a fragment of bronze or crucible. During the ten fieldwork seasons at Ban Non Wat (totalling more than 24 months of excavation) our *modus operandi* has remained conservative: to accept as evidence for copper-base metallurgy graves containing bronzes, crucibles and moulds as mortuary offerings, and the furnaces used to bring copper to melting point.

There are also two models for the transmission of mining, smelting and casting expertise from the north into Southeast Asia. White and Hamilton favour a rapid movement of founders from the Altai to the site of Ban Chiang that left no impact on the uptake of bronze technology in modern China (White and Hamilton 2014). This contrasts with a model that favours a progressive southerly spread of the necessary metallurgical skills that can be traced archaeologically from the Central Plains of the Yellow River to the Yangtze River region, then further south into Lingnan, reaching Southeast Asia by the end of the 2nd millennium BC (Higham et al. 2011). In this, we follow Roberts (2009, p. 473) when he concluded that 'For the "spread" of metallurgy to occur, a sufficiently skilled individual or a group would have to move to a new ore source. This is a process that can be seen, not only throughout Europe (Ottaway and Roberts 2008), but throughout Eurasia'. One recently-identified compelling reason for the penetration of this technical knowledge south has been the seminal role of the city site of Panlongcheng, located in the Yangtze region, in sourcing and transmitting tin from the rich Lingnan deposits north to the Shang state centred at Zhengzhou (Liu et al. 2019).

We must also address the theoretical framework within which the social impact of bronze metallurgy is considered. This concern is not confined to Southeast Asia. As Earle et al. (2015, p. 633) have written of the Bronze Age in Europe: 'two major paradigms are competing in Bronze Age research: one that stresses elite-controlled long-distance trade networks (e.g. Kristiansen and Larsson 2005; Kristiansen and Earle 2014), another that stresses local processes and smaller-scale tribal or segmentary interaction (e.g. Harding 2000, 2013; Kienlin 2015).' We argue that in evaluating what impact, if any, bronze had on socio-economic and cultural patterning, it is necessary to take a holistic approach that considers the location of settlements relative to resources and natural exchange routes.

White's new (2019) model is a departure from her earlier work, signalled by the substitution of Bronze Age by 'bronze period' and Iron Age with 'iron period'. Previously, starting with *Ban Chiang: The Discovery of a Lost Bronze Age* (White

1982) and works following (e.g. White 1995, p. 111; White and Hamilton 2009, pp. 357, 360; 2014, pp. 807–808, 821, 828), the Neolithic/Bronze/Iron convention was used — the convention that has been and remains standard for other authors in the region (e.g. Bellwood et al. 2011; Pigott and Ciarla 2007; Pryce et al. 2014a, b; Oxenham et al. 2015; Rispoli et al. 2013; Killick 2014; Martinón-Torres and Rehren 2014). The new paradigm that is claimed for interpreting evidence for the adoption and development of metal technology in mainland Southeast Asia adopts an 'anthropology of technology' approach, stressing the relevance of the rates and regional variations in the adoption of copper-base metallurgy; by what means knowledge was transmitted; why it was incorporated into an existing technological system; and how the technology, once adopted, changed over time. White concludes that bronze had little if any social impact in essentially bottom-up communities with no overt presence of a hierarchy. As implied above, this approach is contrasted with what is characterized as the old, or conventional, paradigm rooted in the 'Three Age System' for the later prehistoric sequence of mainland Southeast Asia – a nomenclature that represents (for White) old-style ('Anglophone') processualism, and involves an assumption that the presence of metal in itself inevitably stimulates the rise of controlling social elites and the state. This 'top-down' approach, according to White, perpetually seeks those who control metal, ignoring or dismissing evidence that does not fit the predetermined model.

Most Southeast Asian specialists now agree that the series of newly-dated prehistoric sites in Southeast Asia and Southern China (Table S1), together with the preferred models for the transmission of knowledge, provide the chronological scaffolding vital for assessing the cultural changes that occurred during later prehistory and the Early Historic period in Southeast Asia (Higham and Higham 2009; Higham et al. 2015; Pryce et al. 2018a, b). In this paper we begin by concentrating on consumer/settlement sites on the Khorat Plateau of Northeast Thailand, and the three mining and production centres on its margins. We then proceed beyond the prehistoric sequence into the formation of early states of interior Southeast Asia.

The Key Mining and Consumer Sites

Mining and smelting in the Khao Wong Prachan sites of Central Thailand, and at Vilabouly in Central Laos, date to the late 2nd millennium BC (Fig. 2; Rispoli et al. 2013; Tucci et al. 2014; Cadet et al. 2019; Higham et al. 2019a). New radiocarbon determinations place the first evidence for bronze artefacts at Ban Non Wat, Ban Chiang, Ban Lum Khao and Non Nok Tha on the Khorat Plateau in the 11th–10th centuries BC (Fig. 3; Higham and Higham, 2009; Higham et al. 2014; Castillo et al. 2018). As far west as Central Myanmar, the transition from the late Neolithic to the initial Bronze Age at Oakaei has been dated to c. 1000 BC (Favereau 2018; Pryce et al. 2018a, b; Pradier et al. 2019).

An interaction sphere linking Southeast and East Asia existed well before the first evidence in the former for metallurgy. This is seen in the southward expansion of rice and millet farmers who reached Southeast Asia by 2000 BC, and the long-established exchange in the cowrie shells native to the warm seas of Southeast Asia

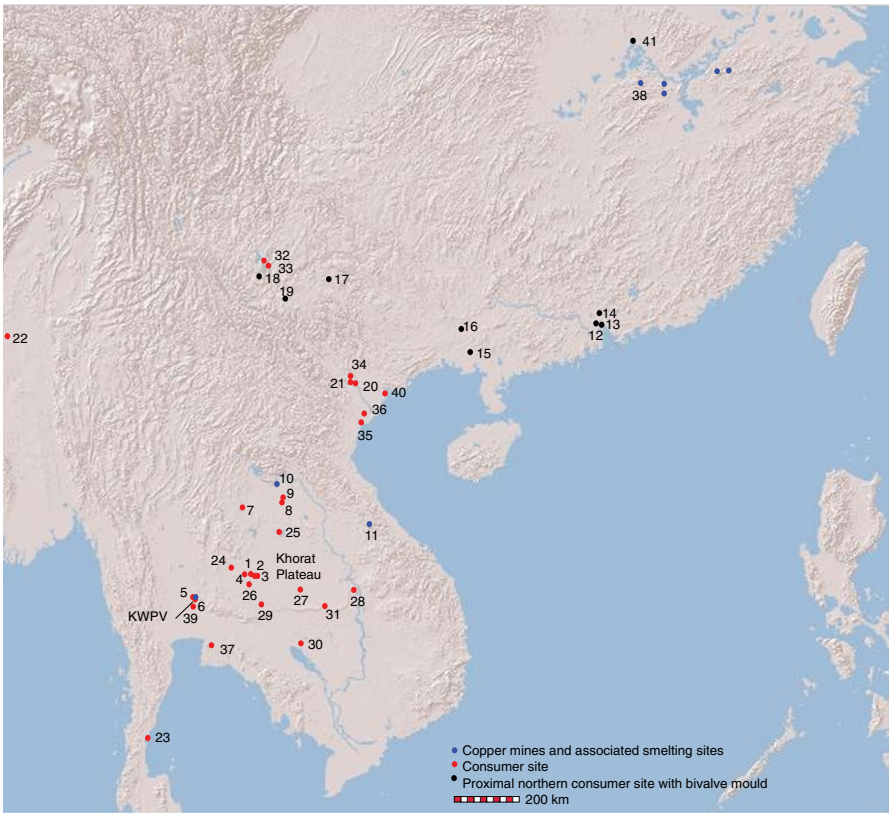

Fig. 2 Map showing the location of key sites. 1. Ban Non Wat, Noen U-Loke, 2. Ban Lum Khao, 3. Ban Prasat, 4. Non Ban Jak, 5. Non Pa Wai, 6. Nil Kham Haeng, 7. Non Nok Tha, 8. Ban Na Di, 9. Ban Chiang, 10. Phu Lon, 11. Sepon, 12. Tangxiahuan, Dameisha, Guoluwan, 13. Yapowan, Nanshawan, Zengchuanbu, 14. Longxue, 15. Gantuoyang, 16. Yuanlongpo, 17. Wayao, 18. Haimenkou, 19. Yinsuodao, 20. Dong Dao, Go Mun, 21. Than Den, 22. Oakaei, 23. Khao Sam Kaeo, 24. Muang Sema, 25. Muang Fa Daet, 26. Ban Tanot, 27. Prasat Hin Khao Plai Bat, 28. Wat Phu, 29. Phanom Rung, 30. Angkor, 31. Preah Vihear, 32. Shizhaishan, 33. Lijiashanm 34. Lang Ca, 35. Dong Son, 36. Man Bac, 37. Khok Phanom Di, 38. Tonglüshan, 39. Tha Kae, 40. Viet Khe, 41. Panlongcheng (graphics program: freehand mx)

that are found in their thousands in the Shang Dynasty cities of the Central Plains of China (Peng and Zhu 1995). Lead isotope analyses of the first known Southeast Asian bronze castings are likewise revealing that early exchange and presumably intangible technical knowledge, spanned considerable distances: early copper in Myanmar has the lead isotope signatures for the Khao Wong Prachan Valley (hereafter KWPV) in Central Thailand and the Vilabouly copper source in Laos, respectively c. 1000 and 1500 km to the southeast (Pryce et al. 2018a, b).

As a convenient shorthand, we term the period from about 1100 to 500 BC in mainland Southeast Asia the *Bronze Age*, with no implication or anticipation that the cultural impact of metallurgy is the same as that identified elsewhere in the Old World. Hereafter the term *bronze* refers to a copper/bronze metal, without our

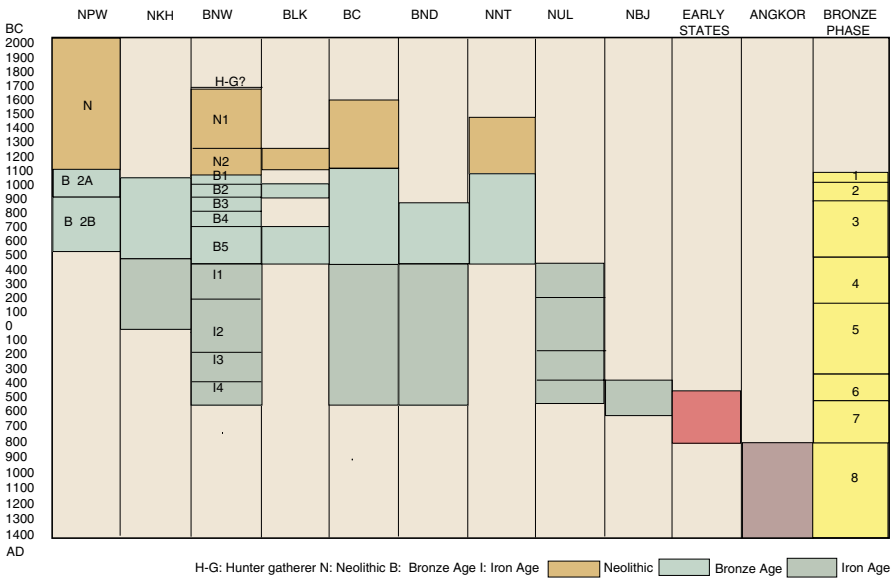

Fig. 3 The chronological relationships between the key production and consumer sites. NPW: Non Pa Wai; NKH: Nil Kham Haeng; BNW: Ban Non Wat; BLK: Ban Lum Khao; BC: Ban Chiang: BND: Ban Na Di; NNT: Non Nok Tha; NUL: Noen U-Loke; NBJ: Non Ban Jak (graphics program: freehand mx)

necessarily having full knowledge of its composition. The Bronze Age was succeeded by the millennium of the *Iron Age*, with the same caveat. Our intention is to investigate how bronze metal was deployed from its initial presence to the state society of Angkor, a period of about 2400 years, and explore unfolding sociotechnical systems. The study concentrates on prehistoric sites located in Central Thailand and the Khorat Plateau to the northeast, where the best evidence for the earlier prehistoric period is to be found (Fig. 2).

