A New Chronology for a Prehistoric Copper Production Centre in Central Thailand Using Kernel Density Estimates

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Abstract

The Khao Wong Prachan Valley of central Thailand is one of four known prehistoric loci of co-occurring copper mining, smelting and casting in Southeast Asia. Many radiocarbon determinations from bronze consumption sites in Northeast Thailand date the earliest copper-base metallurgy there in the late 2nd millennium BC. By applying Kernel Density Estimation to ca. 100 new AMS radiocarbon dates, we conclude that the first millet farmers settled the valley by 2000 BC, and initial copper mining and rudimentary smelting began in the late second millennium BC. This dovetails with the established dates for Southeast Asian metal consumption sites.

Introduction

Current evidence across much of prehistoric Eurasia suggests that copper-base metallurgy was in place by the 4th millennium BC, prior to the 3rd millennium BC eastward transmission of tin-bronze technology (Roberts et al. 2009). Thus in Eurasia's complex mosaic of culture areas, experienced metalworkers were often present and ready to engage with the new tin-bronze. Knowledgeable metalworkers may well have been the vectors of this technology transfer (Pigott 2018:191; Ciarla 2013:31, 37-38).

In Mainland Southeast Asia (MSEA), despite its rich copper and tin deposits (Fig. 1), no archaeological metal is documented prior to the late 2nd millennium BC, a remarkable situation given the general antiquity of metallurgy at the scale of the Asian landmass, and in particular the relative proximity of MSEA to metal-using cultures of the eastern Steppe, northwest China and on its Central Plain dating to the later 3rd and early 2nd millennium BC (Pigott 2018:216, Fig. 3). The dating of the first copper-base technology in Southeast Asia has been determined on the basis of consuming sites. Below, we present a new chronology for smelting and casting sites in Central Thailand.

Fig. 1 Map showing the location of copper and tin, copper mines and the sites mentioned in the text. 1. Non Pa Wai, Non Mak La, 2. Nil Kham Haeng, 3. Sai On, 4. Noen U-Loke, 5. Ban Non Wat, 6. Khok Phanom Di, 7. Non Ratchabat, 8. Non Nok Tha, 9. Ban Na Di, 10. Ban Chiang, 11. Vilabouly, 12. Phu Lon.

The Coming of Tin-Bronze Metallurgy to MSEA

When and by what routes and mechanisms this technology was transmitted from the eastern Steppe into MSEA has been long debated (Pigott and Ciarla 2007). There is a consensus that the ultimate origins of Southeast Asian tin-bronze metallurgy lie on the Eurasian Steppe and that this technology arrived fully developed across much of Southeast Asia (cf. Pryce 2019a). However, this technology appears to have arrived only partially developed in central Thailand, a distinction based upon the dislocation between the earliest competent foundry but rudimentary primary smelting techniques at the site of Non Pa Wai, supported by lead isotope analysis (LIA) (Pryce et al. 2010; 2014; 2018).

At the heart of the debate for prehistoric Thailand is what Pryce (2014) terms the ‘long’ and ‘short’ chronologies. The ‘short’ chronology dates the appearance of copper-base metallurgy to ca. 1100/1000 B.C. (Fig. 1; Ciarla 2007a, Higham and Higham 2009, Higham et al. 2011, 2014, 2015). In this view, copper/bronze coincided with the rise of social elites at the site of Ban Non Wat (BNW), an occupation site incorporating a Bronze Age cemetery (Higham 2011). Following an in-depth assessment of the archaeology of the Chinese Bronze Age, the ‘short’ chronology has been held to be compatible with the transmission of tin-bronze technology that, it has been argued, originated ultimately in the Seima-Turbino Horizon (Chernykh 1992, Chernykh and Kuzminykh 1989) moving progressively from the Steppe onto the Chinese Central Plain via the Hexi From there the technology gradually moved south into Lingnan and eastern

Yunnan (e.g., Ciarla 2013). Numerous sites in Lingnan have revealed tin-bronze technology and socketed implement casting in bivalve moulds, positioned closely for transmission into MSEA (Fig. 2; Ciarla 2013; Higham et al. 2014). This would have been expedited by human traffic proceeding along the radial flow of rivers south from the Yunnan hub (Takaya 1987:3, Fig. 2).

