# A new chronological framework for prehistoric Southeast Asia, based on a Bayesian model from Ban Non Wat

Charles Higham[1] & Thomas Higham[2]

*The authors offer a new chronological framework for prehistoric Southeast Asia, based mainly on the Bayesian modelling of 75 radiocarbon dates from well-stratified excavations at Ban Non Wat. The results are revolutionary. Neolithic practice now begins in the second millennium and hierarchical state-forming activity is dated to a 'starburst' around 1000 BC. The authors reflect on the social implications of the new model – and on the criteria for an ever stronger chronology.*

*Keywords:* Southeast Asia, Thailand, Neolithic, Bronze Age, Iron Age, radiocarbon, Bayesian modelling

## Introduction

As Movius observed of the European Upper Palaeolithic, *'Without ... a* [chronological] *framework the over-all picture becomes confused and, in certain instances, almost meaningless. Time alone is the lens that can throw it into focus'* (Movius 1960: 355). The passage of time is equally vital for a proper understanding of the prehistoric sequence in Southeast Asia. While the cultural sequence is agreed by most scholars, its timing is not. The ancestors of the first rice farmers in Southeast Asia probably lived in the Yangtze Valley to the north (Liu *et al.* 2007), and spread south, via the coast and the major rivers, to enter the broad riverine plains of Southeast Asia. They brought their Austro-Asiatic languages, and a way of life that centred on settled village communities incorporating widespread exchange in exotica, a sophisticated ceramic industry, weaving, and a mortuary tradition that involved both extended inhumation and interment in lidded jars. This Neolithic settlement phase was followed by the adoption of copper-base metallurgy, in which copper and tin were alloyed from the earliest known contexts. The transition into the Iron Age has not been precisely dated, but it is known that early states were forming by the fourth to fifth centuries AD. The timing and the degree to which Iron Age communities developed social and technological sophistication prior to the rise of early states is poorly documented: Noen U-Loke is the only extensively-excavated Iron Age site in Thailand to be published (Higham, C.F.W. *et al.* 2007).

[1] *Department of Anthropology, University of Otago, PO Box 56, Dunedin, New Zealand*
[2] *Oxford Radiocarbon Accelerator Unit, Research Laboratory of Archaeology and the History of Art, Dyson Perrins Building, University of Oxford, OX1 3QY, UK*

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We do not know when the first farmers reached Southeast Asia and there remains a basic uncertainty over the date for the inception of copper-base metallurgy in Southeast Asia. This has generated a lack of understanding of the social changes that occurred with the early Bronze Age. As Muhly (1988: 16) stressed 20 years ago in a dictum still true, *'In all other corners of the Bronze Age world ... we find the introduction of bronze technology associated with a complex of social, political and economic developments that mark the rise of the state. Only in Southeast Asia ... do these developments seem to be missing.'* One of the objectives of our recent excavations at Ban Non Wat has been to open an area large enough to identify just those variables Muhly describes.

In retrospect, the causes of controversies over chronology are readily understood (Solheim 1968; 1970; Bayard 1972, 1979; Gorman & Charoenwongsa 1976; Bayard & Charoenwongsa 1983; Higham 1983; Loofs-Wissowa 1983). Radiocarbon determinations have virtually all been derived from charcoal, with its problems of 'old wood'. Only very rarely has the species of tree been specified, a practice that needs to be addressed in future dating programmes. No recognition was given to the unreliability of mixed samples (Ashmore 1999). In many cases, the relationship between a charcoal sample and the event being dated was unreliable. Major cultural changes, such as the beginning of copper-base metallurgy, have been dated on the basis of only a handful of determinations. When a sample of dates was available, the construction of the site's chronology followed procedures now shown to be importantly wrong (Bayliss *et al.* 2007: 9).

Resolving this situation first requires a prehistoric site with a cultural sequence spanning the early Neolithic to the end of the Iron Age. Such sites are very rare in Southeast Asia. Phases within such a site would need to be ordered in terms of a relative chronology, and we would then require a sufficient number of radiocarbon determinations, preferably generated on the basis of samples with no inbuilt age, to provide dates for the successive cultural phases identified. Armed with such a series of dates we could apply the refinement of the Bayesian approach as outlined by Bayliss *et al.* (2007). The Bayesian method is able to provide us with quantitative, probabilistic estimates of archaeological events through a combination of calibrated radiocarbon likelihoods and given archaeological information, for example, the sequence of phases within a site's sequence (see Buck *et al.* 1992, 1996; Bronk Ramsey 1995, 2005; Higham, T.F.G. *et al.* 2005, 2007; Bayliss & Whittle 2007; Fuller *et al.* 2007 for further details and examples). The model also generates boundaries and an assessment of the duration of phases, making it possible to consider the rate and impact of cultural changes. This paper presents the results of such a Bayesian analysis undertaken on the sequence at the prehistoric settlement of Ban Non Wat.

## Ban Non Wat

Ban Non Wat is a moated prehistoric site located in the upper catchment of the Mun River on the Khorat Plateau of Northeast Thailand (Figures 1 and 2). Its position gives easy communication and exchange by the Mun Valley to the Mekong River in the east. In a westerly direction, a pass following the watershed over the Petchabun Range takes one to the broad plains of the Chao Phraya River system, and the Khao Wong Prachan Valley, a major centre of prehistoric copper mining. Excavations at Ban Non Wat over



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*Figure 1. Map of Southeast Asia, showing the location of the sites mentioned in the text.*

seven seasons have uncovered an area of 892m$^2$, within which 637 human graves have been identified, together with much evidence for industrial and domestic activities including bronze casting (Figures 3 and 4). It is crucial to adopt the most stringent criteria for defining cultural contexts, since Thai settlement and cemetery sites are stratigraphically complicated by numerous pits, postholes and graves, not to mention bioturbation. We define a Neolithic context by mortuary or occupation remains with domestic animals or plants but no evidence



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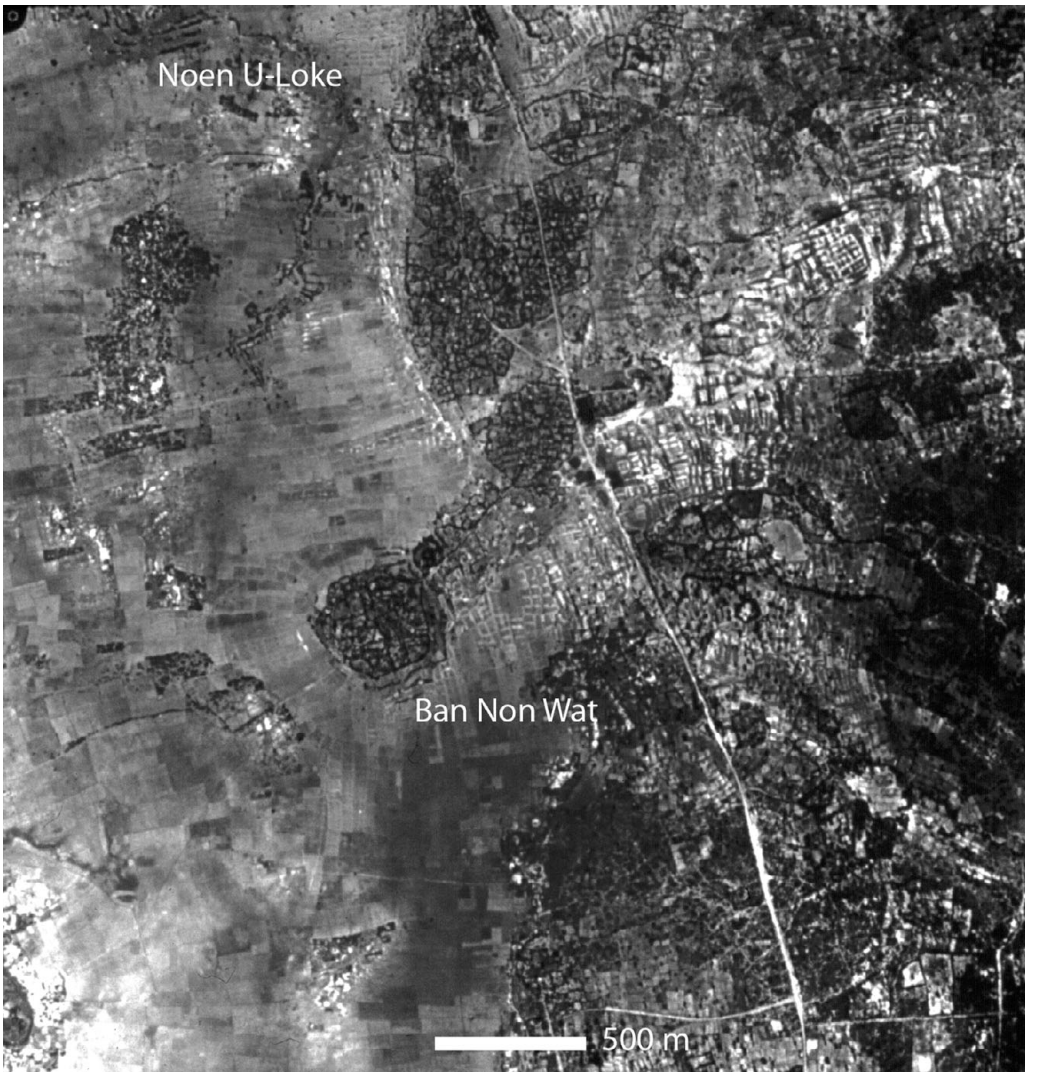


