Changing social inequality from first farmers to early states in Southeast Asia

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When the first rice farmers expanded into Southeast Asia from the north about 4,000 y ago, they interacted with hunter-gatherer communities with an ancestry in the region of at least 50 millennia. Rigorously dated prehistoric sites in the upper Mun Valley of Northeast Thailand have revealed a 12-phase sequence beginning with the first farmers followed by the adoption of bronze and then iron metallurgy leading on to the rise of early states. On the basis of the burial rituals involving interment with a wide range of mortuary offerings and associated practices, we identify, by computing the values of the Gini coefficient, at least two periods of intensified social inequality. The first occurred during the initial Bronze Age that, we suggest, reflected restricted elite ownership of exotic valuables within an exchange choke point. The second occurred during the later Iron Age when increased aridity stimulated an agricultural revolution that rapidly led to the first state societies in mainland Southeast Asia.

Gini coefficient | wealth inequality | climate change | burial rituals | rice farming

The calculation of Gini coefficients (GCs) has identified a marked increase in social inequality in Western Eurasia related to a transition from labor-limited to land-limited economies (1). Related projects have provided similar insights by comparing post-Neolithic Western Eurasia to North and Mesoamerica (2). Here, we identify similar changes over a period of 2,500 y in the Upper Mun Valley of Northeast Thailand. This cultural sequence has the very rare advantage of being dated by multiple radiocarbon determinations, each refined through Bayesian analysis such that in some instances, cultural changes can be identified on a generational basis. Derived from four sites, there are 12 phases (Fig. 1). Neolithic 1 represents the initial settlement by incoming rice farmers in the 18th century BC, found at the key site of Ban Non Wat (3). Neolithic 2 began in ca. 1250 BC and ended with the first of five Bronze Age (BA) phases: BA 1, 1050 to 1000 BC (4); BA 2, 1000 to 900 BC; BA 3, 900 to 800 BC; BA 4, 800 to 700 BC; and BA 5, 700 to 420 BC. The four Iron Age (IA) phases ended with the transition into regional states in the sixth through seventh centuries AD (5, 6) and are dated IA 1, 420 to 100 BC; IA 2, 200 BC to AD 200; IA 3, AD 200 to 400; and IA 4, AD 300 to 500. The final phase dates from AD 500 and is described as the early historic period when early states were forming. All phases have provided human burials, the mortuary rituals being the data we deploy in order to assess social inequality. These mortuary data are unique in Southeast Asia. There are 540 intact adult human burials, a great variety in the quality and quantity of grave goods, recovered from constantly evolving approaches to the layout of the interments. We find dispersed graves, nucleated groups of burials, and residential burials cut through house floors. For vital periods of this sequence, there is also an unrivalled database of environmental evidence and details of the agricultural regimes.

The Upper Mun River region controls the east–west passage across the Petchabun Range, linking the Central Plain and coast with the elevated Khorat Plateau (*SI Appendix*, Fig. S1). Occupants not only had privileged access to exotic goods but also commanded rich salt deposits. Throughout the period covered, a changing catalog of desirable rarities sourced west of the Petchabun pass were incorporated into mortuary rituals. Marine shell came in the form of cowries, beads, bangles, and earrings. Marble was worn as earrings and bangles. Copper from mines in the Khao Wong Prachan valley has been identified in the earliest BA graves (7). With the opening of maritime trade routes in the later first millennium BC, marble and shell gave way to bronze, agate, carnelian, glass, gold, and silver ornaments as well as the introduction of iron technology. To the east, the Mun River was a natural conduit for the rich copper output from Vilabouly in upland Laos.

The first farmers settled the upper Mun Valley in the 18th century BC, bringing with them domestic rice, pigs, and cattle. Through archaeobotanical investigations looking at macroremains in two of these sites, evidence of rice and associated weed species allowed us to reconstruct farming systems dating from the transitional Neolithic through BA period to the Late IA. Rice cultivated in rain-fed fields was a component of the subsistence base until a sharp deterioration in the strength of monsoon rains from ca. AD 200. The ensuing period of relative aridity then stimulated an agricultural revolution, documented in the construction of moat reservoirs that fed irrigated, wet rice fields, plowing in place of hoe cultivation, interment of the dead in rice-filled graves accompanied by iron sickles, and a surge in infant mortality that probably reflects environmental degradation involving the spread of malaria and other aquatic pathogens.