Fig. 2. Map showing the location of key sites in the transmission of copper base technology into Southeast Asia. 1. Non Pa Wai, Nil Kham Haeng, Non Mak La, 2. Phu Lon, 3. Ban Non Wat, 4. Vilabouly, 5. Ban Chiang, 6. Khok Phanom Di, 7. Non Ratchabat, 8. Oakaei, 9. Haimenkou, 10. Huoshiliang, 11. Xichengyi, 12. Taosi, 13. Erlitou, 14. Kamyshnoe, 15. Verkhnyaya Alabuga, 16. Novonikolskoe.. Note the radial nature of the rivers flowing south from Yunnan.

The 'long' chronology, as advocated by White and Hamilton (2014), argues for a rapid movement along the eastern flanks of the Himalayas of tin-bronze-using metalworkers of the Seima-Turbino horizon (ca. 2300 – 1700 BC), whose origins lie in the Altaï Mountain district of western Mongolia and which spread west and east across northern Eurasia (Marchenko et al. 2017). They maintain that these metalworkers, and/or their "trainees" (Pryce 2014), moving southeast off the eastern Steppe, skirted the Central Plain, as well as the Yellow and Yangtze basins, passing finally through Yunnan, to reach Northeast Thailand at Ban Chiang by ca. 2000-1800 BC (White 2008; White and Hamilton 2014). They argue that the metallurgical material culture that reached Ban Chiang from the Steppe was transmitted relatively intact into Southeast Asia with few socio-cultural consequences. However, while arguments have been made for a Steppe origin of the metallurgy that arrived in Yunnan, its advent there is to late to support the 'long'chronology (Chiou-Peng 2018; Li and Min 2014).

Only a precise chronological framework will order these alternatives in terms of plausibility. Here, we report on new research that dates three prehistoric metalworking communities of the Khao Wong Prachan Valley (KWPV) on the Lopburi Plain of central Thailand: Non Pa Wai (NPW), Nil Kham Haeng (NKH) and Non Mak La (NML) (Fig. 3).

Fig. 3. Map showing the sites mentioned in the text in the Khao Wong Prachan area, 1.

Non Pa Wai, 2. Non Mak La, 3. Nil Kham Haeng, 4. Khao Tab Kwai, 5. Khao Phu Ka, 6. Noen Din, 7. Khok Din, 8. Khao Sai On, 9. Khao Pha Daeng.

The first two are among the largest prehistoric copper production sites known in Eurasia. In figures 4, 6 and 7, we illustrate the extent to which TAP opened multiple excavations to investigate possible variations in the cultural sequences and activities. They were responsible for smelting quantities of local copper ore mined in the KWPV (Natapintu 1988:115, Table 2). Only three other archaeologically documented copper producing locations in Southeast Asia: the Khao Sai On Mineral District lies immediately south of the KWPV, with a mining locus and two copper producing sites at Khok Din and Noen Din (Pryce et al. 2013; Ciarla 2008, 2007b); the mining complex of Phu Lon on the southern bank of the Mekong River, (Pigott 2019; Pigott and Weisgerber 1998; Natapintu 1988); and the Vilabouly Complex in Laos (e.g., Cadet et al. 2019; Tucci et al. 2014). These sites currently supply the available metal production evidence in Thailand and Laos that underpins discussions of the development of copper-base technology in Southeast Asia (Pryce et al. 2018).