Copper mines and nearby smelting sites are located in the KWPV of Central Thailand; at Vilabouly in central Laos; and at Phu Lon on the southern bank of the Mekong River (Natapintu 1988, 1991; Pigott and Natapintu 1988; Pigott and Weisgerber 1998; Pigott et al. 1997; Tucci et al. 2014; Cadet et al. 2019). The best documented lie in the KWPV, where the production sites of Non Pa Wai and Nil Kham Haeng are situated close to the nearest copper mines on the Lopburi Plain at Khao Tab Kwai, the hill known as Khao Phu Kha and slightly further from several other local mines (Natapintu 1988). The sequence in the valley is crucial to interpreting origins and changes that copper production underwent during prehistory. Occupation began in about 2200 BC with a Neolithic settlement and cemetery at Non Pa Wai (T. Higham et al. 2020). The inhabitants cultivated millet, and were engaged in exchange for exotic marine shell ornaments (Weber 2010; Ciarla et al. 2017). The 27 burials contained finely-decorated ceramic vessels and, sometimes, the anvils used to manufacture them. There were stone adzes, stone bangles and shell beads. Some of the Neolithic burials lie in Non Pa Wai's shallow basal deposit that was to be severed by Bronze Age burials. It is these that have provided the earliest indications

of copper-related metallurgical activity (Fig. 3). This activity is currently dated to c. 1100–1000 BC (Rispoli et al. 2013; Higham et al. 2020). Two metal founders were interred in this deposit with pairs of ceramic, bivalve casting moulds, and one burial contained a socketed axe comprised of over 99 wt% copper (Pigott et al. 1997). The Non Pa Wai basal deposit is capped by c. 2 m of the so-called 'industrial deposit' marking a period of intensive copper smelting and small, portable ingot casting. This deep accumulation of smelting debris came to cover c. 5 hectares, in which massive amounts of copper ore and host rock, slag, and hundreds of thousands of crucible fragments were mixed with tens of thousands of fragmentary cup and conically-shaped ceramic moulds for large-scale ingot casting. Non Pa Wai metalworkers smelted easily-exploited mixed oxidic and sulphidic ores in large, single-smelt ceramic crucibles (Pryce et al. 2010).

Nil Kham Haeng lies about 3 km southwest of Non Pa Wai. It comprises a mixed occupation and industrial complex that incorporates living surfaces and human burials amidst metres of finely crushed copper ore, degraded crucibles and host rock deposited in thin lenses across an area of c. 5 ha. A great deal of effort was also expended in crushing the ore prior to smelting. Fourteen Iron Age burials were excavated, some notably richer in terms of grave goods than at early Non Pa Wai. Mortuary offerings included carnelian beads, metal arm bangles and so-called ceramic furnace chimneys. Significantly, locally produced, multiple, thin cordiform socketed implements which we will encounter again in the early Iron Age at Ban Non Wat, were found in clusters in several of the burials. In terms of chronology, metal composition production intensity and artefacts cast, the challenge is to dovetail evidence from these production sites with the presence and deployment of bronzes in consumer sites on the Khorat Plateau.

Excavated consumer sites on the Khorat Plateau are concentrated in the upper reaches of the Mun River floodplain. This strategic region commands exchange via a pass over the Petchabun upland from Central Thailand over which came exotic marine shell and marble ornaments, and bronzes (Fig. 2; Higham and Rispoli 2014). Ban Non Wat is a key site. Its sequence began with possible hunter-gatherer burials followed by two Neolithic phases, six divisions within the Bronze Age occupation, and three for the Iron Age (Fig. 3). Human burials are associated with all occupation phases. Ban Prasat is located 20 km to the east, and excavations there have exposed a Bronze and Iron Age cemetery (Monkhonkamnuanket 1992). Ban Lum Khao was initially occupied during the later Neolithic (about 1400–1100 BC), followed by an early and a late Bronze Age cemetery (Higham and Thosarat 2005). There are four Iron Age phases at Noen U-Loke, known as IA1–4 (Higham et al. 2007). Non Ban Jak has four sub phases within IA4 that extend into the early Historic Period.

We refer to three further excavated sites in the northern Khorat Plateau. The sequence at Non Nok Tha began in the fifteenth century BC with Neolithic burials that transitioned into the Bronze Age in the 11th or tenth century (Bayard and Solheim 2009; Higham et al. 2014). Ban Chiang has basal Neolithic occupation and burials dated from the sixteenth century BC, followed from the eleventh century by Bronze and then Iron Age phases. White and Hamilton, in reporting on the Bronze Age at this site, dissent from this widely accepted chronology in favour of a much earlier uptake there of bronze casting, but we adhere to the chronology based

on human bone collagen dates in this essay (White and Hamilton 2018; Higham et al. 2015). Ban Na Di was occupied during the later Bronze Age and the Iron Age (Higham and Kijngam 1984).

These prehistoric sites are, in effect, mini tells. The monsoon brings heavy rainfall from late April to November, followed by a long dry season. Provided there is sufficient water, rice will mature on the same plot of land with no need to fallow. It might surprise those accustomed to more temperate habitats that village settlements were occupied for centuries, even millennia. This allows cultural changes to be tracked with a constant thread, but it also requires their interpretation to be tempered by the experience of excavating. All sites incorporate pits, postholes and human graves that create disturbance exacerbated by bioturbation from insects and animals, and redeposition by heavy monsoon rains. Hence it is not unusual to encounter fragments of bronze or iron in layers where they must be intrusive and inadmissible as evidence for metallurgy. The burial of an individual wearing a bronze ornament, or associated with a weapon, tool, crucible or casting mould is taken as assured evidence, as is a clay-lined furnace for melting bronze prior to casting, usually surrounded by broken crucibles, moulds, and casting spillage.

The Earliest Bronze in the Central Area of Ban Non Wat

Ban Non Wat is located strategically in the upper Mun Valley of Northeast Thailand, where a pass over the Petchabun upland creates a choke point as exchange brought exotic goods from the Central Plains. During the Bronze Age, these included marine shell and copper. Excavations at Ban Non Wat over ten seasons have uncovered an area of 854 m^2 in the centre of the site, and 10 smaller squares distributed strategically across it (Higham and Kijngam 2009, 2010, 2012a, 2012b; Kanthilatha et al. 2017). The four major stratigraphic units in the central excavation are numbered from 2 to 5, each with subdivisions. All contain a combination of occupation remains, such as post-holes, pits and middens, and c. 650 inhumation burials. The Neolithic occupation belongs to layers 5:3 to 4:7. Bronze Age occupation accumulated within layers 4:6 to 4:2, while the Iron Age settlement is seen in layers 4:1 to 2:1. The junction between Neolithic, Bronze and Iron Age occupation does not present with clarity. There are no sterile layers indicating a period of abandonment. Inhumation burials were cut down into preceding occupation layers, and only rarely was a grave cutting identified before the skeleton was encountered, other than when the silhouette of the burial lay on the surface of the natural substrate. Given such disturbance, the distribution by layer of bronze artefacts, moulds and crucibles cannot be expected to reflect reality.

Nevertheless, a general picture is possible. Fragments of bronze, moulds and crucibles found their way into Neolithic layers. However, there was also a series of intact and undisturbed midden deposits containing Neolithic potsherds, stone adzes, shellfish and faunal remains. No bronze and no crucibles were found in any of these. We also find that the number of moulds and crucibles was low then and in the initial Bronze Age contexts before rising steadily to a peak with the latest Bronze Age (Fig. 4). Thus the number of crucibles in the initial Bronze Age layer 4:6 numbered

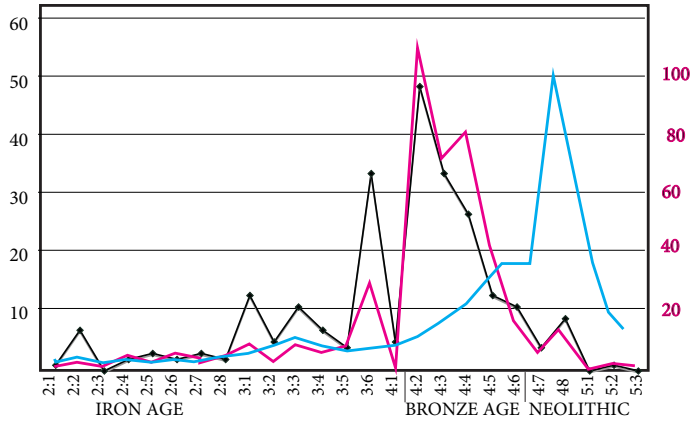

Fig. 4 Graph showing the change in the presence of moulds, crucibles and stone adzes at Ban Non Wat over time. Black: moulds; red: crucibles; blue: stone adzes (graphics program: freehand mx)

Table 1 The number of moulds and crucibles from occupation deposits at Ban Non Wat

Neolithic					Bronze Age					Early Iron Age							
Layer																	
5:3	5:2	5:1	4:8	4:7	4:6	4:5	4:4	4:3	4:2	4:1	3:6	3:5	3:4	3:3	3:2	3:1
Mould																	
0	1	0	8	4	10	12	27	34	49	5	33	4	6	10	5	12
Crucible																	
0	0	1	9	5	10	23	83	78	117	3	33	10	10	12	9	12

20, rising to 117 in layer 4:2, then falling to five in the first Iron Age context. The same is true for the distribution of moulds and bronze artefacts (Table 1). Martinón-Torres and Rehren (2014, p. 110) have defined furnaces as 'typically immobile structures that contain the charge, such as charcoal and minerals, and are used for the smelting of ore to metal, or the melting of metal for casting'. We have identified several clay-lined furnaces, each associated with crucible fragments and casting spillage. The base of one of these, to bring copper or bronze to melting point, was found in layer 4:5, but it had been dug down from a higher level because only the base has survived. A second furnace was found in layer 4:3, and there were more in layer 4:2 (Fig. 5). The presence of small fragments of casting spillage, crucibles and moulds within the vicinity of these furnaces confirms that they were used in metallurgical industry as opposed to any other furnace-based material production and indicates the presence of bronze casting.

The transition from late Neolithic to initial Bronze Age burials (c. 1050 BC) saw continuity in ceramic vessel forms, but marked changes in the orientation of the burials and mortuary wealth. One young woman, for example, was interred in a wooden coffin in the form of a boat. Bivalve shells had been placed by each hand,

Fig. 5 A clay-lined furnace with a complete crucible and charcoal-rich rakeout, surrounded by bronze casting spillage, from the Bronze Age 4 context at Ban Non Wat. Scale 10 cm. (Higham and Kijngam 2012a p. 453) (graphics program: tiff photoshop)

Fig. 6 The copper axe at the shoulder of Ban Non Wat burial 569. Scale 5 cm. (Higham and Kijngam 2012a, p. 10) (graphics program: freehand mx)

one of which has been radiocarbon dated to 1049–899 cal. BC. A copper-base axe lay at her left shoulder (Fig. 6). This is one of seven Bronze Age 1 (BA1) burials, five of which are associated with a socketed bronze axe or other implement (Fig. 7).