*Figure 2. The sites of Ban Non Wat and Noen U-Loke, viewed from the air.*

for metallurgy. We recognise a Bronze Age context on the basis of a burial with a copper-base artefact in direct association, a hearth associated with moulds and crucibles, or a burial containing crucibles or moulds as mortuary offerings. For the Iron Age, we accept the presence of iron or evidence for iron forging in secure contexts. Adopting these criteria, the cultural sequence falls into at least 12 phases, each characterised by different mortuary and occupational activity.

There were 13 flexed burials, characteristic of the indigenous Southeast Asian hunter-gatherers (Figure 5A) and the material items placed with these dead are quite distinct from those found with the assuredly Neolithic (Neo) 1 and 2 burials.



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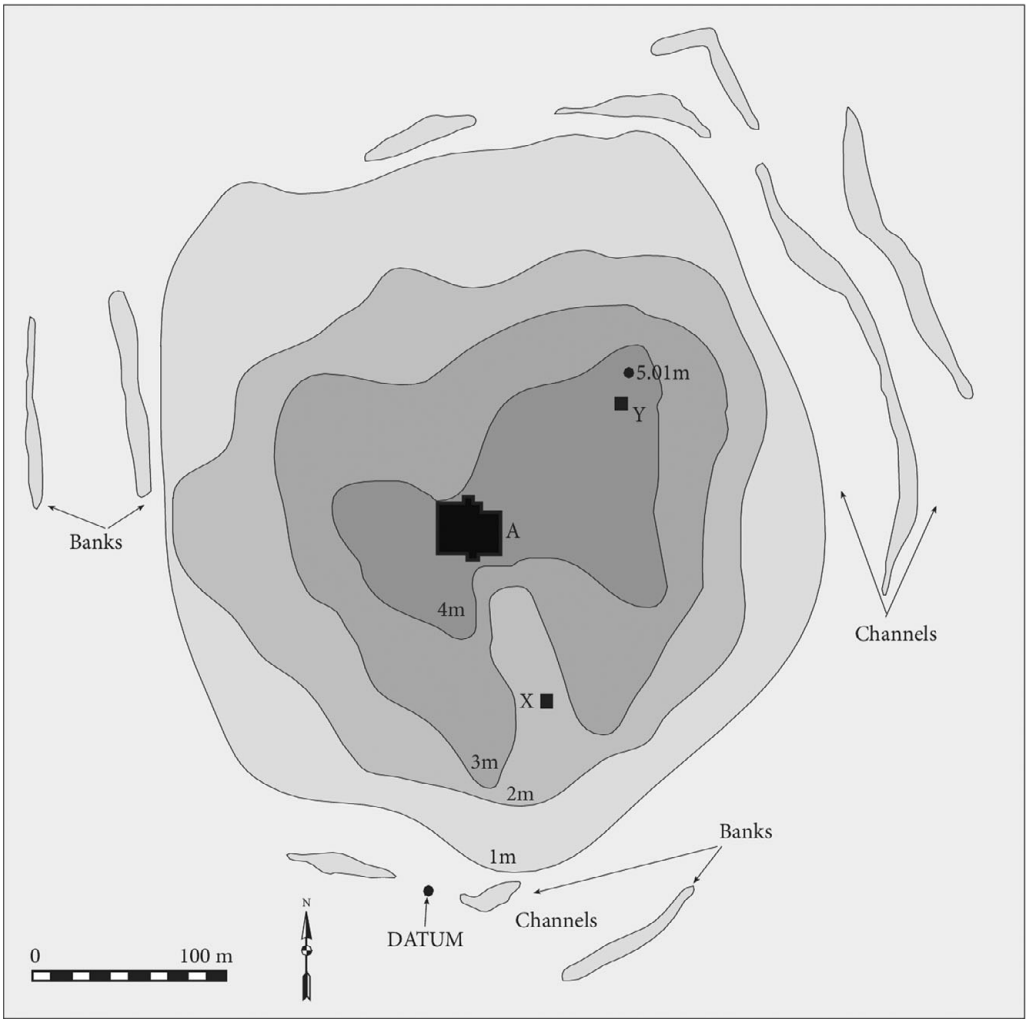


*Figure 3. Plan of the prehistoric site of Ban Non Wat, showing the areas excavated (A, Y and X).*

The Neolithic 1 cemetery contains extended supine inhumation graves and lidded jars for containing the corpse (Figure 5B). The ceramic vessels found in association fall into a widely-recognised tradition, involving decoration with complex incised designs (Higham 2004; Wiriyaromp 2007; Rispoli 2008). Other grave goods included marine shell ornaments, pig skeletons and freshwater bivalve shells. Neo 2 burials are normally found orientated on an east-west axis, and grave goods are markedly poorer than in Neo 1, comprising in the main, globular cord-marked vessels and the occasional freshwater bivalve shell (Figure 5C). When there is a superposition involving Neo 1 and 2, the latter are always later.

There are five Bronze Age (BA) phases at Ban Non Wat. BA 1 burials were accompanied by a series of small ceramic vessels that have their closest parallels in the late Neolithic graves at the nearby site of Ban Lum Khao. All five individuals were also interred with one copper base artefact (Figure 5D). BA 2 burials fall into four groups, each disposed in a row. The