We estimate the GCs for each of the 12 phases, implementing recently developed statistical methods (8) to tackle issues of comparability and precisions of estimates computed across different sample and population sizes and units of wealth ownership. These methods allow us to enrich the understanding of

Significance

This is an exploration of social change, measured by means of the Gini coefficient, that has been applied to a 2,500-y cultural sequence in Southeast Asia. The results indicate pulses of elevated social inequality from different stimuli, some transient but the last, due to an agricultural revolution consequent to climate change, enduring.

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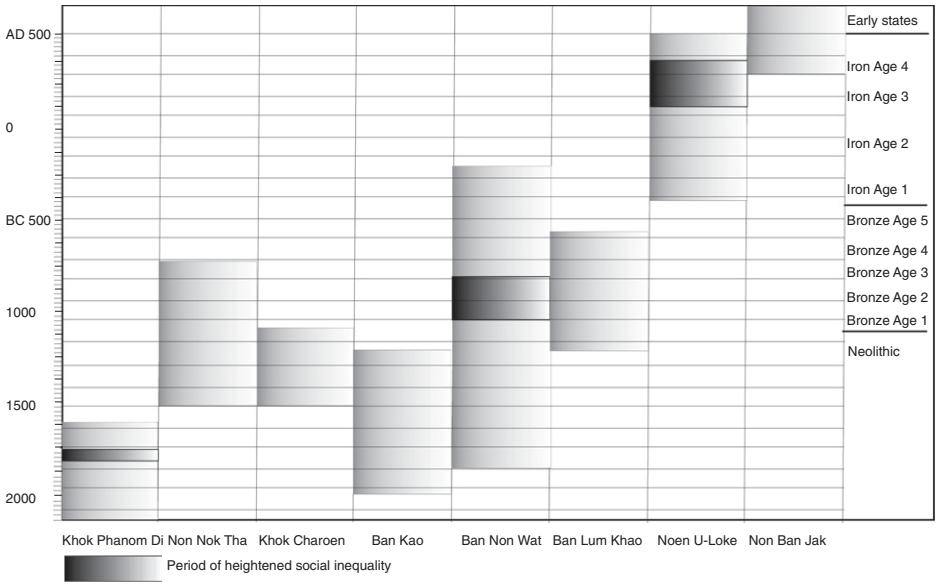

Fig. 1. The chronological relationships between the sites under discussion, showing the pulses of increased social inequality.

the ancient Northeast Thailand cultures by providing an unprecedented quantitative assessment of the changes of social inequality in the region across 2,500 y. In particular, the GCs permit us to quantify precisely the link between the aforementioned changes in environmental conditions and farming systems and the increase of wealth inequality. In addition, we show that these quantitatively assessed patterns of inequality resemble those found by other projects in Western Eurasia (1) and might constitute a methodological and substantive basis for future contributions on ancient global social inequality.

The Sites

Ban Non Wat is a moated settlement with the longest sequence in Southeast Asia that covers the initial Neolithic to the end of the IA. The Neolithic 1 and 2 cemeteries involved unnucleated burials that covered much of the excavated area (*SI Appendix*, Fig. S2). There are too few BA 1 burials for analysis, but they were located in a relatively tight group. With BA 2 we encounter discrete rows of burials that present as a very wealthy elite enclave. BA 3A and B form a tight cluster. BA 4 burials fall into four probable groups, all deemed contemporary, that comprise rows and columns in which the graves were placed head to toe. BA 5 graves were grouped in a cluster that merged by horizontal stratigraphy into a seamless transition into IA 1 graves that comprise two groups distinguished by the orientation of the body, one with the head to the north, the other to the south (*SI Appendix*, Fig. S4). Later IA graves at this site are sparse. Ban Lum Khao has a small number of Neolithic 2 burials that gave way to an extensive cemetery of BA 2 graves, the ceramic typology of which matches that of the BA 2 at Ban Non Wat (9). There are very few IA 1 burials at Noen U-Loke. During IA 2 and 3, the dead were interred in tight clusters on a checkerboard pattern that gave way in IA 4 to rows of graves (10). At Non Ban Jak, these same rows were found during IA 4, but at this site, the preservation of house walls and floors reveals that the dead were interred within residential rooms (6) (*SI Appendix*, Fig. S5).