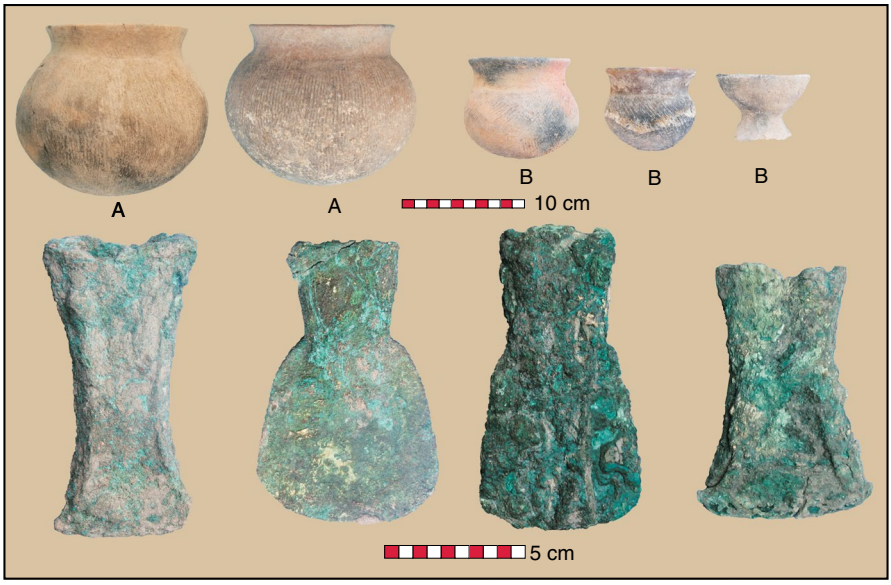

Fig. 7 Top row: (A) mortuary vessels of the late Neolithic; (B) mortuary vessels of the initial Bronze Age. Bottom row: socketed copper-base axes of the initial Bronze Age, all from Ban Non Wat (graphics program: freehand mx)

Identifying the source of this earliest copper, and the presence or otherwise of evidence for casting socketed axes during this phase at Ban Non Wat, is clearly relevant. Pryce et al. (2014a, b) have found that the socketed axe from burial 453, that of a 2-year-old, comprises 98.1% copper and just 1.6% tin, and that none of the BA1 copper samples matches the lead isotope signature for the three known Southeast Asian copper ore mines. We suggest that the metal might have come from a South Chinese source, where similar socketed axes have been identified in several sites dated slightly earlier or contemporary with BA1. Ciarla (2007) has made a detailed case for strong links between Southeast Asia and a series of southern Chinese sites, including Yuanlongpo, on the basis of close parallels in casting technology and what was cast (Fig. 2; Higham et al. 2015). It is also noted that the massive copper mining complex of Tonglüshan in Hubei Province was being mined at this juncture (Zhou Baoquan et al. 1988).

Cawte (2008) has found that all the analysed metal prills adhering to the crucibles at Ban Non Wat contained copper and significant quantities of tin and could not, therefore, have been used to cast the early virtually-pure copper axes (Fig. 8; Supplementary Information). The analysis of mould surfaces also indicates that bronze with a significant amount of tin was being cast (Supplementary Information Table S1). We suggest that the most parsimonious interpretation for the initial presence of copper-base axes with minimal amounts of tin at Ban Non Wat during the late 2nd millennium BC is that they were exotic imports from a distant source, rather than the work of resident founders.

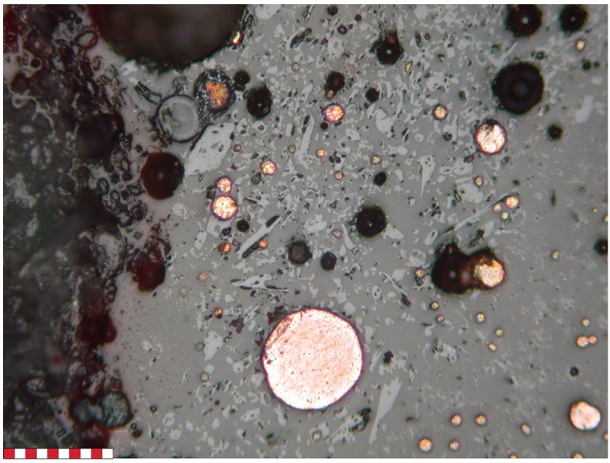

Fig. 8 Photomicrograph of slag sample from Bronze Age 4 at Ban Non Wat (width of image 50 × magnification). Note bright copper prills and light grey needle-like inclusions of tin oxide showing the *in situ* making of tin bronze objects at this site. (Cawte 2008, p.117) (graphics program: tiff photoshop)

Ban Non Wat Bronze Age 2, c. 1000–900 BC

The second Bronze Age mortuary phase is dated c. 1000–900 BC. The BA1 graves are on the same orientation, and fit neatly within those for BA2 with only one slight disturbance (Fig. 9). We suggest that there was direct continuity between these two phases, but the contrast between them is acute. Graves were laid out in four rows, and were endowed with wealth unparalleled in Southeast Asia at this period. Ceramic vessels multiplied in number and forms. Wealth was represented by marine shell and marble ornaments and bronze axes, awls, chisels and bells (Fig. 10). The figures speak for themselves: in 46 BA2 and 3A burials, there are 999 pottery vessels, 88 bronze artefacts, 772 *Trochus* or *Tridacna* shell bangles, 43 marble bangles and 159,135 shell beads. The strategic importance of the upper Mun Valley is self-evident when these figures are compared with the numbers of exotic artefacts in the three sites in the remote northern reaches of the Khorat Plateau. For example, the c. 31 earlier Bronze Age burials at the 1975 excavation at Ban Chiang yielded a bronze spear, five anklets, no exotic shell or stone bangles and possibly two shell beads.

Graves were also far bigger than necessary to accommodate the body, that for burial 571 being 4.50 m long (Fig. 11). At least five individuals were exhumed and re-interred. Wealth crossed age and sex boundaries (Higham 2011a). The two axes analysed were again high in copper, with 98.9% and 96.7% respectively. The lead isotope signature of three specimens is compatible with copper mined in the KWPV in Central Thailand (Pryce et al. 2014a, b), where early burials contained metal founders, two of whom were interred with bivalve axe moulds (Pigott et al. 1997; Fig. 8; Ciarla 2007; Fig. 11). A socketed axe interred with a juvenile, like those at Ban Non Wat, comprised 99 wt% copper, and has been identified as an import (Pryce et al. 2011). By this juncture, therefore, copper mining, smelting and casting specialists were established in the KWPV, but we cannot yet determine whether any

Fig. 9 The Bronze Age 1 and 2 cemeteries at Ban Non Wat, showing the close physical relationship between the two, and the incidence of copper-base mortuary offerings (graphics program: freehand mx)

were based at, or at least visited, Ban Non Wat. What is evident from the new chronology is that the BA2 burials at Ban Non Wat were contemporary with the early founders at Non Pa Wai. The elite wealth of BA 2 is also seen at Ban Prasat, located along the same strategic exchange route. There is an exposure there of a BA2 cemetery matching Ban Non Wat in terms of mortuary wealth (Monkhonkamnuanket 1992). A second exposure of BA2 graves c. 40 m northeast of the main square at Ban Non Wat was markedly poorer, with no metal and few exotic ornaments. The BA2 cemetery excavated at Ban Lum Khao lies on the edge of the site. The burials are also markedly poorer than in central Ban Non Wat and no bronze burial goods were encountered (O'Reilly 2004a).

Fig. 10 Copper-base artefacts from Bronze Age Ban Non Wat. (A) Chisels BA2. (B) Nells, BA3. (C) Arrowheads, BA4–5. (D) Anklets BA3A. (E) Axes, BA2 (graphics program: freehand mx)

The definitive radiocarbon chronology for Ban Chiang in the remote northern reaches of the Khorat Plateau equates the initial Bronze Age there with BA 1–2 at Ban Non Wat (Higham et al. 2015). Burial 76 dates to c. 1025–935 BC (OxA-24047 and 30,669), and the copper in the associated socketed spear comes from the mines at Vilabouly, c. 350 km to the east (Pryce et al. 2014a, b). This spear comprises a

Fig. 11 Burial 571 from Ban Non Wat BA2. The man, accompanied by a copper-base axe, lay in a grave 4.5 m long. (Higham and Kijngam 2012a, p. 49) (graphics program: Adobe Illustrator)

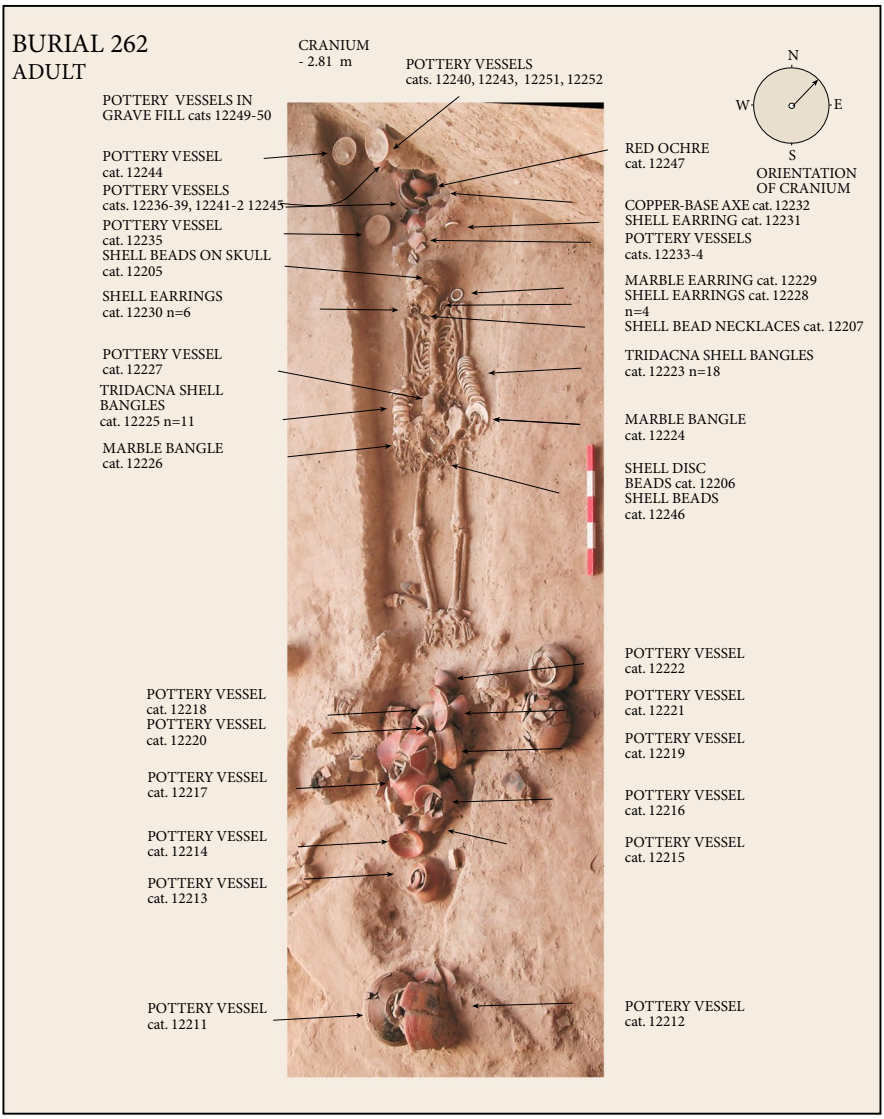

Fig. 12 Ban Non Wat burial 262, a wealthy individual interred with many exotic shell and marble ornaments, ceramic vessels and a copper-base socketed axe (Higham and Kijngam 2012a, p.183) (graphics program: freehand mx, saved as a .pdf)

10% tin bronze with possible post-cast annealing (Hamilton and Nash 2019). However, the early Bronze Age graves at this site were very poorly endowed.