Fig. 4. Plan of Non Pa Wai, showing the excavated operations

The Sites of the Khao Wong Prachan Valley, Central Thailand

Non Pa Wai was initially settled by sedentary millet farmers, followed by new arrivals familiar with metallurgy who exploited local ore to smelt copper, albeit in a rudimentary fashion with no evidence for alloying with tin (Fig. 4; Pryce et al. 2010; Pigott 2019;). Two burials contained ceramic bivalve moulds for casting socketed axes using suspended cores (Fig. 5). Metal, however, was always rare. Over time, copper production intensified, resulting in the formation of up to two metres of a disturbed and poorly stratified grey, fine-powdery deposit covering about five hectares. This distinctive "Industrial Deposit" (ID) is densely packed with slag, ore, and ceramic crucible and mould fragments.

Fig. 5. Non Pa Wai: a founder's burial dating to the late 2nd millennium BC containing bivalve moulds for casting a socketed axe, and a copper-base fish hook.

Neighbouring Nil Kham Haeng (NKH; Fig. 6) comprises a six metres deposit of varve-like lenses of pea-sized crushed ore, host rock and often slag. Compared to NPW, smelting was more consistent and proficient (Pryce et al. 2010). Mixed in the lenses are larger slag, crucible and mould fragments and the remains of clay-lined bowl furnaces as well as domestic potsherds and animal bones. Extended burials were interleaved among the multiple layers, some containing disassembled, but complete, ceramic chimneys and small, cordiform-shaped, copper-base implements (Pigott 2019). Certain of these held marine turtle carapaces and one contained spherical carnelian beads (Rispoli et al 2013).

Fig. 6. Plan of Nil Kham Haeng, showing the excavated operations

Non Mak La (NML) contained extended burials dating from Neolithic to Iron Age (Fig. 7, Weiss 1989). The Bronze Age graves contained a few copper-base bangles and other ornaments, domestic pottery, and freshwater bivalve shell offerings. While metallurgical debris was encountered in the occupational matrix during TAP excavations, it was not as dense as that at NPW and NKH (Pigott 2019). However, in a different location, Thai excavations tested a ca. 1m deep copper smelting, slag heap spread across ca. 100 m^2 (Natapintu 1988).

Fig. 7. Plan of Non Mak La, showing the excavated operations

Previous Dating Initiatives in the KWPV

During the above excavations between 1986-1994, charcoal samples were taken, and flotation recovered millet and rice grains and *Spilanthes* seeds. Using radiocarbon determinations based on charcoal, Pigott and colleagues initially dated the commencement of copper smelting at NPW at about 1500 BC, characterized by "a great burst of intensive copper production" that continued into the early 1st millennium BC and which began to tail off after about 700 BC. Their placement of the industrial activity at NKH between ca. 1100-300 BC would mean that there was an overlap of a few centuries between the copper smelting at these two sites (Pigott et al. 1997:127).

Subsequently, Rispoli et al. (2013:108-9) presented a new chronology based on strict chronometric hygiene that accepted only five of the 31 radiocarbon determinations.

Instead, they relied more on the relative chronologies of ceramic evidence and well-dated artefact classes. They dated the earliest occupation of NPW between ca. 1800-1100, followed by two phases of burials, the first from ca. 1100-800 BC and the second from ca. 800-500 BC, each contemporary with local copper production. Thereafter, the copper smelting and casting debris were placed in the period from ca. 500 BC to ca. AD 200. At NKH, they placed basal copper extraction between ca 500-200 BC, followed by two mortuary phases over the period ca. 200 BC-AD 600. Thus, dating the accumulation of industrial debris has veered between mainly late 2nd/early 1st millennium BC at NPW (Pigott et al. 1997) and entirely in the later 1st millennium BC at NKH (Rispoli et al. 2013). Given the differences between these two chronologies, we present a new strategy to resolve this discrepancy and integrate the crucial evidence for KWPV copper production with the deployment of its output to regional consumption sites.