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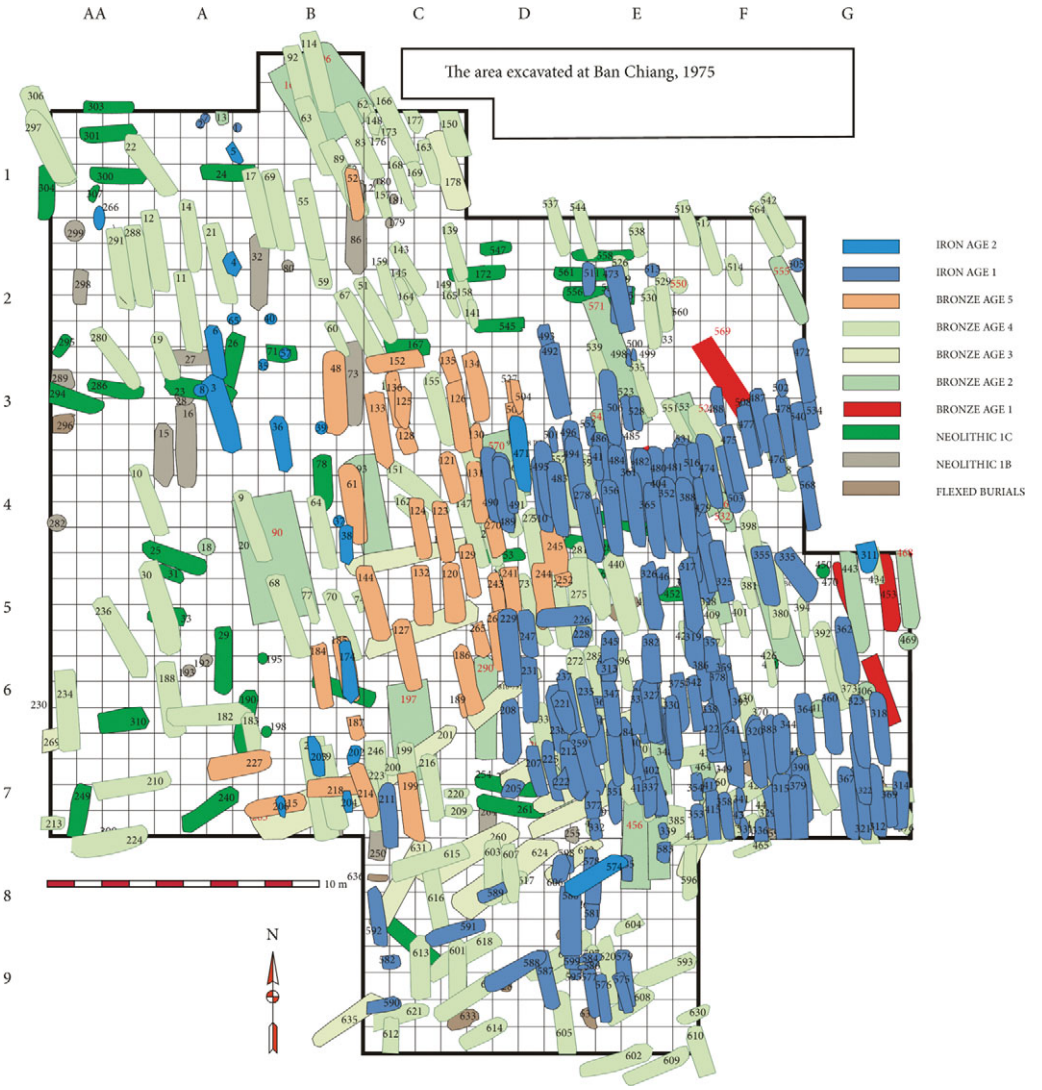


*Figure 4. The mortuary plan of Ban Non Wat.*

most southerly comprises nine or ten graves. There are seven graves in the second group, 10-11 graves in the third group and a double grave outlier in the far north of the excavated area. BA 2 graves are always stratigraphically later than those of Neo 2 and BA 1, and they display hitherto unrecognised mortuary wealth. The remains of three men and three women had been partially exhumed after interment, and then reburied. We think that this might well reflect their exceptionally high ritual and social status. Mortuary offerings included copper-base socketed axes, chisels and points, anklets and rings (Figure 5E). Up to 50 or 60 ceramic vessels were placed with the corpse, which was wrapped in a fabric shroud and contained within a wooden coffin. Some of these pots were decorated with elaborate painted designs, which harken back to those found on Neolithic 1 ceramics. One vessel, found with



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*Figure 5. Burials of the successive mortuary phases, to the same scale. Note the size of the Neolithic 1 and Bronze Age 2 and 3 graves. A) flexed burial 633; B Neolithic 1, burial 86; C) Neolithic 2, burial 562; D) Bronze Age 1, burial 569; E) Bronze Age 2, burial 197; F) Bronze Age 3, burial 263; G) Bronze Age 4, burial 549; H) Bronze Age 5, burial 126; I) Iron Age 1, burial 473.*

an infant, was painted with what looks like a stylised human face. The dead wore exotic shell and marble ornaments and shell beads over the body might have been stitched onto their clothing. Multiple strands of shell beads were worn as necklaces and belts, and some individuals wore up to 22 shell earrings. By any comparative measure, these individuals can be termed elite, even princely.

BA 3 incorporates 13 very rich burials, set out on a different orientation (Figure 5F). Where there is a superposition, they invariably seal BA 2 graves. Most individuals in this phase were buried on a north-east to south-west axis, wearing numerous marine shell and marble bangles, and associated with well-crafted ceramic vessels. Some people were also buried with socketed bronze axes, while one infant wore bronze anklets embellished with 30 bronze bells.

BA 4 involves many graves, set out in rows with the head usually orientated to the north-west. Where there is physical relativity to BA 1-3, they are always later. While the ceramic vessels are clearly derivative from earlier forms, they are generally smaller and lack painted designs. The burials are markedly poorer in terms of mortuary wealth, and bronzes are very rare. However, one man, surely a bronze founder, was buried with 29 clay bivalve moulds for casting bangles and axes (Figure 5G). These burials are always sealed by those of BA 5. The latter reveal further developments in the form of ceramic vessels. The dead during this phase were often accompanied by spindle whorls and grey clay that may well have been



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used in dying cloth. One BA 5 individual was accompanied by a crucible for casting bronze. On the basis of horizontal stratigraphy, BA 5 developed seamlessly into the early Iron Age (IA 1). Indeed, it is only on the basis of the presence of iron artefacts that on occasion one can distinguish the two, for the ceramic vessels are virtually identical. The Iron Age burials contain sets of iron tools; there are both iron and bimetallic (bronze hafts) spears, glass earrings, carnelian and agate ornaments and pots filled with fish skeletons (Figure 5I).

The few burials of the last prehistoric phase, IA 2, are distinguished by ceramics that include vessels of the so-called Phimai Black tradition. Their distribution lies mainly to the west of IA 1 burials, but where there is a superposition, they are always later. Exotic hard stone and glass ornaments are found but most of these burials are not far below the present ground surface, and are badly disturbed by more recent activity.

## Radiocarbon dating

Table 1 (see Appendix) shows the radiocarbon determinations for the cultural phases at Ban Non Wat. Further determinations for the surrounding Iron Age moats and embankments are also available but are not incorporated below (McGrath *et al.* 2007). Samples submitted from the first three seasons comprised charcoal and human bone from *in situ* contexts, and a handful of determinations were processed in Arizona on the basis of rice chaff found as a ceramic temper. However the human bone had no remaining collagen for dating and the charcoal samples were susceptible to the problem of 'old wood'. This was well illustrated by two samples from burial 28, a Neo 1 jar-burial. The first determination, based on charcoal within the vessel, gave 3680±30 BP, while the second based on a freshwater bivalve shell artefact found as a mortuary offering gave 3170±27 BP, a difference of 510 years.