Bronze Age 3 (c. 900–800 BC) at Ban Non Wat is divided into sub-phases 3A and 3B. BA 3A burials overlay those of BA2, on a different orientation. Mortuary wealth continued as with BA2. Burial 262, for example, was interred with 23,682 shell beads, 30 ceramic vessels, 29 shell and two marble bangles, 10 shell earrings

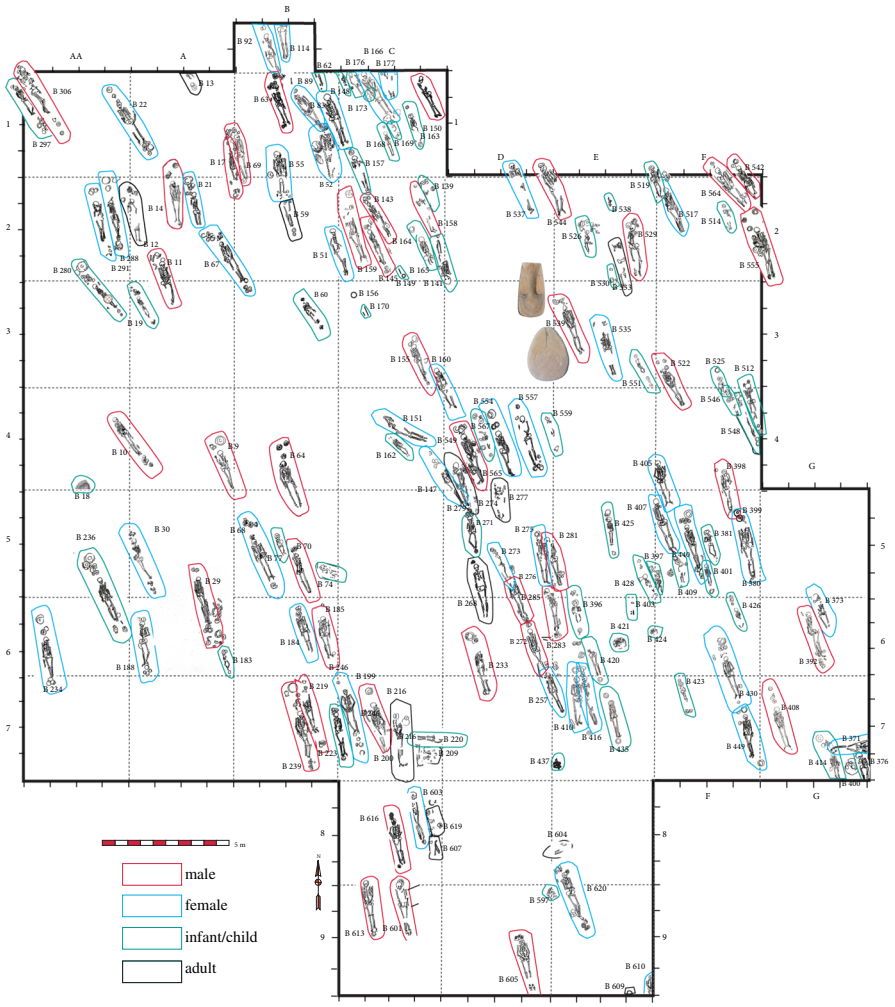

Fig. 13 The Bronze Age 4 cemetery at Ban Non Wat. The moulds show the location of the founder burial (graphics program: freehand mx)

and a socketed bronze axe (Fig. 12). An infant wore anklets linked with 30 bronze bells. However, with BA3B, exotic mortuary offerings including bronze artefacts fell sharply, represented by a single bell.

The Establishment of a Local Casting Tradition at Ban Non Wat

The reduction in social mortuary display seen in BA3B was maintained in BA4 (c. 800–700 BC), in which 162 burials covered the excavated area in four groups (Fig. 13; Smith et al. 2015). Bronze mortuary offerings were virtually absent: just an arrowhead and two fragmentary bangles. However, local casting was now being

Fig. 14 The Ban Non Wat founder's burial 549, Bronze Age 4. (A) Arrows point to the concertina moulds. (B) Close up image of a set of concertina moulds. The arrow points to alignment marks. (C) A second set of concertina moulds. (D) The two bivalve axe moulds found beyond the head (Higham and Kijngam 2012a:) (graphics program: freehand mx)

undertaken. Burial 549 contained the skeleton of a young to middle-aged man. Two clay bivalve axe moulds lay beyond his head, and 25 bangle moulds were found grouped beside his right knee and left shoulder (Fig. 14). The latter, known as 'concertina moulds' were employed in sets, each mould receiving metal to cast two bangles on each side (Higham 2008). They were bookended by two moulds for

casting only on the interior surface. The six moulds found in this configuration by the shoulder would have cast 20 bangles in one pour. This mass production raises the intriguing issue of explaining the presence of just two fragmented bronze bangles in the other 161 burials of this phase. Moreover, this founder does not stand out as being special or wealthy, being accompanied by four pottery vessels, one of which contained some fish bones. The rarity of bronzes and lack of other mortuary wealth continued into BA5 (c. 700–420 BC), with just two arrowheads from 29 burials, although the mass production of bangles suggests that there was specialised production.

BA 4–5 was the heyday of the presence of casting furnaces, crucibles, moulds and fragments of bronze. These were concentrated in small-scale facilities for casting. Four complete crucibles and over 600 fragments have been recovered. All those analysed show the presence of copper and its common alloy partners, tin and lead, in varying proportions. Microscopically, they evidence a general clay matrix of typical clay elements. It is not known whether additional sand was kneaded into the clay; however, some fragments appear to have a denser concentration of quartz grains than others. Crucibles were tempered with rice chaff and display a silica-rich lagging layer to protect them, enhance their refractiveness and allow re-use, a widespread practice also seen at Phu Lon (Vernon 1996–97), Ban Chiang (Vernon et al. 2019), and Ban Na Di (Higham 1996; Maddin and Weng 1984).

The 359 ceramic, mostly fragmentary, casting moulds from Ban Non Wat provide insight into the repertoire of the metal smith and the copper industry. There are two forms determined by cross-section. Moulds for ornaments were rectangular, and in the case of the burial 549 founder, facilitated mass casting with mould leaves stacked together like books on a shelf. Those for axes, chisels and spears were semicircular with implements being cast individually (Fig. 15). Quantitative results from our XRF analyses of both sides of these moulds have revealed the presence of many elements of particular interest to metallurgy, as well as the presence of unusual quantities of various alkalis on the casting surfaces (Cawte 2008; Supplementary Information). The elements CuO, SnO_2, and PbO are the most likely to be detected in mould casting residue, indicating that a tin-bronze alloy was melted and poured into the mould, corroborating the results from the crucible analyses. A dusting of charcoal on the interior surface was also used to extend the life of the moulds.

Non-mortuary Bronze Artefacts

On-site bronze casting during BA 4–5, despite the virtual absence of bronzes in the contemporary burials, raises the question of what was cast, and how it was deployed. Some bronzes may have been exported from Ban Non Wat, but we have no evidence for this. However, about six hundred fragments of bronze from occupation contexts were recovered during the 2002–2007 seasons. Recognizable artefacts are dominated by bangles and rings, but the majority have no surviving form. Many amorphous fragments were found in the vicinity of the clay furnaces used to raise bronze to above melting point, and probably represent casting debris and splatter from the industrial procedures. Since they were associated with furnaces from

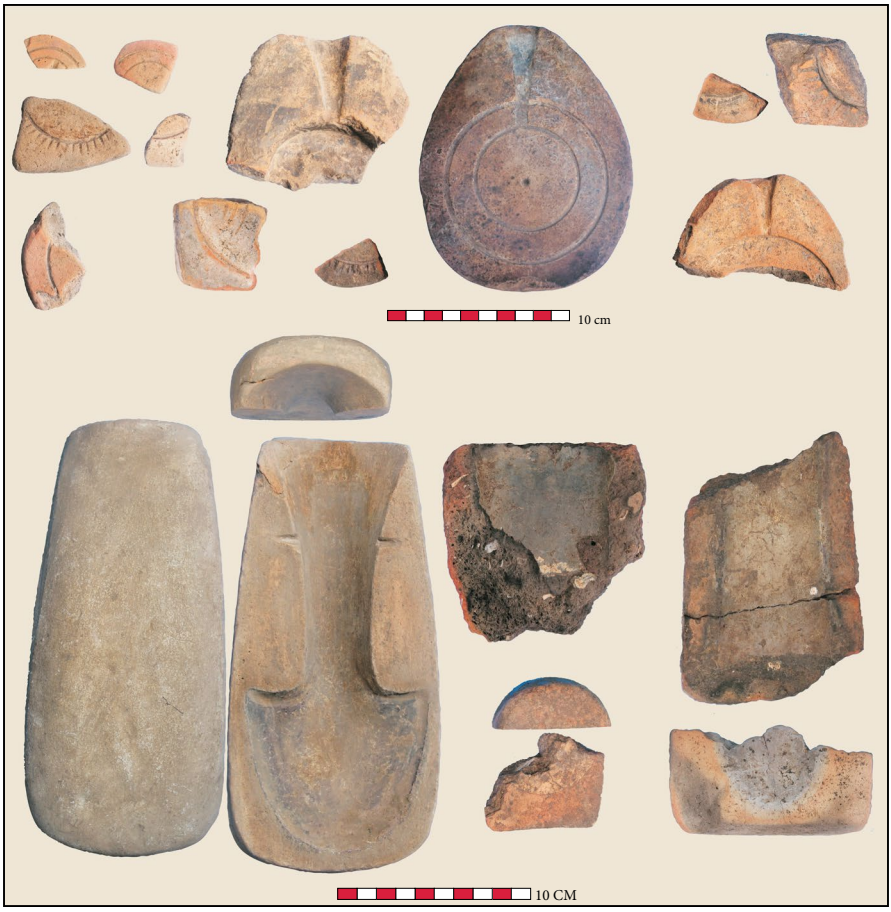

Fig. 15 Ceramic moulds from Bronze Age Ban Non Wat. Upper series for casting bangles with a rectangular cross section, lower series for casting axes with a rounded cross section (graphics program: freehand mx)

Bronze Age contexts, they are confidently placed in the sequence. Most flecks were so corroded that it was not possible to obtain their alloy proportions. However, each of three specimens we have investigated using optical and scanning electron microscopy give insight into the nature of potential castings, including proportions of alloy partners and possible ore types. All have been alloyed, with copper–tin–lead being the predominant combination, and only one having a combination of copper and tin.

Hardly any fragmentary or complete tools or weapons have been identified in any occupation contexts at Ban Non Wat, despite the substantial number of axe moulds. This probably reflects the greater benefit of recycling large but broken artefacts. Without having a sufficiently representative sample of moulds, it would be misleading to draw conclusions on what was valued or cast from the surviving fragments of bronze. At Ban Non Wat, however, the bronze founders were responsible

for supplying the bangles worn in life – but not, it seems, death – and tools that include socketed axes and chisels, both applicable to wood working. Given the many mould fragments and the great number displaying casting depressions, it has been possible to generate a more accurate view of the prehistoric bronze industry at Ban Non Wat than, for example, at Ban Chiang where none of the four mould fragments survived sufficiently to reveal what was cast. In terms of moulds, there was a slight predominance of industrial implements over ornaments. However, the former would have consumed by far the greater volume of copper. The lack of larger objects in the general archaeological assemblage suggests that these objects represent considerable 'value' given their large volume. One of bronze's most useful qualities is its ability to be recycled. 'Because of the metal's recyclability, small utilitarian metal tools are unlikely to be discarded and hence after extensive use would be remelted and recast' (Pigott et al. 1997, p. 134). This would help explain the disproportionate number of bronze bangles in the domestic sample as compared to the mould data, which indicates a demand for axes to use on site, or perhaps be exchanged. Thus the number of stone axes declined sharply once bronze axes were available (Fig. 4). This period equates with the high point of copper production at later Non Pa Wai and early Nil Kham Haeng (Higham et al. 2020).