The long chronological sequence at Ban Non Wat also allowed for an examination of any changes in the farming systems and the plant-based diet. Ban Non Wat samples dating to the Neolithic–BA transitional period provided evidence of a predominantly rice-based diet and a dryland farming system. In order to differentiate between dry- and wet-rice farming, weeds found in association with rice were used as a proxy, as these are often found in specific habitats or ecologies. The reliance on rice persisted until the IA at Ban Non Wat with no major added component from any other economic crop including pulses. However, changes in the farming system took place during the IA and by the Late IA, bunded wetland agriculture was in place. Wetland rice is at least twofold to threefold more productive than dry rice although more labor intensive (11, 12). Investments in rice cultivation are believed to be responsible for demographic expansion, such as in the Gangetic Plains of India and in the Upper Mun River Valley sites.

A total of 38 archaeobotanical contexts were analyzed at Non Ban Jak, which again showed rice being the most important economic crop. Half of the contexts were made up of more than 50% rice, including one which was solely comprised of rice remains. Cotton boll fragments and spindle whorls have also been identified in Non Ban Jak signifying craft production. The rice was cultivated under wet conditions and the presence of green algae (*Chara zeylanica*) indicates permanent wet fields or irrigation. It is evident that at Non Ban Jak, the population had specific roles, including farmers and craft specialists.

Methods

Although the social organization represented in each sample has been published, no systematic measurement of pulses in inequality throughout the 2,500 y has been undertaken. By initially taking the frequencies of just one exotic item found over time, however, there are intriguing implications. For the Neolithic and BA sequences, the average number of exotic marine shell bangles reveals an overwhelming increase during the BA 2 and 3 phases (*SI Appendix*, Fig. S3). In the case of the IA, we find a similar sharp rise in the number of exotic bronze ornaments during IA 3 at Noen U-Loke, followed by a decline in the latest IA contexts (*SI Appendix*, Fig. S4). In this study, we have applied the values of the GC to cultural phases over the entire 2,500-y sequence in order to identify and, if possible, explain instances of a rise in social inequality over the longue durée. The great strength of enlarging upon such findings through quantitative estimates such as the GC lies in the fact that we involve all artifacts placed in each individual grave. We have divided these into six groups: pottery vessels, artifacts that are exotic, ritual and useful, food remains, and the number of bronze or iron artifacts.

There is the perennial issue of adjusting raw numbers to take into account the potential value of an item in the prehistoric mind. Thus, should a useful spindle whorl have the same status as a gold bead necklace? Although acknowledging the potential of modern bias, we have adjusted numbers to

take this problem into account. For example, a bronze artifact, agate pendants and exotic shell bangles have been multiplied by a factor of 5, a gold or silver item by 10, iron by 3, and marble and shell earrings by 2. A list for each item is given in *SI Appendix*, Table S1.

We measure the extent and change of inequality across site and phase by estimating the GC, an indicator that is widely used to describe the concentration of an asset (or a sum of) in a population. It is measured as one half the mean of the wealth difference across each pair of units in a population, divided by the average wealth in the population, and it assumes values between 0 (complete equality) and 1 (complete inequality). Its capability of summarizing the extent of concentration of all the burial artifacts across all the population units in each phase makes it a key method for our aim of reconstructing the patterns of change of social inequality across 2,500 y.

As it is often the case with archaeological or historical sources, we also acknowledge the presence of methodological challenges that could potentially hinder our capacity to draw effective conclusions or make meaningful comparisons across coefficients estimated at different space and time. In a recent contribution, coauthored by two of the current authors, five methodological issues, arising when inequality is measured from archaeological datasets, were singled out, and a statistical procedure was set up to account for them (8). These issues are the following: 1) the bias due to small sample size, 2) the different population size across cultures, 3) the comparability of the GC estimated on different wealth assets (house area and grave wealth), 4) the comparability across GC estimated on individual or household wealth, and 5) the lack of individuals with no wealth.

The estimation of the GC for our sites presents challenges 1, 2, and 4, and we briefly describe here how we tackle them following Fochesato et al. (8) (in *SI Appendix*, we show the validity of their method to correct our GC). First, we acknowledge that our excavations might only be a sample of the entire population. Using multiple archaeological datasets, the authors have found that the GC computed on a subsample is on average larger than the one computed on the entire population, with the discrepancy between the two declining steadily as the subsample becomes larger (8). They also showed that the relation between the upward bias and sample size is similar across different datasets, and here, we found that this result holds true when tested on our current dataset (*SI Appendix*, section S2). This suggests that their method can be used to correct our GC.