Given our deep scepticism over the validity of a handful of dates from charcoal or organic temper in ceramics as a basis for determining the timing of cultural changes, we decided to base the dated sequence primarily on freshwater shell. Such shells were placed with the dead throughout the prehistoric occupation of Ban Non Wat, probably reflecting a high ritual or spiritual value. There are two genera: *Hyriopsis* and *Pseudodon*. These shells may have been valued as heirlooms and thus be antique when buried. However, this seems less likely than is the case for charcoal, and their association with specific individuals is held to be a more reliable index of date than charcoal derived from either grave fill or non-mortuary contexts. Given the ubiquity of well-provenanced freshwater bivalve shells within burial contexts at Ban Non Wat, we investigated their utility for direct AMS radiocarbon determinations. A modern individual collected live in 2006 from the vicinity of the site yielded a measurement of 106.8 ± 0.3 pMC. When compared with modern terrestrial post-nuclear bomb radiocarbon records and a charcoal standard regularly measured in the Oxford laboratory, the result is indistinguishable, suggesting there is no significant reservoir effect, at least in the modern era. Further comparisons between freshwater shell and well-provenanced charcoal from the same contexts yielded good agreement between the results (e.g. burial 290, Table 1). Again, the results are indistinguishable at 68.2%. Changes in the reservoir from which these shells originate could influence their utility as a chronometer, but in terms of comparison with the contemporary atmospheric $^{14}C$ levels at the time, this would only make the results older than their 'true age'. The absence of a limestone-based



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catchment within the hydrological system makes a hardwater effect unlikely. Taken together, our initial data suggests that freshwater shell ought to be reliable for dating, provided that no recrystallisation has occurred which could introduce exogenous carbon of a potentially younger or older age. This was carefully checked at ORAU prior to AMS dating. None of the shells showed any evidence for recrystallisation.

In practice, however, some charcoal specimens have been included in the dated sequence, especially from settlement contexts (see Table 1). Radiocarbon determinations for Neo 1 come from charcoal associated with occupation middens at the base of the site containing ceramic sherds matching those from Neo 1 burials. The Neo 1 burials are dated by charcoal found within lidded mortuary vessels and freshwater bivalve shells placed as mortuary offerings. Phase 3 Later Neolithic 1 occupation determinations come from charcoal in occupation contexts. As a check, we considered five determinations from the nearby site of Ban Lum Khao taken on charcoal found in the initial Neolithic occupation phase that underlie and thus predate the burials there that are virtually identical with Neo 2 graves at Ban Non Wat (Higham & Thosarat 2004a). Dating material from the Neo 2 burials themselves is difficult because the inclusion of freshwater bivalve shells became infrequent. The fifth phase is early Bronze Age occupation. These determinations come from *in situ* hearths located at the base of the square Y1, which underlie all subsequent Bronze Age graves in that area of the site. Phase 6 represents BA 1, and phase 7 incorporates the very rich BA 2 graves containing bronze artefacts. This is followed by phase 8 (BA 3). Phase 9 involves BA 4 graves and phases 10-12 are described as BA 5 and Iron Age (IA) 1-2.

## Bayesian analysis

The prior cultural information for the Bayesian analyis was inserted by dividing the dated graves and settlement features into 12 groups in sequence (Figure 6). We used OxCal 4.0 (Bronk Ramsey 1995) to calibrate the radiocarbon determinations, which were then modelled within these groups (Figure 7). Initial runs of the model disclosed some obvious outliers denoted by low agreement indices, variations which might, in part, be due to some of the issues raised earlier (principally inbuilt age and reservoir variability) but could also be influenced by statistical variation (statistically speaking, 5% of the dates would be expected to fail this test). In subsequent runs of the model, these were questioned in the sequence. The final iteration of the model produced acceptably high agreement indices, which act as a measure of the reliability and reproducibility of the model. Posterior probability distributions are shown in Figure 7, and ranges are listed in Table 1 at the 95.4% confidence interval. The model also showed the likely dates of the boundaries between the phases dominated by the cultural groups (Figure 8), and individual probability distributions were obtained for the span of each phase (Figure 9).

## Results

The date range for the Neolithic settlement of Thailand has in recent times variously been set anywhere from the fifth to the late third millennium BC, while the inception of the Bronze Age might fall in a range from the late third to the late second millennium BC



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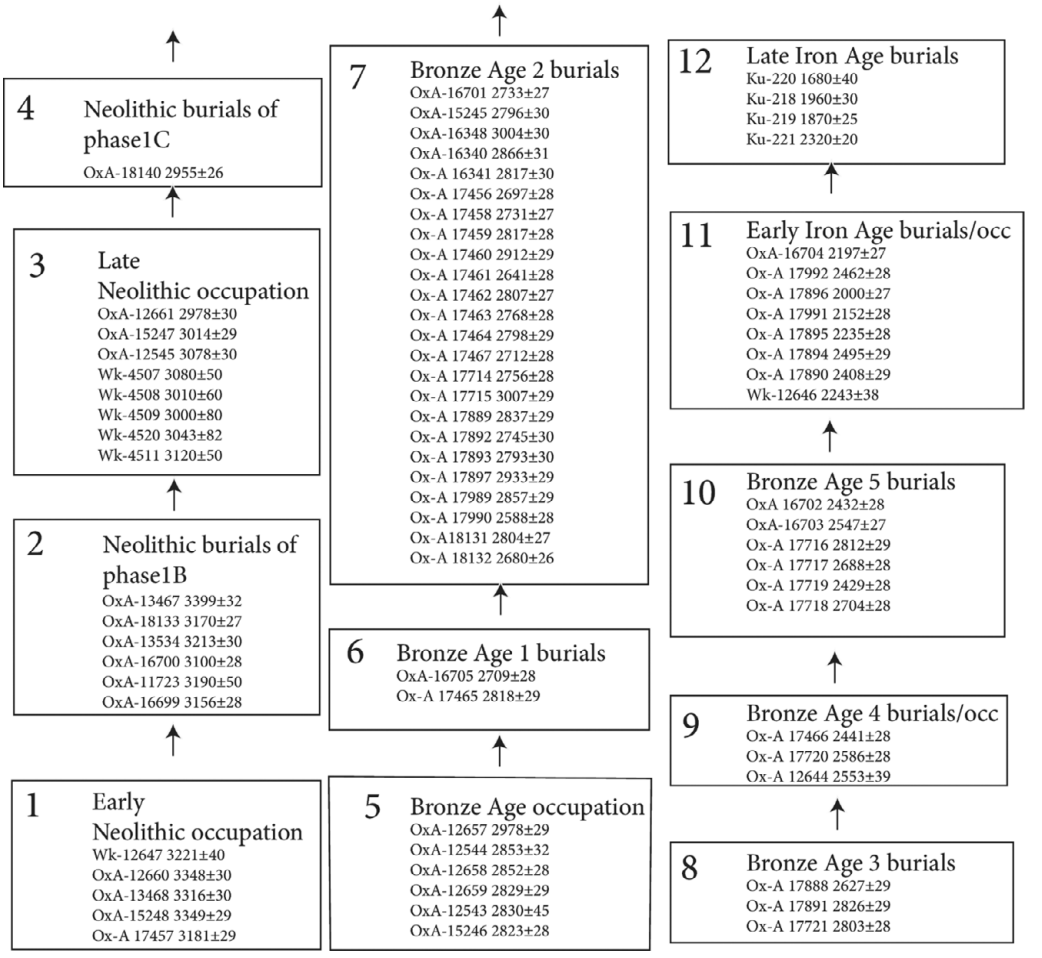


*Figure 6. Summary of the relative order of occupation and mortuary phases at Ban Non Wat.*

(Higham 1996; White & Pigott 1996; White 1997). The new data comprise 75 radiocarbon determinations for the cultural sequence at Ban Non Wat and five for the nearby settlement of Ban Lum Khao (Higham, T.F.G. 2004). Our results (Table 2) show that the flexed burials were among the earliest encountered, and lasted until the eleventh century BC. The initial Neolithic settlement of Ban Non Wat began in the mid-seventeenth century BC and lasted in the vicinity of 150 years, while the Neo 1 burials date from about 1460 cal BC, and lasted for two generations or about 50 years. The later Neolithic occupation is dated to about 1400 cal BC, with a very brief time span. This was followed by the Neo 2 burial, which is dated to 1259-1056 cal BC. The transition from the late Neolithic to the Early Bronze Age settlement took place between 1053-996 cal BC. At virtually the same time five BA 1 burials were laid out, followed very soon by four spatially discrete sets of outstandingly rich burials, three containing the graves of men, women, infants and children. The span for these burials lies between 135-185 years at 68.2% probability, so may represent six or seven generations. This is consistent with the number of burials and their disposition. BA