The Remote North

Ban Na Di is located in the Sakhon Nakhon Basin in the northern reaches of the Khorat Plateau, a region that, unlike the upper Mun River valley, is remote from natural exchange routes. A modest-sized excavation of 65m^2 identified Bronze Age industrial, mortuary and occupation remains that a new set of radiocarbon dates on human bone collagen places between c. 800 and 500 BC (Higham et al. 2015). This was succeeded by early Iron Age occupation and burials dating from the fifth century BC. The Bronze Age layers and burials were contemporary with BA 4–5 at Ban Non Wat. The occupants used crucibles set in clay-lined furnaces to bring bronze past its melting point (Fig. 16; Higham and Kijngam 1984). A handful of stone bivalve

Fig. 16 A clay lined furnace at Ban Na Di to bring bronze to melting point prior to casting (graphics program: Adobe Photoshop)

moulds for casting socketed axes were found, together with two complete crucibles and 86 pieces of crucible. Some of the 243 bronzes found in occupation and industrial contexts represent casting spillage, but there were also nine broken bangles, five arrowheads, two fish hooks and two beads. No axes were recovered. Nearly all of these comprised tin bronze, but the founders were aware of the different properties of the alloy, for the two beads were made of a leaded bronze (Seeley and Rajpitak 1984). The arrowheads were annealed and cold worked to harden them prior to sharpening. Several of the stone bangles found in burials had broken in antiquity and had been repaired by boring holes on either side of the break and securing the pieces with wire-like bronze ties. These were cast with a bronze comprising copper, tin and arsenic (Maddin and Weng 1984). Despite the presence of furnaces, moulds and numerous crucibles, bronzes were sparingly associated with the dead. Of 36 burials, just three individuals wore a total of 23 bangles. There are thus strong parallels with the last two Bronze Age mortuary phases (MP4–5; c. 800–420 BC) at Ban Non Wat.

Non Nok Tha has been reinterpreted on the basis of a new set of radiocarbon determinations based on the human bone collagen (Higham et al. 2014). Bayard and Solheim (2009) identified an Early Period I–II, which is Neolithic, followed by Early Period III, the initial Bronze Age (c. 1000–800 BC. They divided their Middle Period, which is also Bronze Age, into eight phases, but we prefer one phase of short duration dated within the span c. 800–500 BC. This corresponds to Ban Non Wat MP 4–5. As at Ban Na Di and Ban Chiang, bronze mortuary offerings are very rare. In 161 burials, there were 28 bangles and five socketed axes (Table 2). However, there were founders' burials present, seen in the four crucibles and 10 sandstone axe moulds found in mortuary contexts, while fragments of crucible, casting spillage and some unfinished stone moulds were also present.

Ban Chiang is located c. 20 km north of Ban Na Di. The Bronze Age there is divided into early and late periods (Higham et al. 2015, 2019a). None of the burials found in either remotely matched in wealth those from Ban Non Wat, and many graves were disturbed and incomplete. For the c. 36 early-period graves designated EP III–IV (contemporary with Ban Non Wat BA1–3A), bronzes were limited to one spearhead and five anklets. The c. 41 later burials from EP V–VI, corresponding to Ban Non Wat BA4–5, contained an axe, four bangles and five anklets from burials. Only four incomplete sandstone moulds were found in Bronze Age contexts, so what was actually being cast there is not known, despite the preponderance of bangle fragments in occupation layers (Hamilton 2019). It is, however, intriguing that as at Ban Non Wat, the number of crucibles fell away during the late Iron Age (Vernon et al. 2019).

These three sites present a clear contrast with Ban Non Wat. The available mortuary data for the six centuries of the Bronze Age (c. 1050–450 BC), have not provided any evidence for a wealthy aggrandizer elite.

The Iron Age

The Iron Age in the Upper Mun Valley is divided into four phases, IA1–4 (Fig. 3). The largest exposure of an IA1 cemetery comes from Ban Non Wat, where there was

Table 2 The number of burials and copper-base artefacts in mortuary contexts from the sites in Northeast Thailand under review. The final column shows the number of fragments of bronze from occupation deposits

Site	Period	burials	axe	chisel	awl	fish hook	bangle	finger ring	toe ring	torc	belt	earring	anklet	neck lace	spiral	bell	arrow	spear	mould	fragmnts
BNW	BA1	7	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	c. 620
BNW	BA2	32	14	5	2	0	0	0	0	0	0	0	0	0	0	31	0	0	0	
BNW	BA3a	32	1	0	0	0	0	0	0	0	0	0	5	0	0	30	0	0	0	
BNW	BA3b	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
BNW	BA4	162	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	29	
BNW	BA5	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	
BLK	BA2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	20
BLK	BA5	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
NNT	BA	161	5	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	10	
BC	EBA	c. 38	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	94
BC	LBA	c. 35	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	
BND	BA	36	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	
BND	IA	24	0	0	0	0	4	0	0	0	0	0	2	0	1	0	0	0	0	
BC	IA	45	0	0	0	0	18	0	0	0	0	0	2	2	0	0	0	0	0	
BNW	IA1	142	0	0	0	0	67	5	0	0	0	0	14	0	0	0	2	3	0	
NUL	IA2	23	0	0	0	0	30	53	16	0	0	2	1	0	1	21	0	0	0	
NUL	IA3	32	0	0	0	0	486	423	117	1	10	41	58	0	11	3	0	0	0	
NUL	IA4	21	0	0	0	0	74	116	7	0	0	11	11	0	2	0	0	0	0	

BNW Ban Non Wat, *BLK* Ban Lum Khao, *BC* Ban Chiang, *BND* Ban Na Di, *NUL* Noen U-Loke

Fig. 17 Innovative bronze items cast during the Iron Age at Ban Non Wat and Noen U-Loke. (A) Anklet, BNW IA1. (B) Bangle, BNW IA1. (C) Arrowhead BNW IA1. (D) Cordiform socketed implement, BNW IA1. (E) Noen U-Loke torc or neck ring, NUL IA1. (F) Spear with bronze haft and iron blade, BNW IA1. (G) Multiple bangles, NUL IA3. (H) Ear lobe insert, NUL IA3. (I) Multiple finger rings NUL IA3. (J) Head spiral, NUL IA2. (K) Belt, NUL IA3. (L) Bronze torcs on Noen U-Loke burial 27. (M) 75 bangles on the left arm of Noen U-Loke burial 14. (N) Three bronze belts and 67 finger rings, burial 14, Noen U-Loke (graphics program: Illustrator)

a seamless transition from the BA5 into the IA1 cemetery. The number of bronzes in burials increased markedly, dominated by bangles, anklets and rings, but including weaponry: the IA1 graves at Ban Non Wat contained three spears with a bronze haft and iron blade, a sure sign of the initial Iron Age, as well as two bronze arrowheads (Fig. 17C). One burial also contained two cordiform bronzes matched precisely in ceramic moulds and castings from Nil Kham Haeng in the KWPV (Fig. 17D, cf. Pigott et al. 1997, Fig. 17). Two ornamented anklets and two bangles from infant burials were cast by the lost wax method (Fig. 17A–B). While exchange with Central Thailand continued during this period, some of the copper identified at Ban Non Wat was compatible with lead isotope signatures from Vilabouly in upland Laos (Pryce et al. 2014a, b; Cadet et al. 2019).

Fig. 18 (Top) A cache of clay socket moulds has been severed by an Iron Age burial at Ban Non Wat, scale 10 cm. (Bottom) Iron Age burial clay socket mould from Ban Non Wat, sheathed in lead (graphics program: freehand mx)

In this period, the number of crucibles, moulds and bronzes declined, but there was continuity in terms of the clay-lined furnaces for melting the alloy and casting. The moulds were for casting bangles, axes, rings and spears, but there are also caches of clay mould plugs for fitting into a bivalve axe mould to create a hollow socket on casting (Fig. 18). Mould plugs were first identified by V. C. Pigott at Non Pa Wai in Central Thailand (Pigott et al. 1997). Some from Ban Non Wat were still sheathed with lead, which would have been melted out and increased the alloy's fluidity, thus facilitating the ingress of molten bronze into the mould's interstices (Fig. 18). Despite the many such casting-related artefacts, not one bronze axe was found in a burial, or in any occupation context during this early IA period, again

stressing the importance of recovering moulds rather than just fragmentary artefact remains when attempting to judge what was being cast.

At Ban Na Di, the transition into the early Iron Age was marked by continuity and change. Clay-lined furnaces continued to be used to melt bronze alloys, and 218 fragments of crucible were recovered. These, however, were now tempered with rice chaff rather than clay grog. There were no stone moulds, but 13 clay moulds for casting bangles and bells were found. Founders now cast bangles by the lost wax method. A clay core was covered in wax in the form of the proposed casting, some of which bore grooved or raised ornamentation. The core was then invested with fine clay, then a second layer of coarse, chaff-tempered clay. One of these was complete and never used. A bangle still had traces of beeswax on the surface, but how the wax survived the casting procedure is a mystery. The preferred alloy for casting bangles now contained significant amounts of lead (Seeley and Rajpitak 1984). Identifiable fragments of bronze in occupation contexts come from 37 bangles, 13 finger rings, three bowls and three bells. Twenty-four IA1 burials were found, which, as at Ban Non Wat, directly succeeded those of the latest Bronze Age. Of these, just four wore bronze ornaments: four bangles, two anklets and one coil. The same situation is found at early Iron Age Ban Chiang, where three anklets, nine bangles and a bimetallic spear were found in c. 20 graves.

The Later Iron Age

The later Iron Age is best documented at Noen U-Loke and Non Ban Jak, the former covering the full Iron Age sequence in the upper Mun Valley (Higham 2011b). The employment of bronze during this period must be considered in conjunction with growing evidence for a sharp fall in the strength of monsoon rains that precipitated an agricultural revolution (Wohlfarth et al. 2016; Castillo et al. 2018). This involved the construction of reservoirs around a growing number of settlements, the reticulation of water into permanent, bunded rice fields, and preparation of the soil by ploughing with the tractive power of the water buffalo or cattle. It has been argued that the creation of improved demarcated land in conjunction with conflict was a stimulus to the rise of a commanding social elite (Higham et al. 2019b).

Just five moulds and no crucibles have been found relating to the later Iron Age at Noen U-Loke, located only 10 km east of Non Ban Jak. This might mean that bronze casting was undertaken in another part of this large settlement. However, the rarity of moulds and crucibles in the later Iron Age is also encountered at Non Ban Jak where, despite extensive excavations, neither moulds nor crucibles have been recovered. This contrasts with the abundant and innovative bronze mortuary offerings from both sites. Even from IA1 at Noen U-Loke, a man was interred wearing three bronze torcs (Fig. 17E) and bangles, accompanied by two spearheads. By IA3, the dead were interred with a new range of bronze ornaments: finger, toe and ear rings, spirals, belts, anklets and discs inserted into the ear lobes. There was a quantum leap in the weight of bronze with elite individuals (Table 2). One man of IA3 wore four belts with sophisticated catches, discs in each ear, 124 finger rings, 33 toe rings and 20 bangles. A man in burial 14 of the same phase was interred wearing 150 bronze

bangles, three belts and 65 finger and toe rings (Fig. 17M–N). All this was contemporary with the massive output of copper from the Vilabouly mines, although as yet there has been no LIA study of the Noen U-Loke bronzes.

The final Iron Age at Noen U-Loke and Non Ban Jak saw a reduction in the weight of bronzes from the exceptionally high level seen in the preceding IA3. Thus a male individual interred in burial 1 at the former site wore 59 finger rings, 22 bangles and two ear spirals. At Non Ban Jak, bronze belts, rings, bangles and anklets were commonly interred with the dead, despite the absence of any evidence for on-site casting in the areas excavated. In the Bronze Age sites, amorphous fragments, many of which we interpret as casting debris, represent a high proportion of non-mortuary bronzes. The reverse is the case at Non Ban Jak, where mortuary offerings comprise 90% of the 482 bronzes recovered. The balance is made up of bangle fragments (3.9%), rings (2.9%), amorphous fragments (2%) and bells (1.2%). We cannot rule out the possibility that the bronze casting workshops at Non Ban Jak were away from the areas excavated, but the consistent rarity or absence of moulds and crucibles also suggests that there might have been regional foundries that supplied bronze ornaments to these consumer sites, while iron replaced bronze for tools and weapons.