The KWPV AMS ^{14}C-Dating Programme

The industrial deposits at NPW and NKH, with varying degrees of stratigraphic disturbance, are highly challenging to date. While Bayesian analysis of multiple samples is the most effective method of dating a prehistoric site, it is best applied to a stratified sequence in which sample selection is aimed at selecting dating materials that avoid residuality or intrusion (Bayliss et al. 2007). Without these prerequisites, we have determined that Kernel Density Estimation (KDE) is the most appropriate method of dating human presence and activity at NPW, NKH and NML (Bronk Ramsey 2017), linked with a judicious input of typological evidence (Rispoli et al. 2013). While a domesticated millet or rice grain may come from a disturbed context, it does nevertheless date the presence of humans. We have also dated a limited number of charcoal samples.

This dating initiative is a necessary and positive step towards an integrated chronological schema that will allow Southeast Asian archaeologists to discuss in some detail both chronological and interregional interactions within prehistoric Thailand and, ultimately to meld these new data in a pan-regional overview designed, for the first time, to give Southeast Asian archaeologists the ability to speak chronologically across the greater region.

KDE Sample Selection and Treatment Regimen

The new radiocarbon determinations were dated at the Oxford Radiocarbon Accelerator Unit (ORAU). Where possible, single archaeobotanically-identified seeds were directly AMS dated, together with charcoal samples from selected contexts. In Tables S1 and S2, we report the analytical data associated with each sample. We Set out the pretreatment codes in Table S2 that correspond with the chemistry applied to pre-clean the laboratory. In some instances we used a variation on our routine method and applied a less robust pre-treatment method (ORAU code 'RR'; see Brock et al. 2010). This involves a demineralization with 1M HCl (1 hour), a 15 min ultrasonication in fresh 1M HCl, rinsing in ultrapure water (4 times) before a final ultrasonication, again in fresh ultrapure water for 5 minutes (x6 or until the water remained clear). The samples were then acidified for a further 5 minutes in 1M HCl and rinsed twice with ultrapure water. Samples that were larger or more robust and less fragile seeds were pretreated using the 'ZR' method. This includes a base wash designed to solubilise humates (Brock et al. 2010).

Following pretreatment, samples were dried and weighed into a pre-cleaned tin capsule and combusted in a EA-IRMS system, consisting of a CHN elemental analyser (Carlo-Erba NA, 2000) coupled to a gas source isotope ratio mass spectrometer (Sercon 20/20). Purified CO_2 from the combustion was converted to graphite using established protocols (Dee and Bronk Ramsey, 2000) and AMS dated in either the Oxford HVEE accelerator mass spectrometer or the MICADAS system.

<u>KDE Modelling – The Results</u>

We used the KDE modelling approach outlined by Bronk Ramsey (2017) to analyse the NKH, NPW and NML datasets using two approaches based on 91 new AMS samples. The first included the single entity samples; primarily *Setaria italica* and *Oryza* sp. The second added unidentified charcoal results. The reason for running two KDE Models is to explore preliminarily aspects of both human subsistence, which we correlate with the direct dating of agricultural crops, and metallurgical behaviour; which we link to the direct dates of single samples of charcoal some of which derived from metals-related activities and daily human occupation (Fig. 8).

Figure 8. KDE Models. A: the single entity model (n=10) from Non Pa Wai, B: the single entity and charcoal model (n=43) from Non Pa Wai. C: the single entity model (n=29) from Nil Kham Haeng, D: the single entity and charcoal model (n=39) from Nil Kham Haeng, E: the single entity model (n=11), from Non Mak La, F: the single entity and charcoal model (n=14) from Non Mak La. The younger determinations from Non Mak La, as shown in table 1, are not included in order to focus on the earlier part of the dated sequence. The sampled KDE estimated distribution is shown in dark grey. The blue line and lighter blue band represents the mean ±1σ for the KDE distribution obtained by the MCMC process. The light grey distribution evident particularly in the left hand model is the Sum distribution.