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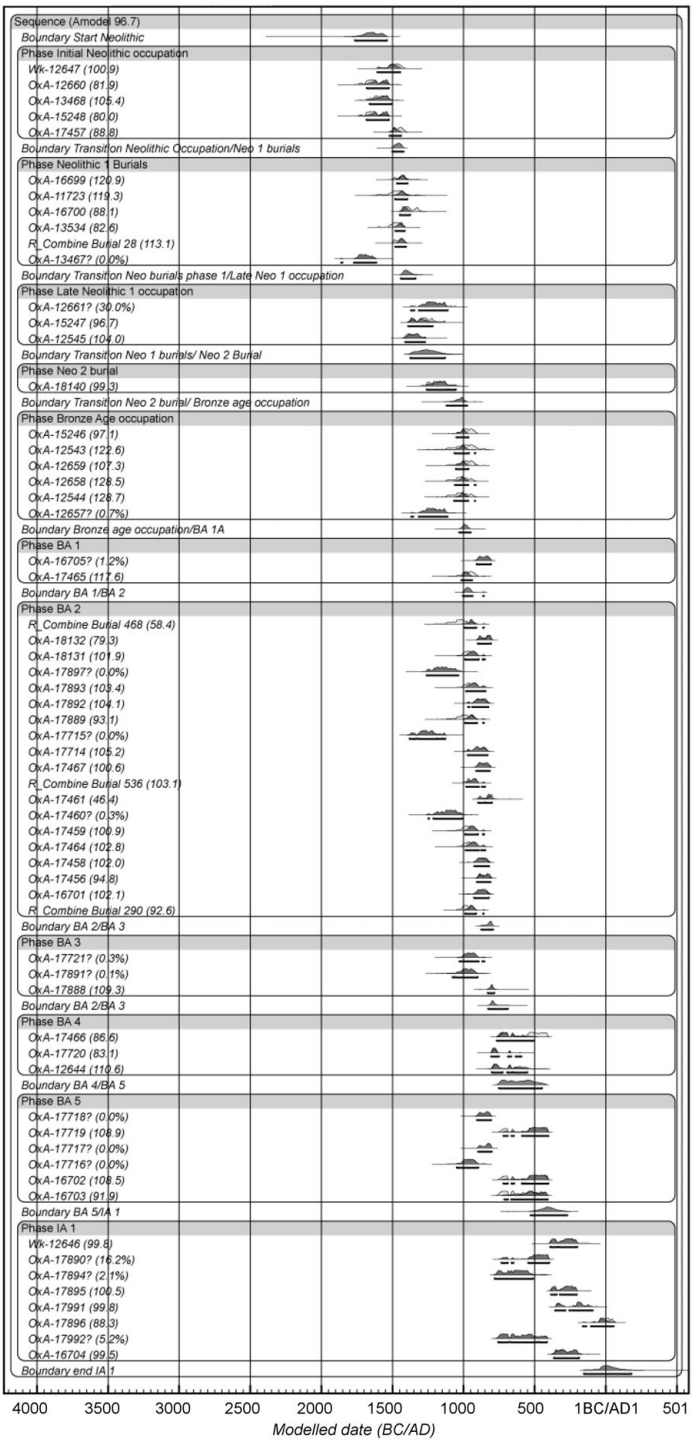


*Figure 7. Probability distributions of dates relating to the cultural sequence of Ban Non Wat (OxCal v4.0.5 Bronk Ramsey (2001); r:5 IntCal04 atmospheric curve (Reimer et al. 2004)).*



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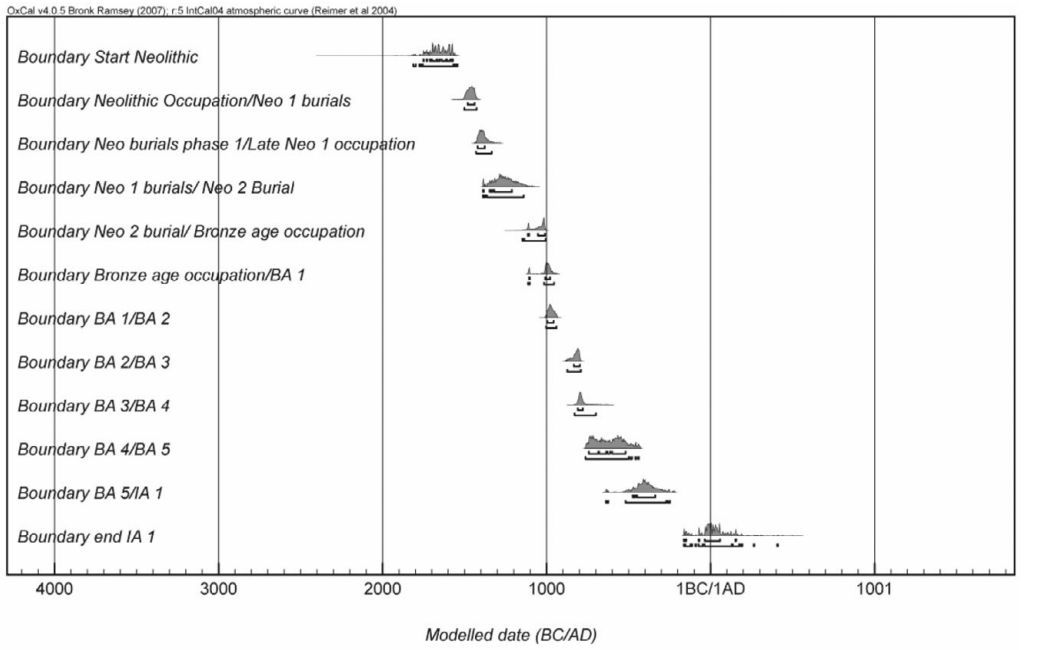


*Figure 8. The boundaries between the successive phases of occupation and mortuary activity at Ban Non Wat.*

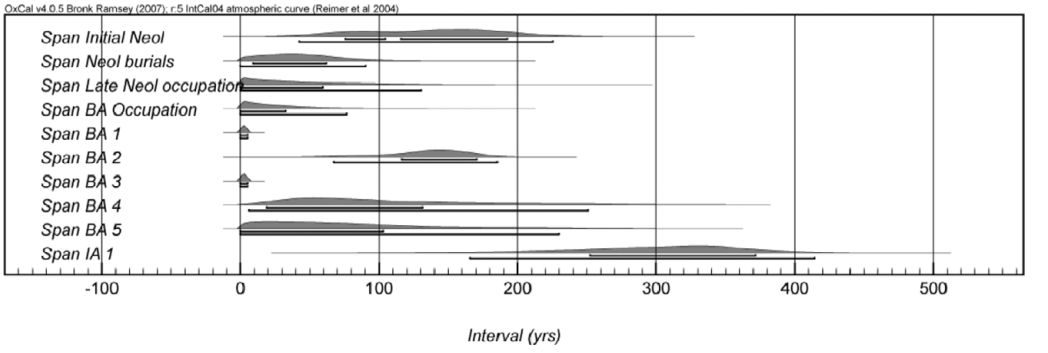


*Figure 9. The spans of the occupation and mortuary phases at Ban Non Wat.*

3 burials seal one group of BA 2 graves. Equally wealthy, this group is dated to the ninth century BC with a span of only a few years. Perhaps they were only one generation later than those they overlie.