The Early Historic Period

The cultural sequence at Non Ban Jak extends into the early Historic Period, seen in the numerous pottery vessels characteristic of the Dvaravati state of Central Thailand from the sixth century AD (Barram and Glover 2008). The late occupation also includes structural foundations associated with a clay figurine of the Buddha. This occupation reflects a rapid and pervasive cultural change on the Khorat Plateau that involved the foundation of regional states. In the upper Mun Valley, one of the Iron Age moated sites, Muang Sema, was hugely expanded with a new moat and bank to enclose about 150 hectares, the new bank covering an Iron Age cemetery. The expanded urban area is dominated by the brick foundations for a Buddhist community that involved ordination and assembly halls. Muang Sema is located at the gateway to the Khorat Plateau, and it seems beyond reasonable doubt that it represents the major centre of a nascent state. Nor is it alone on the plateau: a similarly large site featuring a Buddhist community is located further north at Muang Fa Daet, which strategically dominates traffic up the course of the Chi River and to the north via the Pao River. Further sites containing Buddhist remains virtually cover the extent of the plateau (Murphy 2010).

A small corpus of inscriptions records the foundation of early states (Higham 2016). A seventh century Sanskrit text from Muang Sema lists a gift of buffaloes, cows and slaves to the monastic community by the king of a polity named Sri Canasapura. Three further inscriptions record a royal dynasty, and further gifts to Buddhist foundations of rice fields, cattle and gold and silver utensils. Royal status, Buddhism and Hindu deities were intertwined and expressed in temple foundations, their embellishments and sustenance.

This rapid foundation of early states by the seventh century AD in Thailand was associated with a transformation in bronze casting. The village of Ban Tanot lies just 20 km south of Ban Non Wat. In 1961, a bulldozer struck the remains of a gigantic bronze statue of the Buddha in the ruins of a stupa. Stylistically dated to the late eighth century AD, it is estimated that the statue would have stood between 3 and 3.6 m high (Guy 2014). This is but one of a large corpus of bronze statues in the Mun Valley, and reflects the wide spread of Buddhism (Murphy 2010). At least 53 bronzes of the Buddha were found in a concealed cache at Prasat Hin Khao Plai Bat, in Buriram Province, the earliest of seventh century style and cast by lost wax. Through endowing temples and sponsoring specialist bronze workshops to furnish them with bronze images of the gods, the new royalty made merit and burnished their elite status. Within a handful of generations, society and its use of bronze were transformed.

The Rise of the Civilization of Angkor.

Buddhist states on the Khorat Plateau arose at the same time as small, competitive kingdoms south of the Dang Raek upland in northern Cambodia, where the elite were more aligned with Hindu deities. In the early ninth century, these coalesced into a unified state with its centre north of the Tonle Sap, or Great Lake, at a location known today as Angkor. Until the late tenth century, most Angkorian inscriptions are concentrated south of the Dang Raek escarpment, but thereafter they indicate an expansion north to incorporate the Mun Valley into the kingdom. Vice-regal centres were established at Phimai, Phanom Rung and Wat Phu, linked by road to the capital; the last of these lies strategically within range of the Laotian copper deposits (Hendrickson 2010).

The agricultural revolution that occurred during the late Iron Age in the Mun Valley and northern Cambodia involved the control of water to ensure a successful rice harvest. This underwrote the durability of the Angkorian kingdom through the diversion of sacred rivers, the storage of water in colossal reservoirs, and its distribution into irrigated bunded rice fields (Castillo et al. 2018). The monsoon rains are unpredictable: a dry interval during the rainy season can spell disaster without human intervention. The king, himself regarded as a divinity, both engineered the construction of reservoirs and interceded with the gods to fill them. Temples, from village shrines to royal temple mausolea, housed images of the gods that, over time and on the preference of the current ruler, could be Siva, Visnu, or the Mahayana Buddha. That royal patronage was a key driver of the Angkorian bronze industry is reflected in the contemporary inscriptions, and eyewitness accounts. The foundation stela to the temple of Preah Khan, composed by King Jayavarman VII's son Virakumara, listed 20,400 statues in gold, silver, bronze and stone across the kingdom. Many of the gold statues would have been gilded bronze. The Phimeanakas inscription, named after the temple in the royal place of Jayavarman VII, describes how the Queen Jayarajadevi donated statues to temples to make merit. Zhou Daguan, who visited Angkor in 1296, described how the massive Baphuon temple mausoleum was sheathed in bronze (Uk and Uk 2010). During the reign of Suryavarman II, the floors of the temple at Preah Vihear were covered in bronze. There is also the evidence of archaeology. Srah Srang is a reservoir at Angkor flanked by a cemetery containing the jars that held cremated remains. B.-P. Groslier's excavations

Fig. 19 The head of the gilded bronze statue of Visnu Anantaśāyin from the Western Mebon, Angkor, as discovered (École française d'Extrême-Orient) (graphics program: Adobe Photoshop)

Fig. 20 Reconstruction of the gilded bronze statue of Visnu Anantaśāyin, from the Western Mebon, Angkor (Dr Marnie Feneley) (graphics program: Adobe Photoshop)

there have shown that bronzes – including statues of Buddha, Visnu riding the eagle Garuda, mirrors and jewellery – continued to be interred with the dead long after the end of the prehistoric period (Courbin 1988).

Deities were carved in stone and cast in bronze. Arguably the best-known bronze statue was discovered in 1936 when a villager digging into the Mebon Temple in the

centre of the massive Western Baray (reservoir), retrieved a bronze thumb 15 cm long. This led to the recovery of 40 pieces of bronze that had once formed a statue of Visnu Anantasayin (Fig. 19). In her detailed examination of this statue and its setting in the centre of Angkor's largest reservoir, Feneley (2017) has ascribed it to the reign of King Suryavarman II, who came to the throne in 1113. He associated himself with Visnu, the creator of the universe and controller of water, who was given the posthumous name Paramavisnuloka, 'he who lives in the sacred world of Visnu'. Zhou Daguan might well have been referring to this statue when he described a bronze Buddha in an island temple with water that gushed from its navel (Uk and Uk 2010). The statue would have been between 5.5 and 6 m long when complete, and was, in the main, cast from bronze containing 8.3 wt% tin (Azéma et al. 2018; Fig. 20). It was cast in sections by the lost wax method, the component parts being riveted together. Some casting flaws were covered with patches and the entire bronze was gilded, since traces of gold were observed when it was excavated and during recent analyses. The foundry responsible for this massive statue is not known, but it might have been on the island itself. If not, its components would have been shipped across the baray, and assembled *in situ*. It would have conjoined the King with the universal creator in the control of water in its sacred role to ensure the health of the state.

Jayavarman VII (reigned 1181–1218) was responsible for the construction of a formidable number of temples in addition to a network of roads, hospitals, and rest houses. He also had constructed the walled city of Angkor Thom that incorporates his temple mausoleum and palace precinct. The latter has attracted several excavations, beginning in 1916 with Henri Marchal, followed by Glaize in 1941–7 and B.-P. Groslier from 1952 to 1958 (Vincent 2014). Many bronzes were recovered, including moulds, copper ingots weighing 3.55 kg, and unsuccessful castings of deities. Small statuettes reflect Jayavarman VII's devotion to the Buddha. There are objects that would have been used in ceremonies, such as bells, saucers, spoons and bowls. The bas reliefs of Angkor Wat and the Bayon portray elites being carried in palanquins with bronze finials, suspension hooks and rings that would probably have been gilded. Palace interiors included lamps, bronze plaques to decorate furniture and balusters. The occupants wore bronze hair pins, rings and pendants. Even the pulleys to adjust the blinds were cast in bronze. Royal processions involved banners and flags held aloft on masts embellished with bronzes.

In the northeastern quarter of the palace precinct Polkinghorne et al. (2014) have excavated a bronze-casting workshop that might have extended over an area of 2 ha. Its extent, and the size of the furnaces, crucibles and clay mould pieces, illuminate the sort of facility that would have cast the massive Visnu three generations earlier. Having fashioned the form of the casting in clay, often with reinforced internal iron or wooden scaffolding, the future bronze was created in wax. This was enclosed in a layer of rice-tempered clay before the wax was melted out and replaced by liquid bronze. Basin furnaces linked to a tuyère were used to melt the bronze. One furnace with a diameter of 0.5 m could have held 18 kg of bronze. The size of the sprues through which the molten metal entered the mould suggests that statues weighing hundreds of kilograms were cast at this facility. Surviving bar-shaped ingots probably travelled from the mines, and although the copper has not been sourced it is

under analysis. The entire operation is a reflection of prehistoric lost wax casting technology: both imported ingots, mixed their preferred alloys, and employed clay furnaces and crucibles. The difference is in the sheer scale of the Angkorian foundry. It is also stressed that the palace foundry was closely linked to and surely reflects royal patronage.

The Upper Mun Sites: Summary.

Based on the analytical evidence we have thus far, we have identified eight phases in copper/bronze technology in the Upper Mun Valley in particular, and the Khorat Plateau and North Cambodian plains in general (Fig. 3).

Phase 1 (c. 1050–1000 BC). Ban Non Wat BA1. Socketed copper axes were imported. We have not as yet identified the source of the copper, but among the analysed artefacts there is no lead isotope signature compatibility with known Southeast Asian sources. Burials were considerably richer than during the preceding late Neolithic, although pottery forms persisted. Copper mining commenced in the KWPV and at Vilabouly.

Phase 2 (c. 1000–850 BC). Ban Non Wat BA2–3A. Socketed axes and chisels were imported, with at least some of the copper now coming from the KWPV mines and production sites in Central Thailand. At Ban Non Wat, there is no convincing evidence for on-site casting. Burials in central Ban Non Wat were spectacularly wealthy, in terms of exotic shell ornaments that were very probably manufactured in Central Thai sites such as Tha Kae (Ciarla et al. 2017). There were also marble imports, bronze axes, chisels and bells, and the new range of pottery forms. Contemporary burials in another part of the site were markedly poorer. A socketed bronze spear at Ban Chiang was cast from copper sourced at Vilabouly in Laos.

Phase 3 (c. 850–420 BC). Ban Non Wat BA 3B–5. Bronze casting was now established at Ban Non Wat and all other Khorat Plateau sites of this period. Moulds reveal that socketed axes and bangles were the principal products. However, the number of bronzes in burials declined to almost none. This period witnessed massive copper output from the KWPV.

Phase 4. (c. 420 BC–AD 100) IA1 at Ban Non Wat and Noen U–Loke. Casting continued at Ban Non Wat but was less intensive. Some innovations were seen in lost wax ornaments, torcs and lost-lead socketed axes. Spears had bronze hafts and iron blades. There is no evidence for elite burials at Ban Non Wat during IA1. Copper output from the KWPV sites continued, but Vilabouly supplied much of the copper in Southeast Asia.

Phase 5 (c. AD 100–400). IA2–3 at Noen U-Loke. Despite the extreme rarity of moulds and crucibles, the quantity of bronzes reached unprecedented levels. Technical sophistication increased. On balance, it is suggested that most of these bronzes were imported rather than locally cast. There is also marked regionality. In the northern reaches of the Khorat Plateau, bronze mortuary offerings remained very rare.

Phase 6 (c. AD 300–600). IA4 at Noen U-Loke and Non Ban Jak. Evidence for local casting seen in the presence of moulds and crucibles was not found at the latter site, and was extremely rare at the former. The range of bronzes found in burials was maintained but the quantity declined.

Phase 7 (c. AD 600–1000). The Kingdom of Sri Canasapura. With the rapid formation of small state societies under influence from Dvaravati Central Thailand, a

handful of late Iron Age moated sites were greatly expanded into regional centres, seen at Muang Sema. New demands on copper, tin and lead were needed to cast statues of deities that could only have been undertaken in specialist foundries.