The NPW charcoal/single entity model shows three peaks, the principal one centred around 1200 BC, and two smaller peaks earlier, around 2000 BC (Fig. 8A). Our interpretation is that the earlier peaks correlate with a Neolithic presence, while the later peak corresponds with the Bronze Age occupation. There are very few determinations, however, so caution is required in interpreting the KDE plot too far. The second plot for NPW contains an additional 33 charcoal determinations (Table S1). This plot is similar but the peak of the distribution centres around 1000 BC and extends over one to two centuries either side. We suggest that this peak corresponds with metal production. The evidence also suggests that a period of abandonment occurred at the site between Neolithic and Bronze Age phases (Fig. 8B).

The NKH charcoal/single entity model (Fig. 8D) shows a major peak between ca. 900-400 BC, and a smaller pulse of probability around 1200 BC, but which demonstrates continuous occupation at the site. In the single entity only plot, the earlier pulse disappears (Fig. 8C).

At NML we excluded the very young determinations in the models in order to focus only on the Neolithic and Bronze Age periods. The two models are very similar and show two peaks. The older, centred on ca. 1500 BC and the later one, around 1000 BC, are most likely to represent two occupational age ranges corresponding to the Neolithic and Bronze Age periods, as defined within the continuous occupation of this site (Fig. 8 E-F).

NPW and NKH are 3 km apart. Given the differences in smelting technology between the two (Pryce et al. 2010), it is vital to assess their relative chronology. In figure 9, we present the KDE modelling for the two sites, which suggests that copper smelting at NKH began as that at NPW was tailing off (cf. Rispoli et al. 2013). We suggest smelting activity was most probably transferred from one site to the other with a slight overlap. However, at this juncture we have no conclusive evidence as to why smelting appears to have shifted locations.

Figure 9: KDE plots of NPW (mauve) and NKH (blue). Note that as one distribution declines so the other increases. See text for details.

Integrating Bronze Consumption Sites in Northeast Thailand: Ban Non Wat As Case Study

A key issue is the integration between this new chronology and the dating of the consumption sites located ca. 175 km to the east on the Khorat Plateau. Ban Non Wat lies in the direct path of any exchange that linked this region with copper production in the KWPV (Fig. 1). The transition from the late Neolithic to phase 1 of the Bronze Age at BNW saw a sharp rise in the wealth interred with the dead (Higham and Higham 2009). Burial rituals were more complex and four of seven burials contained a copper-base socketed axe. The analysis of one of these revealed almost pure copper (98.1 wt. % Cu; Pryce et al. 2014). The radiocarbon chronology for this site places these burials in the 11th century BC. We link this phase directly with the basal founder's burials at NPW, which we have dated within the span ca. 1200-800 BC. The dovetailing of the two sites is not only reflected in the chronology. At NPW, we know that founders cast deep-socketed copper axes. This technique, Steppic in origin, is widely documented in northern Vietnam and Southern China (Ciarla 2013). The intriguing outcome of the first results of lead isotope analyses is that the Bronze Age 1 socketed axes from BNW and that from a NPW burial were not cast from KWPV copper, nor that of the two other known prehistoric copper producing areas in Southeast Asia. We find this startling/intriguing?, and suggest that copper and sparingly tin-alloyed axes reached BNW and NPW as exotica, through exchange, at about the same time that the surface copper veins in the KWPV were identified and exploited by immigrant founders (Pryce et al. 2010, 2011). This was not confined to the KWPV, for an early, bronze socketed spear from a Ban Chiang burial dated to ca. 1025-935 BC has a lead isotope signature entirely consistent with copper mines 300 km distant at the Vilabouly Complex, in upland Laos, that are themselves now also dated ca. 1000 BC and later (Pryce et al. 2014). KWPV ore has now been documented in use in Myanmar also ca. 1000 BC (Pryce et al. 2018.).