The transition from BA 3 to BA 4 took place between 810-780 cal BC. Numerous BA 4 graves were laid out in long rows and were interred over a period of between 20-133 years. It is considered probable that the rows formed at the same period, perhaps reflecting a rise in the population. Individuals were distinctly poorer than their predecessors. Now only a handful of ceramic vessels were placed beyond the head and feet, and bronzes were rare almost to the point of being absent. However, local casting was undertaken, evidenced by one man interred with multiple sets of bivalve clay moulds for the casting of bangles and



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**Table 2. A summary of the prehistoric chronology for the upper Mun Valley, based on the radiocarbon determinations for Ban Non Wat, Ban Lum Khao and Noen U-Loke.**

| Cultural period | Date in calibrated radiocarbon years (BC) |
|---|---|
| Flexed burials | 1750-1050 |
| Neolithic 1 | 1650-1250 |
| Neolithic 2 | 1250-1050 |
| Bronze Age 1 | 1050-1000 |
| Bronze Age 2 | 1000-900 |
| Bronze Age 3 | 900-800 |
| Bronze Age 4 | 800-700 |
| Bronze Age 5 | 700-420 |
| Iron Age 1 | 420-100 |
| Iron Age 2 | 200-AD 200 |
| Iron Age 3 | AD 200-400 |
| Iron Age 4 | AD 300-500 |
| Early Historic | 500- |

socketed axes. Some individuals wore shell and marble bangles or beads, but never in the former abundance.

By the eighth century, we enter the region of the radiocarbon calibration curve known as the Hallstatt Plateau (Zaitseva *et al.* 2005). This has affected the establishment of a tight chronology for the BA 5 cemetery. The burials, while including ceramic vessels derived from BA 4 prototypes, present a new configuration. Graves were tightly grouped in rows and many contained spindle whorls that probably reflect specialist weavers. Again, no burial remotely matches the wealth of those found four centuries earlier during BA 2 and 3.

As one progresses eastward, some burials incorporated iron offerings, in the form of large spears, three at least being bimetallic with bronze hafts and iron blades. The *terminus post quem* for the Iron Age burials lies between 464-347 cal BC at 68.2% probability. There were sets of iron tools, and iron bangles. Some rare glass ornaments were encountered: earrings and beads. This horizontal stratigraphy with a merging between the late Bronze Age and the use of iron suggests that we have encountered the very beginnings of iron technology at this site, dated in the late fifth century BC. Graves were tightly packed in rows and superimposed in a palimpsest of skeletons. No individuals stood out on the basis of mortuary wealth or display. However, at the site of Noen U-Loke, only 3km distant, we identified a surge in mortuary wealth in the later Iron Age, a phase only poorly represented as yet at Ban Non Wat. It was probably during this slightly later juncture, that the water control measures in the form of banks and moats were constructed round these settlements. These were substantial engineering works that would have entailed much labour. Their construction implies a high degree of social control over resources.



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## Implications for social change

Excavations at the site of Ban Chiang in 1975 led to White's (1995) view of a heterarchic social organisation for Bronze Age Southeast Asia. However if we were to superimpose the area excavated there over any part of the mortuary plan for Ban Non Wat, we would find that in one area there was no evidence for Neolithic occupation and in another, no rich Bronze Age burials (Figure 4). In the west of the opening at Ban Non Wat, there would be no Iron Age burials and in the north no flexed interments. We feel that small sample sizes lie behind the dating anomalies, and accept that *'Explaining (or eliminating) this anomalous situation is one of the major challenges of archaeological and archaeometallurgical research during the next decade*' (Muhly 1988: 16).

If, for the moment at least, we accept that the chronological contexts at Ban Non Wat are the more representative, we find that the initial Neolithic settlement, by a highly sophisticated community, was considerably later than the fifth millennium BC as suggested by White on the basis of two radiocarbon determinations (White 1997: 103), and later than the third millennium BC contexts found as almost standard in the literature. Most significantly, we have found that the Bronze Age began as a brief starburst of social display in about 1000 BC, a millennium later than has been suggested by White and Pigott (1996) and Bacus (2006). With the later Bronze and early Iron Ages, the dense packing of graves is compatible with a longer duration, perhaps reflecting a sharp rise in the population of Ban Non Wat. The site was now the focus of iron forging, bronze casting, weaving and pottery manufacture. It was also a period when salt was processed on a large scale, and when social friction was on the rise, seen in the production of iron weaponry, and the construction of defensive banks and moats round settlements sometimes uncomfortably close to each other. One young man at Noen U-Loke was killed when an iron arrowhead severed his spine (Higham, C.F.W. *et al.* 2007: 227). These are all factors that underlie the rapid crystallisation of early Southeast Asian states in the fourth and fifth centuries AD.

Acceptance of this dated cultural sequence means viewing Southeast Asian prehistory in a new light. Until the eighteenth century BC, the uplands and inland plains were occupied by small groups of hunter-gatherers, while the rich coastal estuaries attracted settlement that was probably of a more sedentary nature (Higham & Thosarat 1998). This extensive area then witnessed the intrusion of fully-fledged Neolithic groups bringing with them their domestic rice, millet and domestic stock. These people can be traced in terms of their material culture, north into Lingnan and ultimately, the valley of the Yangtze River. Possibly at Ban Non Wat, and assuredly at the site of Khok Phanom Di, we can identify cultural contacts between hunter-gatherers and farmers (Higham & Thosarat 2004b; Bentley *et al.* 2007). Exchange networks rapidly formed, bringing marine shell and exotic stone to inland communities. It may well have been through such networking, that during the late eleventh and tenth centuries, copper and tin smelting and trade in finished bronzes, or metal in ingot form, were established. At this point, social display in mortuary contexts rapidly entered a new and impressive phase. This was not confined to one or two individuals in a group, nor was it restricted to members of one sex. Rather, we find mortuary lobes in which men, women, infants and children were equally endowed with wealth objects. Whereas at Ban Non Wat, all burials of this period were wealthy, contemporary graves at nearby Ban Lum Khao, while

containing virtually identical early ceramic vessels, were starkly poorer, without a single bronze grave good being encountered (Higham & O'Reilly 2004). Identifying a similarly poor BA1-2 lobe of the Ban Non Wat cemetery would suggest a markedly hierarchic social order there.

However, after a handful of generations, the degree of wealth at Ban Non Wat declined sharply. Only in the latter stages of the Iron Age, just on the cusp of state formation, did mortuary wealth rival the level attained in the Early Bronze Age. White (1995: 101) commenting on the late development of states in Southeast Asia, wrote that *'This lateness seems striking, as prehistoric archaeology has demonstrated the long term presence of two technological and economic factors considered important in state formation elsewhere: i) cultivation since the fourth millennium BC of a cereal (rice), ... and ii) specialized production of copper-base metals dating at least from the first half of the second millennium BC.'*

The chronological framework for Ban Non Wat provides a stark contrast. It implies that in little over two millennia, a series of cultural developments that began with pioneer rice farmers, ended with the early foundations of the Kingdom of Angkor. The sequence at Ban Non Wat when linked with that of Noen U-Loke suggests that there were at least two periods of hierarchic social development during the Early Bronze and the later Iron Age, and a much more rapid development of indigenous states than has previously been suggested.

## Conclusion

With the development of Bayesian statistical analyses of large samples of provenanced radiocarbon determinations, we have entered a new phase in the appropriate employment of the radiocarbon dating technique. We have identified and dated a cultural sequence that radically shortens the duration of the prehistoric period from the initial settlement of farmers to the foundation of early states. Hence, a vibrant, innovative and constantly changing cultural pattern appears in place of five somnolent millennia. In our view, the number of samples on which previous interpretations are based is insufficient, and their correspondence with the events being dated is often questionable. We conclude that problems associated with inbuilt age, mixed samples, the unreliability of results from organic ceramic tempers, insufficient determinations and methods of interpretation now shown to be importantly wrong, require the rejection of all previous attempts to date Southeast Asian prehistory radiometrically. While this might seem radical and drastic, we feel that in establishing a firmer chronological foundation, we offer a stronger model for future testing. We are well aware that in doing so, the chronological framework for Ban Non Wat is unlikely to incorporate the earliest regional evidence for Neolithic, Bronze or Iron Age periods, but demonstrating this will require many dates from assured contexts, in which prior knowledge permits the application of the Bayesian method. These will necessarily entail periods of long, dedicated and intensive fieldwork.