Phase 8 (c. AD 1000–1300). The Upper Mun Valley became an integral part of the Kingdom of Angkor under the vice regal dynasty of Mahidharapura. Bronzes were cast in royal workshops, the best-documented being located in the palace precinct of Angkor Thom. Statues of deities were used to project the king's role as mediator between earth and heaven. Smaller bronzes, often in the form of gods, were used to decorate buildings, fashion personal ornaments and produce elite furnishings, such as those on palanquins.

The Wider Picture

We have traced a sequence in the interior of mainland Southeast Asia, spanning the first known bronze artefacts to the royal foundries of Angkor. At least two millennia of exchange of goods and ideas within an interaction sphere that stretched from the Central Plains of China to the islands of Southeast Asia found a new gear in the second half of the first millennium BC. Maritime trade brought settlers with new ideas and goods from South Asia. The Qin and Han rulers increased contact with northern Vietnam by expanded trade and ultimately, imperial conquest. The Khorat Plateau sites were shielded by distance from the direct impact of these developments, but in Yunnan, the Dian leaders of Shizhaishan and Lijiashan reveal in their bronzes contact and influence from the Eurasian Steppes (Chiou-Peng 2018). South Asian exchange along the so-called Maritime Silk Road stimulated the rise of port cities. Glass and hard stone ateliers were established at Khao Sam Kaeo in peninsular Thailand as it grew into a flourishing cosmopolitan centre by the fourth century BC (Bellina 2017). It is highly likely that knowledge of iron smelting and forging came by this route, (Biggs et al. 2013; Petchey et al. 2018), for ripples of South Indian influence are seen in the early Iron Age cemetery at Ban Non Wat, where the dead were interred with glass, carnelian and agate ornaments as well as iron weapons and tools. Contemporary with Phase 4 on the Khorat Plateau, the bronze founders at Khao Sam Kaeo were familiar with Indian high-tin bowls, Western Han mirrors and Dong Son drums, none of which has an isotope signature that matches the three known Southeast Asian copper sources. Bronzes were imported, but the presence of ingot moulds and crucibles evidences local workshops, in which Pryce et al. (2017) have found evidence for smelting cassiterite (tin) ores to produce high-tin bronzes, a procedure derived from South Indian metallurgy.

The Dong Son culture of northern Vietnam is another contemporary of Phase 4. It originated in a sequence named after the sites of Dong Dau and Go Mun that present close similarities with Phases 1–3 on the Khorat Plateau, but the range and quality of the Dong Son bronze industry is of a different order of magnitude to that seen on the Khorat Plateau. Dong Son was a complex warrior society, best documented in the scenes that decorate its bronze drums and situlae. These show river or ocean warfare on impressive vessels, with combatants wielding spears and bows. Drums cast by the lost wax method are the hallmark of the Dong Son bronze repertoire (Bennet 2008). Although iron was known, bronze dominated. It was cast into weighty ploughshares,

spears and crossbow bolts of which c. 10,000 were recovered in one cache from the walled centre of Co Loa (Kim 2015). A drum from this centre weighs 72 kg, and would have called on a substantial amount of ore, depending on its quality. Naturally, crucibles were far larger than any known on the Khorat Plateau; one that survives in the grave of a bronze founder at Lang Ca having a capacity of 12 kg of bronze. The 300 graves at Lang Ca contained 650 bronze offerings but just two of iron. The dominance of bronze is also seen in the boat coffins. That from Viet Khe contained over a hundred bronzes, including small drums, vessels, a sword, spear and arrowheads. The elite of the Dong Son culture led an increasingly complex social order until nipped in the bud by a Han Chinese army.

Discussion

> Documenting 'technology transfer' or the introduction of technology by one non-literate ancient people to another, has to be one of the most complex issues an archaeologist can face.
> (Hosler 2014, p. 356).

Our discussion rests on very few excavations of any size, and even fewer useful final reports. Any conclusions are, therefore, likely to be modified by new research. Ban Non Wat is the most intensely excavated site, yet only c. 0.6% has been opened. Moreover, the squares distributed across the site present different sequences. That in the centre has hunter-gatherer occupation followed by Neolithic, Bronze and Iron Age layers. A square to the south has a sequence beginning in the later Iron Age, another to the northeast was first occupied in Bronze Age 2. Doubtless much remains to be discovered at this and the handful of other sites that form the basis of this discussion.

We suggest that it is necessary to outline the nature of the Neolithic communities that first came into contact with metal. Rice and millet farmers expanded into Southeast Asia by riverine and coastal routes from the north (Rispoli 2008; King et al. 2015; Higham 2017). Dating from the late third millennium BC, they encountered and interacted with the long-term hunter-gatherers; this is seen most clearly at the Vietnamese site of Man Bac (Oxenham et al. 2011). Khok Phanom Di, formerly located on the estuary of the Bang Pakong River in Central Thailand, is the best documented Neolithic settlement (Higham and Thosarat 2004). Its occupation spanned five centuries from c. 2000 BC, and included seven mortuary phases that reveal a sophisticated trading community based on its status as a ceramic manufacturing centre (Vincent 2004). Thus, women were interred with their tools of trade: ceramic anvils for shaping pots, and stones for burnishing them. One was interred wearing clothes embellished with over 120,000 exotic shell beads, with horned shell discs on her chest, ear ornaments and a bangle. An infant in the adjacent grave who died aged about 18 months was accompanied by a miniature clay anvil, and 12,447 shell beads. Men wore decorated marine turtle carapace breastplates. The point is that here was a community that imported exotic shell ornaments, stone for adzes, granite for hoes and ochre for mortuary rituals. Pottery vessels were manufactured in quantities for export, and the forms of the shell beads and turtle carapaces are matched in

the contemporary Neolithic cemeteries in the Lopburi region, location of the future copper mines of the KWPV.

Although not as abundant as at Khok Phanom Di, shell beads were found in the Neolithic graves of Ban Non Wat, as were exotic cowry shells (Higham and Kijngam 2010). The Neolithic settlements comprised rice or millet farmers who maintained domestic pigs and cattle. They participated in long-distance exchange and their communities were stable, measured over five centuries at Khok Phanom Di and six at Ban Non Wat. The former was abandoned before the appearance of the first metal, but during the eleventh century BC, the inhabitants of Ban Non Wat encountered socketed copper-base axes and placed them with the dead.

Only seven BA1 graves were encountered in the main square, but they inform us that, compared with the immediately preceding Neolithic 2, imported exotic shell ornaments markedly increased. The first trochus shell bangles were interred with an infant, and shell bead necklaces and belts were worn. The number of ceramic vessels far exceeded that of the late Neolithic. The lead isotope signature of the copper axe from burial 453 does not match any known copper source in Southeast Asia, and we suggest that it and the other three were exotic imports. Until the results of further lead isotope analyses by Pryce's BROGLASEA project are available, we cannot suggest a likely source. However, their forms match those known from many contemporary and slightly earlier sites in Lingnan, southern China, and this must be high on a list (Fig. 2; Ciarla 2007; Pigott and Ciarla 2007; Higham et al. 2011; Pryce et al. 2014a, b, p. 291). Given the establishment of copper mining, smelting and casting in Lingnan in the late 2nd millennium BC, it is almost to be expected that these socketed axes entered long-established exchange routes. At Ban Non Wat, they joined equally exotic shell and marble jewellery in expressing increased mortuary wealth, at least compared with their immediate Neolithic ancestors.

We need more evidence for this vital transition but, at present, it is possible to propose a model for the transfer of metallurgy into Southeast Asia. The proximal source was Lingnan and Yunnan, both of which received their own knowledge from the early states of the Yellow and Yangtze river basins. The first copper-base artefacts probably reached Southeast Asian late Neolithic communities, as at Ban Non Wat and Ban Chiang, towards the end of the 2nd millennium BC by travelling along long-established exchange routes. This was followed by the arrival of individuals versed in identifying and exploiting copper ores by the same routes and at about the same time. We see them active at Non Pa Wai and Vilabouly by about 1000–1100 BC, and their output again entered routes for exchange active for the millennium of the Neolithic. Testing of this model is on-going, with further lead isotope analyses incorporating southern Chinese mines and Southeast Asian consuming sites, while it will be interesting to analyse strontium isotope data from the early founders, as at Non Pa Wai, to try to reveal patterns of human mobility.

The formulation of models of social change has been based necessarily on the evidence drawn from mortuary data, but the procedures involved in mining, trading, casting, and what was cast, are increasingly relevant. Excavations at Non Nok Tha in 1966–8 began to open a window on the social world of Bronze Age Southeast Asia. Bayard, who directed fieldwork there, suggested on the basis of two slightly different ceramic vessel forms that this was a cemetery used over centuries, if not

millennia, by two communities, one rather wealthier, in terms of mortuary offerings, than the other (Bayard 1984, 1992).

Two areas of Ban Na Di were excavated in 1981, one consistently having slightly more exotic mortuary offerings than the other. I concluded then that 'settlement and mortuary data are consistent with a system of flexible lineage ranking of which the unequal and restricted distribution of valuables in cemetery contexts are the archaeological embodiment' (Higham 1984, p. 250).

Following the excavation of Ban Lum Khao in 1996, and having undertaken a detailed analysis of the Bronze Age 2 cemetery there, we concluded that:

> there was very little difference in mortuary wealth between contemporaneous inhabitants at Ban Lum Khao. This is not to say that the evidence is indicative of an egalitarian society, but it does seem to indicate that there was no entrenched hierarchy. Such a result is not, in the case of Thailand, unusual, for few Bronze Age sites provide definitive evidence for the pre-eminence of one group over another.
> (Higham and Thosarat 2004, p. 328).

Dougald O'Reilly presented his own analysis of the Ban Lum Khao cemetery. He wrote:

> Higham (1989) recognized as early as 1989, that Bronze Age settlements were most likely autonomous units comprising no more than 500 individuals. He also noted that 'the attainment of status was flexible rather than fixed and that the relative position of each autonomous community was given to fluctuation and, therefore, instability (Higham 1989:187). This is, in fact, what more recent proponents of the heterarchical model are proposing for Southeast Asia (White 1995; White and Pigott 1996).
> (O'Reilly 2004b, p. 330).

Writing before the excavation of Ban Non Wat, White (1995, p. 110) argued for a heterarchical social system, noting that 'grave differentiation at Ban Chiang, Ban Kao, Ban Na Di, and Non Nok Tha has not been identified in terms of overtly exclusive placement combined with a degree of wealth outstanding from the continuum (i.e., an outstandingly rich grave in a special location suggestive of a chief or chiefly lineage)'.

It is suggested that the excavations at Ban Non Wat have opened a new dimension in identifying and understanding social change as bronze entered the exchange networks at the end of the 2nd millennium BC (Higham 2011a). One of the most important facts about the BA2 cemetery at Ban Non Wat is the consistent wealth displayed in the graves of men, women and infants. The dead, laid out in neat rows with barely one instance of intercutting an earlier grave, must surely represent an enduring level of opulence over several generations (Fig. 9). They also lie on the same orientation as BA1 burials, again with little disturbance of their predecessors, and present a seamless transition. Veneration of the ancestors is also strongly hinted by disinterment, perhaps for ritual purposes, and then reburial. The wealth is principally expressed in exotic shell and marble ornaments, and an abundance of fine

ceramic vessels of new forms, many superbly decorated with painted designs that hearken back to those on Neolithic 1 pots. Eighty-two pots were found in a double male burial, 88 in the grave of two females. However, 10 copper-base axes were found in the burials of 11 men, two with seven women, and two with 15 infants. A possibly telling point is found with burial 197, a middle-aged to old male. He was accompanied by two bronze axes, three chisels and an awl. Was he a member of a wealthy elite, or a carpenter? We favour the former, his status reflected in his 23 exotic shell bangles and in over 10,000 beads.