The marked increase in the intensity of mortuary rituals seen with Bronze Age 1 at BNW rose to new heights with the Bronze Age 2 to 3A cemetery at the same time as copper production at NPW was in full swing. This is seen in the number, and the innovative form and decoration of ceramic vessels placed with the dead. Men, women and infants were now interred in very large graves wearing multiple exotic marine shell and marble ornaments. Fourteen of the 32 BA2 dead were accompanied by a deep-socketed, copper-base axe conforming to those cast at NPW (Higham 2011; also Rispoli et al. 2013: 126, Fig. 14). The lead isotope signatures for two BA2 axes and one chisel are highly consistent with the KWPV source, the most reliable cross-dating evidence between the two areas (Pryce 2014). Burial 178 at BNW, a young adult female of BA2, was interred with a socketed axe comprising 96.3 wt % copper that was most probably sourced in the KWPV. Interestingly, furnaces for melting copper at BNW were absent in these early Bronze Age levels. Like all sites, BNW was subject to disturbances from many sources, and it is not possible to be sure that every small artefact was found in situ. Crucible fragments at BNW, for example, were relatively scarce in early Bronze Age levels, such that we think it likely that they were redeposited as the site layers accumulated. Moreover, the remnant metal in all analysed crucibles was a tin-bronze (Cawte 2012). Therefore, we tend to the conclusion that the copper-base artefacts in the Bronze Age 2 burials were imported as finished artefacts, with the KWPV being the only source confidently identified at present (Pryce et al. 2014). This harmonises with the presence of shell bangle workshops identified in the KWPV vicinity, the most likely origin for the nearly one thousand tridacna and trochus shell bangles worn in profusion by those interred at BNW along with copper-base tools and ornaments (Ciarla et al. 2017).

Conclusions

The radiocarbon determinations for the KWPV sites harmonise with the revised chronologies for Non Nok Tha and Ban Chiang and the key chronology for the upper Mun Valley consumption sites of BNW and Ban Lum Khao (Higham et al. 2014, 2015; cf. White and Hamilton 2018:12-19, 32-40, 47, Table 2.3, 174-179). Furthermore, recent dates from north-central Myanmar (Pryce et al. 2018) and central and northern Laos (Pryce & Cadet 2018, Cadet et al. 2019) also provide radiometric Bronze Age transition dates of ca. 11/10th c. BC and are interlinked with LIA data to provide strong support for "short" chronology for the advent of copper/bronze metallurgy in the late 2nd millennium BC in MSEA. We have approached the challenge of dating disturbed industrial sites by employing KDE from samples of seeds and charcoal. In one series of results we have employed all samples, in the second, only the seed fraction has been analysed (Fig. 8) and in a third we have demonstrated the degree of modest overlap between NPW and NKH (Fig. 9). As might be expected, the series containing charcoal samples suggest that some determinations have been affected by inbuilt age. However, the results are consistent between the three sites.

Neolithic millet farmers settled at NPW before ca. 2000 BC, followed by an extended hiatus. Regional copper smelting began ca. 1100-1000 BC, perhaps by new arrivals with substantial though partial knowledge of metallurgy, with intensive copper smelting extending into the later 1st millennium BC. At NKH the single entity (seed-based) KDE model (Fig. 8) indicates that copper smelting began by ca. 900 BC, persisting at least until ca. 400 BC, providing evidence for some overlap with NPW (Fig. 9). At NML the two peaks at ca. 1500 and 1000 BC are held to reflect continuous occupation from the Neolithic into the Bronze Age and a degree of overlap with both NPW and NKH. The extension of activity into the early Iron Age at the three KWPV sites is strongly supported by the detailed evidence Rispoli et al. (2013) have cited for the entire classes of artefacts found in industrial and mortuary contexts. Thus, we have presented here a new and more chronologically precise overview of when and over what timeframe the three sites in the KWPV not only were occupied, but also began to form one of MSEA's major regional copper production centres; an important step in the further understanding of the archaeology of central Thailand and the archaeometallurgy of the greater region.

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