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**Appendix: Table 1. The radiocarbon determinations for Ban Non Wat.**

| Laboratory code | Sample | $\delta^{13}C$(‰) | Radiocarbon age (BP) | Calibrated age range (95.4% confidence) | *Posterior probability distribution (95.4% probability)* |
|---|---|---|---|---|---|
| Period 1. Flexed burials | | | | | |
| OxA-18141 | Burial 454, bivalve shell | −4.61 | 3362 ± 27 | 1741-1537 cal BC | |
| OxA-18142 | Burial 461, bivalve shell | −5.12 | 3204 ± 27 | 1521-1423 cal BC | |
| OxA-15942 | Burial 438, bivalve shell | −5.00 | 2948 ± 29 | 1262-1055 cal BC | |
| Boundary, initial Neolithic occupation *1814-1544 cal BC* | | | | | |
| Initial Neolithic occupation | | | | | |
| Wk-12647 | B3 layer 4:9 feature 1, charcoal from Neolithic hearth | −27.2 | 3221 ± 40 | 1608-1418 cal BC | *1606-1446 cal BC* |
| OxA-12660 | B2 4a:8 feature 35, charcoal from Neolithic shell midden | −25.6 | 3348 ± 30 | 1734-1531 cal BC | *1685-1526 cal BC* |
| OxA-13468 | C1 4:15 feature 1, charcoal from Neolithic shell midden | −27.3 | 3316 ± 30 | 1682-1521 cal BC | *1661-1517 cal BC* |
| OxA-15248 | AA1 5:3, charcoal from Neolithic shell midden | −26.5 | 3349 ± 29 | 1735-1531 cal BC | *1688-1525 cal BC* |
| OxA-17457 | E2 5:2 feature 1, charcoal | −4.5 | 3181 ± 29 | 1505-1409 cal BC | *1522-1440 cal BC* |
| Boundary transition, Neolithic occupation to Neolithic 1 burials *1502-1428 cal BC* | | | | | |
| Neolithic 1 burials | | | | | |
| OxA-11722 | Burial 28, charcoal | −24.3 | 3680 ± 45 | 2150-1935 cal BC | *1489-1402 cal BC* |
| OxA-18133 | Burial 28, bivalve shell | −6.10 | 3170 ± 27 | 1499-1407 cal BC | |
| OxA-13467 | Burial 179, charcoal | −26.2 | 3399 ± 32 | 1862-1616 cal BC | *1866-1609 cal BC* |
| OxA-13534 | Burial 195, charcoal within infant jar burial | −25.7 | 3213 ± 30 | 1598-1419 cal BC | *1487-1415 cal BC* |
| OxA-16700 | Burial 86, bivalve shell *Pseudodon* | −6.74 | 3100 ± 28 | 1434-1304 cal BC | *1442-1377 cal BC* |
| OxA-11723 | Burial 32, charcoal within mortuary vessel | −28.7 | 3190 ± 55 | 1611-1321 cal BC | *1481-1391 cal BC* |
| OxA-16699 | Burial 32, bivalve shell | −5.5 | 3156 ± 28 | 1497-1392 cal BC | *1472-1394 cal BC* |
| Boundary transition, Neolithic 1 burials to late Neolithic occupation *1430-1345 cal BC* | | | | | |
| Later Neolithic occupation | | | | | |
| OxA-12661 | B4 5:1 feature 4, charcoal from a hearth | −25.9 | 2978 ± 30 | 1371-1114 cal BC | *1372-1059 cal BC* |
| OxA-15247 | D5 4:11 to 5:1, charcoal from late Neolithic pit | −27.6 | 3014 ± 29 | 1386-1132 cal BC | *1391-1217 cal BC* |
| OxA-12545 | B2 4A:5 feature 34, late Neolithic charcoal | −24.8 | 3078 ± 30 | 1419-1268 cal BC | *1407-1273 cal BC* |
| Late Neolithic occupation at Ban Lum Khao | | | | | |
| Wk-4507 | B1:B 3:3 pit 1, charcoal | −26.9 | 3080 ± 50 | 1435-1209 cal BC | |
| WK-4508 | A1:C 3:2, charcoal | −27.0 | 3010 ± 60 | 1394-1068 cal BC | |
| Wk-4509 | A1:C3:2 feat. 1, charcoal | −25.7 | 3000 ± 80 | 1410-1019 cal BC | |
| Wk-4510 | B1:A3 surf. 3 pit 1, charcoal | −26.1 | 3043 ± 82 | 1449-1019 cal BC | |
| Wk-4511 | A1:A surf. 3 lens 1, charcoal | −25.9 | 3120 ± 50 | 1461-1255 cal BC | |
| Boundary transition, Neolithic 1 to Neolithic 2 burials *1389-1139 cal BC* | | | | | |
| Neolithic 2 burial | | | | | |
| OxA-18140 | Burial 31, bivalve shell | −2.89 | 2955 ± 26 | 1266-1055 cal BC | *1263-1056 cal BC* |



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**Appendix: Table 1. Continued**