The sampled BA2 axes had insufficient tin or post-casting treatment to improve their mechanical properties, and the presence of copper-base axes in infant graves makes the bronze mortuary offerings more likely to have been rare symbols of status. Although not published, there is a virtually identical elite concentration of early Bronze Age graves at Ban Prasat, about 20 km east of Ban Non Wat. It is beyond reasonable doubt that equally wealthy burials await discovery in the many unexcavated sites of the strategic upper Mun Valley. The excavation of Ban Non Wat has yielded a sea change in identifying socio-economic patterning that coincided with copper-base metallurgy. Elites accumulated an unparalleled measure of wealth, expressed in marine shell and exotic stone ornaments, at the same time as many were interred with copper-base axes, chisels, bells and anklets. There is no imperative to ascribe this social transition solely to the newly available metal artefacts, but nor is there any reason to ignore the potential impact of this new and remarkable material. Access to and possibly a transient ownership of novel and rare bronzes may not have stimulated the virtually self-evident rise of a social aggrandizers at Ban Non Wat and Ban Prasat, but bronzes were certainly interred with the dead to join marble and marine shell ornaments as projections of status.

By the eleventh century BC, the copper mines of the KWPV were open, and two founders were interred in basal Non Pa Wai with bivalve moulds for casting socketed axes (Pigott et al. 1997). At least two of the BA2 axes at Ban Non Wat were cast in copper consistent with the KWPV lead isotope signature (Pryce 2012). We suggest that bronze tools and ornaments now joined marine shell and marble ornaments as symbols of a new but, in the event, transient social hierarchy that developed on this strategic trade route linking Central Thailand with the Khorat Plateau communities. A telling point in favour of social inequality is that nucleated graves both at another part of Ban Non Wat and at Ban Lum Khao, only 20 km to the east and also dating to BA2, were virtually devoid of bronzes and contained very few shell ornaments. Ban Prasat is just 5 km further to the east, and there the centrally-located BA2 dead were as rich as those in central Ban Non Wat. The three northern sites of Ban Chiang, Non Nok Tha and Ban Na Di have no equivalent evidence for social elites. This might be due to the small and possibly unrepresentative areas excavated. At present, however, we suggest that their remote location, far from natural exchange routes, is relevant.

The extreme wealth of aggrandizer graves in BA2 and 3A fell away sharply with BA3B. We also find that during BA4 (c. 800–700 BC), that is our Phase 3, bronze axes and bangles were being cast by resident founders at Ban Non Wat. Furnaces, crucibles and moulds were also found during this phase at Non Nok Tha, Ban Na Di and Ban Chiang. The BA4 cemetery at Ban Non Wat contained 162 graves laid

out in a rows and head to head, that comprise four groups (Fig. 13). An intensive effort has been made to identify any evidence for social distinctions between the four based on mortuary offerings (Smith et al. 2015). There is hardly any. One group has a lower concentration of disc beads, another has several burials interred with the grey clay that might have been used as a mordant in dying cloth. A third group had slightly more bivalve shells, thought to reflect rituals of rebirth. At least in this part of Ban Non Wat, and at all other Phase 3 exposures available, bronzes were not part of burial rites.

The fifth century BC heralded marked technological change, manifested in the upper Mun Valley sites by the virtual end of marine shell and marble imports. The impact of the emergent maritime trade with South Asia brought carnelian, agate and glass ornaments to the IA1 cemetery at Ban Non Wat, and we suggest that knowledge of iron technology came from the same source. Both at Ban Na Di and Ban Non Wat, some bangles were now cast by the lost wax method, a technique that could have been introduced from China, or from the west. There are caches of clay mould inserts for casting socketed bronze axes. The IA1 graves at Ban Non Wat formed two large groups. Again, no evidence for elite burials has been identified. However, our Phase 4 saw a return to bronzes being incorporated in burials. Bangles dominated numerically; other ornaments included anklets and neck rings or torcs. The earliest Iron Age burial at Noen U-Loke contained two socketed bronze spears, and three spears at Ban Non Wat were bimetallic, with bronze hafts and iron points. There were also two arrowheads. This cemetery reflects a handful of generations during which bronzes were locally cast, new techniques were being employed, and potentially offensive weapons were in circulation.

Phase 6, like Phase 2 before it, was one of transformation. New evidence from lake cores has identified a sharp decline in the strength of the summer monsoon that brought a period of aridity. An integrated set of changes, it has been argued, reflect human reaction to this adversity (Castillo et al. 2018; Higham et al. 2019b). Across virtually the entire Mun Valley, and stretching north into the valley of the Chi and across the Daeng Raek escarpment into Cambodia, moats/reservoirs were constructed round Iron Age settlements. These were major feats of engineering. The five reservoirs at Noen U-Loke, each contained by a bank, extended 200 m beyond the site perimeter and were linked to what looks like a canal. Hawken (2011) has identified rice fields enclosed by banks round Cambodian sites of this period, while Parry (1992) has mapped a dam at the large moated site of Ban Chiang Hian. Castillo's analysis of the plant remains from Ban Non Wat and Non Ban Jak has shown a transition from dry-land rice-field weeds to those adapted to wet rice cultivation at this juncture. Smiths now forged weighty socketed iron ploughshares and tanged sickles. Rice grains littered the floors of houses destroyed by fire, and rice straw was liberally used, as in the construction of kilns and the daub on house walls. In sum, there was an agricultural revolution that involved the creation of demarcated rice fields improved by irrigation and cultivated by ploughing (Higham et al. 2019b).

There were also changes in burial practice. The dead were now interred in tightly defined clusters that are most likely to comprise closely related individuals. At Noen U-Loke, exotic jewellery now included gold beads, silver bangles, silver and gold ear inserts, and agate, carnelian and glass beads and pendants. The quantity of

bronze ornaments surged (Table 2). For the second time, we suggest that there was a rise of social elites in the Mun River valley, their source of wealth rooted in preferred land ownership. We cannot discount the likelihood that salt production and exchange were also vital, since many of the moated sites were now ringed by salt-working mounds, and to this day the upper Mun region is noted for its industrial salt production. Phase 6 also witnessed a rise in militarism. Iron points, probably arrowheads, proliferated, and one was found embedded in the spine of a man interred at Noen U-Loke. There are no moated sites in the vicinity of Ban Chiang, Ban Na Di or Non Nok Tha. Nor are there any Iron Age burials close to matching the wealth seen in IA3 at Noen U-Loke. We suggest that the rise of social elites that coincided with the putative agricultural revolution was a phenomenon of the relatively arid Mun Valley not experienced in the three northern sites.

Between AD 500 and AD 700, two cultural trajectories can be identified. At Non Ban Jak, wet rice farming continued as knowledge of Buddhism was being absorbed. The burials were now markedly poorer in terms of exotica, the dead being interred not in tight family clusters, but within houses, a practice that most probably reflects a need to reinforce lineage land ownership. At the same time, a handful of particularly strategic Iron Age settlements were greatly expanded, and included Buddhist establishments supported by royal patronage. Social inequality was now a central feature of Early Historic polities. The royal elite, enriched by ownership of the best land, and in charge of exchange transactions, as contemporary texts describe (Vickery 1998), had the resources to make merit through gifts to their monastery. This procedure not only provided the elite with merit, but it also enhanced the donor's social status. We should therefore see the casting of a 3.5 m high bronze of the Buddha as a self-serving political action by one with access to an unprecedented quantity of metal.

With the Kingdom of Angkor, bronzes were cast on an industrial scale in royal foundries. Their cultural role must be considered in the context of the divine status of the king, who acted as an intermediary between the earth and heaven. Water was the very essence of life, and a key royal role was to sustain the state by ensuring through the rains or reservoirs that there was sufficient. The headwaters of the sacred rivers flowing from the Kulen uplands to Angkor flowed over carved deities and stone linga, phallic symbols of fertility. Statues of the gods, which subsumed rulers and royal ancestors, were living beings, requiring regular attention through feeding and sheltering from mosquitoes. There is no clearer reflection of this than a king identified with Visnu placing a massive bronze of the creator of the universe, Visnu Anantasayin, with water emerging from the navel, in an island temple in the middle of a reservoir measuring 8×2.1 km. As we now know from the royal foundries of Angkor Thom, copper was brought to the capital in large ingots, and cast by lost wax into a myriad of statues, sumptuary vessels, accoutrements to furniture and palanquins, and ornaments.

Conclusions

During the eleventh century BC at Ban Non Wat, a community of rice farmers fortuitously living astride a major trade route, encountered metal in the form of socketed copper axes. The lead isotope signature of one of these does not match any of the known Southeast Asian sources of copper ore, and we consider it likely that the axes were imported through long-established trade links with Lingnan, the southern provinces of modern China. There, axes of similar form were widely being cast in bivalve moulds. At Ban Non Wat, there was a social transformation manifested in burials of remarkable wealth, measured in local ceramic production, exotic ornaments of marine shell and marble, and in addition, copper-base axes, chisels, awls, anklets and bells. This lasted for at least six generations, and we have suggested that it reflects an enduring lineage of social aggrandizers (Higham 2011a). By this period, copper was being mined, smelted and cast in the KWPV and Vilabouly ore sources. We would not be surprised if experienced metal workers were moving into the area from the north and exploring for sources of copper. However, there is no suggestion that the trade in and restricted ownership of copper-base artefacts was uniquely responsible for aggrandizer behaviour, for ceramic vessels, marine shell and marble were quite the most abundant exotic items associated with the dead.

By Phase 3, from the ninth century BC, founders were present in all consumer sites under review, seen in the presence of furnaces, moulds and crucibles. At Ban Non Wat, the principal output was socketed axes and bangles. The limited evidence available indicates that despite local production of bronzes, particularly bangles with an innovative set of multiple clay 'concertina' moulds, these castings were no longer interred with a wealthy elite.

The development of extensive marine and terrestrial exchange of goods, ideas, and people from about 500 BC was probably the means whereby iron technology and the lost wax casting of bronzes reached Southeast Asia. Iron Age 1 graves saw an increase in bronzes, including weapons and lost-wax bangles, at a time when casting in consumer sites seemed to decline. There is no evidence for social change, as in the late Bronze Age the burials were laid out in large, probably corporate, groups. It was with increased aridity as the strength of monsoon rains declined that a seminal social change took place. Water conservation and irrigation into permanent, ploughed rice fields took place at the same time that burials were disposed in tight nuclear groups. Wealth varied between these groups, with elites now interred with gold, silver, precious stone and bronze personal ornaments. We conclude that bronzes, some requiring considerable expertise, came from specialised workshops and were used to designate elite social standing.

There are two instances of the formation of social elites on the Khorat Plateau during prehistory. The first lasted for about two centuries and followed immediately on familiarity with the first socketed copper-base axes. The two sites with wealthy cemeteries are found in a strategic location for accessing exchange of exotic valuables that included early metal castings. In the more remote northern reaches of the plateau, early Bronze Age graves so far known were markedly poorer. There is, as yet, no evidence for matching elite control over production in the vicinity of the

copper mines. This might emerge from extensive excavations, but this is for the future. We suggest that the first copper axes came to the Khorat Plateau along established exchange routes, soon to be followed by the arrival of people already experienced in mining, smelting and casting in bivalve moulds. There is potential to test this if aDNA and strontium isotopes can be examined in the remains of the founder burials.

The second rise in social inequality was generated by the socioeconomic reaction to climatic deterioration. This led to an agricultural revolution that enabled a new elite to enrich themselves through preferential land ownership. The production of surplus rice and probably other resources, such as salt, enabled the aggrandizers to import a new and expanded range of exotic valuables that included gold, silver, carnelian and agate, and not least, much bronze in the form of body ornaments. There is very little evidence for casting during the late Iron Age, and identifying where these bronzes were manufactured is for the future.

Within a few generations, a handful of greatly expanded settlements housed Buddhist communities sponsored by the wealth of nascent royal dynasties. Merit and prestige accompanied the donation of bronze statues that present an entirely new dimension in the quantity of metal being consumed and the skill of the specialist founders. Even this reached a new plane with the Kingdom of Angkor, when kings projected their divinity through temple mausolea sheathed in bronze, and gilded bronze statues that advertised their kinship with the gods.

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