| Laboratory code | Sample | $\delta^{13}$C(‰) | Radiocarbon age (BP) | Calibrated age range (95.4% confidence) | *Posterior probability distribution (95.4% probability)* |
|---|---|---|---|---|---|
| Boundary transition, Neolithic 2 burial to Bronze Age initial occupation *1147-1006 cal BC* | | | | | |
| Early Bronze Age occupation | | | | | |
| OxA-12657 | Y1 9:2 feature 5, charcoal | −26.4 | 2978 ± 29 | 1370-1115 cal BC | *1310-1120 cal BC* |
| OxA-12544 | Y1 9:2 feature 1, charcoal | −24.3 | 2853 ± 32 | 1121-924 cal BC | *1116-974 cal BC* |
| OxA-12658 | Y1 8:4 feature 2, charcoal | −26.3 | 2852 ± 28 | 1117-927 cal BC | *1116-976 cal BC* |
| OxA-12659 | Y1 8:4 feature 3, charcoal | −26.9 | 2829 ± 29 | 1108-905 cal BC | *1116-979 cal BC* |
| OxA-12543 | Y1 8:4 feature 1, charcoal | −25.0 | 2830 ± 45 | 1127-850 cal BC | *1118-973 cal BC* |
| OxA-15246 | AA5 4:7 feature 4, charcoal | −25.6 | 2823 ± 28 | 1052-904 cal BC | *1116-972 cal BC* |
| Boundary transition, Bronze Age occupation to Bronze Age 1 burials *1114-955 cal BC* | | | | | |
| Bronze Age 1 burials | | | | | |
| OxA-16705 | Burial 446, bivalve shell | −4.0 | 2709 ± 28 | 907-809 BC | *909-811 cal BC* |
| OxA-17465 | Burial 569, bivalve shell | −7.1 | 2818 ± 29 | 1051-901 cal BC | *1039-938 cal BC* |
| Boundary transition, Bronze Age 1 to Bronze Age 2 burials *1003-940 BC* | | | | | |
| Bronze Age 2 burials | | | | | |
| OxA-16340 | Burial 290, bivalve shell | −7.80 | 2866 ± 31 | 1130-926 cal BC | |
| OxA-16341 | Burial 290, bivalve shell | −7.40 | 2817 ± 30 | 1056-896 cal BC | *988-916 cal BC* |
| OxA-15245 | Burial 290, charcoal adhering to a femur | −25.4 | 2796 ± 30 | 1020-890 cal BC | |
| OxA-16701 | Burial 90, bivalve shell | −7.50 | 2733 ± 27 | 926-816 cal BC | *930-827 cal BC* |
| OxA-17456 | Burial 571, bivalve shell | −11.3 | 2697 ± 28 | 902-806 cal BC | *906-813 cal BC* |
| OxA-17458 | Burial 550, bivalve shell | −8.10 | 2731 ± 27 | 925-815 cal BC | *925-823 cal BC* |
| OxA-17459 | Burial 555, bivalve shell | −9.4 | 2817 ± 28 | 1047-904 cal BC | *1004-844 cal BC* |
| OxA-17460 | Burial 522, bivalve shell | −8.8 | 2912 ± 29 | 1248-1010 cal BC | *1248-1010 cal BC* |
| OxA-17461 | Burial 532, bivalve shell | −6.8 | 2641 ± 28 | 889-785 cal BC | *897-801 cal BC* |
| OxA-17462 | Burial 536, bivalve shell | −7.4 | 2807 ± 27 | 1041-898 cal BC | *991-843 cal BC* |
| OxA-17463 | Burial 536, bivalve shell | −7.0 | 2768 ± 28 | 997-837 cal BC | |
| OxA-17464 | Burial 543, bivalve shell | −8.3 | 2798 ± 29 | 1021-846 cal BC | *997-846 cal BC* |
| OxA-17465 | Burial 569, bivalve shell | −7.1 | 2818 ± 29 | 1051-901 cal BC | *1004-844 cal BC* |
| OxA-17467 | Burial 570, bivalve shell | −10.7 | 2712 ± 28 | 909-810 cal BC | *911-816 cal BC* |
| OxA-17714 | Burial 105, bivalve shell | −7.7 | 2756 ± 28 | 976-828 cal BC | *975-831 cal BC* |
| OxA-17715 | Burial 106, bivalve shell | −8.2 | 3007 ± 29 | 1380-1130 cal BC | *1380-1130 cal BC* |
| OxA-17889 | Burial 197, bivalve shell | −8.7 | 2837 ± 29 | 1112-914 cal BC | *1006-908 cal BC* |
| OxA-17892 | Burial 293, bivalve shell | −6.7 | 2745 ± 30 | 975-818 cal BC | *973-825 cal BC* |
| OxA-17893 | Burial 302, bivalve shell | −7.9 | 2793 ± 30 | 1014-845 cal BC | *998-842 cal BC* |
| OxA-17897 | Burial 458, bivalve shell | −7.2 | 2933 ± 29 | 1261-1029 cal BC | *1260-1041 cal BC* |
| OxA-17989 | Burial 468, bivalve shell | −7.4 | 2857 ± 29 | 1122-929 cal BC | *1007-912 cal BC* |
| OxA-17990 | Burial 468, bivalve shell | −7.4 | 2588 ± 28 | 815-601 cal BC | |
| OxA-18131 | Burial 455, bivalve shell | −7.23 | 2804 ± 27 | 1040-860 cal BC | *1000-846 cal BC* |
| OxA-18132 | Burial 456, bivalve shell | −10.98 | 2680 ± 26 | 896-802 cal BC | *898-810 cal BC* |
| Boundary transition, Bronze Age 2 to Bronze Age 3 burials *874-793 cal BC* | | | | | |
| Bronze Age 3 burials | | | | | |
| OxA-17888 | Burial 196, bivalve shell | −6.00 | 2627 ± 29 | 835-774 cal BC | *831-787 cal BC* |
| OxA-17891 | Burial 263, bivalve shell | −6.00 | 2826 ± 29 | 1073-902 cal BC | *1067-906 cal BC* |
| OxA-17721 | Burial 154, bivalve shell | −5.60 | 2803 ± 28 | 1039-855 cal BC | *1041-845 cal BC* |



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**Appendix: Table 1. Continued**

| Laboratory code | Sample | $\delta^{13}C$(‰) | Radiocarbon age (BP) | Calibrated age range (95.4% confidence) | *Posterior probability distribution (95.4% probability)* |
|---|---|---|---|---|---|
| Boundary transition, Bronze Age 3 to Bronze Age 4 burials *830-701 cal BC* | | | | | |
| Bronze Age 4 burials and occupation | | | | | |
| OxA-17466 | Burial 564, bivalve shell | −8.00 | 2441 ± 28 | 752-407 cal BC | *769-502 cal BC* |
| OxA-17720 | Burial 145, bivalve shell | −7.90 | 2586 ± 28 | 814-599 cal BC | *806-596 cal BC* |
| OxA-12644 | Y1 7:7 feature 1, charcoal | −25.5 | 2553 ± 39 | 807-5542 cal BC | *803-550 cal BC* |
| Boundary transition, Bronze Age 4 to Bronze Age 5 burials *764-439 cal BC* | | | | | |
| Bronze Age 5 burials | | | | | |
| OxA-16703 | Burial 241, bivalve shell | −4.70 | 2457 ± 27 | 754-413 cal BC | *720-410 cal BC* |
| OxA-16702 | Burial 241, bivalve shell | −4.70 | 2432 ± 28 | 750-404 cal BC | *717-406 cal BC* |
| OxA-17716 | Burial 124,bivalve shell | −8.10 | 2812 ± 29 | 1048-899 cal BC | *1048-901 cal BC* |
| OxA-17717 | Burial 126, bivalve shell | −6.8 | 2688 ± 28 | 898-804 cal BC | *901-802 cal BC* |
| Ox-A-17718 | Burial 133, bivalve shell | −6.60 | 2704 ± 28 | 906-807 cal BC | *906-810 cal BC* |
| OxA-17719 | Burial 135, bivalve shell | −2.7 | 2429 ± 28 | 749-403 cal BC | *720-407 cal BC* |
| Boundary transition, Bronze Age 5 to Iron Age 1 burials *639-249 cal BC* | | | | | |
| Iron Age 1 burials and occupation | | | | | |
| OxA-16704 | Burial 360, bivalve shell | −6.0 | 2197 ± 27 | 370-189 cal BC | *361-180 cal BC* |
| OxA-17992 | Burial 476, bivalve shell | −6.2 | 2462 ± 28 | 756-415 cal BC | *757-414 cal BC* |
| OxA-17896 | Burial 386, bivalve shell | −3.4 | 2000 ± 27 | 51 BC- cal AD 66 | *167 AD-54 cal BC* |
| OxA-17991 | Burial 473, bivalve shell | −7.4 | 2152 ± 28 | 356-93 cal BC | *356-96 cal BC* |
| Ox-A 17895 | Burial 383, bivalve shell | −4.2 | 2235 ± 28 | 388-206 cal BC | *382-202 cal BC* |
| OxA-17894 | Burial 341, bivalve shell | −1.7 | 2495 ± 29 | 782-512 cal BC | *775-516 cal BC* |
| OxA-17890 | Burial 237, bivalve shell | −6.2 | 2408 ± 29 | 734-399 cal BC | *734-400 cal BC* |
| Wk-12646 | Y2 5:5 f. 3, charcoal | −25.4 | 2243 ± 38 | 393-204 cal BC | *388-203 cal BC* |
| Boundary transition, end Iron Age 1 burials *411 cal BC-AD 164* | | | | | |
| Iron Age 2 burials | | | | | |
| Ku-221 | Burial 100, rice chaff temper | −23.8 | 2320 ± 3 | 410-230 cal BC | |
| Ku-218 | Burial 102, rice chaff temper | −24.7 | 1960 ± 30 | 40 BC-cal AD 120 | |
| Ku-219 | Burial 102, rice chaff temper | −24.0 | 1870 ± 25 | 80-220 AD | |
| Ku-220 | Burial 95, rice chaff temper | −17.5 | 1680 ± 40 | 250-430 AD | |



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