Archaeological datasets reporting burial wealth are compiled at the individual level, as females and males were usually buried in single graves with their own rituals. However, wealth distribution is usually assessed between households, the basic population units that shared and used assets. In ref. 8, we used the demographic information of buried individuals in large archaeological datasets, and through different hypotheses about assortment practices, they reconstructed hypothetical households to gauge the ratio of between-household to between-individual inequality. We have replicated their exercise and found a similar ratio to the one published in ref. 8 (*SI Appendix*, section S2). We have used this ratio to adjust the GC as if they were computed on household wealth. A final issue regards the size of the whole population, which might have been different across sites and might have affected the degree of social differentiation in the society. Using the GC computed at different levels of population entities within the same archaeological dataset, a positive relationship between inequality and population size has been found. We adopt this statistical summary to rescale all our GC values to the same population benchmark (*SI Appendix*, section S2).

Differently from Fochesato et al. (8), we have not adjusted our coefficients to take different wealth assets into account, as our data include only one type of wealth (i.e., burial artifacts), nor do we adjust for the potentially absent individuals with no offerings, as each phase/site includes individuals with zero wealth.

Because of the nature of the adopted method, all the adjusted GCs are lower than the unadjusted ones (Table 1). They are, on average, 9% less than the unadjusted GC and the decrease ranges between 8.7 and 9.2% (*SI Appendix*, Table S3). As the signs and the relative sizes of the adjustments are similar across the cases, we conclude that the method, which improves the reliability of the estimates, does not alter the relative hierarchy of the sites/phases with respect to their social inequality. Nor does it reduce the heterogeneity (and richness) of the information provided by the dataset. In fact, the SD across all the adjusted GC is 0.112, slightly larger than the SD across all the unadjusted ones (0.102).

In Fig. 2, we plot the adjusted GC by site and phase, and the time trend of inequality across the whole period estimated through a second-degree local polynomial regression. The time trend detects rising trends of inequality toward the end of the Neolithic, reaching a peak during the early BA. Then, inequality decreased in the subsequent centuries and increased afterward, reaching another peak during the later IA. In Fig. 3, we summarize the measure of inequality by the three main phases in our dataset. Fig. 3 shows that despite a large within-phase variation, inequality during the Neolithic phase was significantly lower than during the BA (P value of the Welch's t test of the mean difference equal to 0.072) and IA (P value 0.073), (*SI Appendix*, Table S4).

Results

During both Neolithic phases at Ban Non Wat, exotic items were rare almost to the point of being absent. For the initial Neolithic, locally made pottery vessels dominated mortuary offerings. One young male did stand out on the basis of the number of ritual bivalve shells, two cowry shells, and pig bones, but the GC is low, and there is no evidence for inequality. The same situation is found for Neolithic 2 burials. There are insufficient burials for the ensuing first BA phase, although continuity is seen in similar forms of ceramic vessel, and there was an undoubted increase in the quantity of exotic ornaments, complexity of ritual seen in one woman being interred in a boat-shaped coffin, and the first presence of copper-base axes.

With BA 2 the situation changed dramatically. Virtually all adults and infants were interred with wealth unparalleled for the period in Southeast Asia. The dead were interred in rows, wearing multiple marine shell and marble ornaments, as many as 80 decorated ceramic vessels in a wide variety of new forms, and often with copper-base axes and rarer metal ornaments. Some adults had been disinterred and then reburied, and graves were far bigger than was necessary to contain the body. Smaller excavations elsewhere on this site have revealed BA 2 individuals who were markedly poorer in every respect. It is suggested that there was a burial place for a social elite and another for the less-well endowed. The upshot of such a uniform degree of wealth among the elite is that the GC for this group fails to distinguish social inequality among its members.

We have therefore combined this elite group with a contemporary cemetery from the nearby site of Ban Lum Khao. Here again, the dead were laid out in rows, with a subset of pottery vessels virtually identical with those from Ban Non Wat. However, the mortuary offerings at Ban Lum Khao were markedly fewer, and the GC is a modest 0.457 (*SI Appendix*, Table S5). When combined, the GC soars to 0.657, the highest we record for any sample. We conclude that there is supporting evidence for a sharp rise in social inequality during the early BA, also detected by the rising time trend shown in Fig. 2. At Ban Non Wat, this was sustained with BA 3 and BA 4 with GC values of 0.542 and 0.603, respectively, before falling with the final phase of the BA (0.350).

At Ban Non Wat, the late BA cemetery merged with that of the initial IA, the latter comprising two nucleated groups containing 70 complete adult burials. New exotic ornaments now comprised very rare items of glass, agate, and carnelian of ultimately South Asian origin and a marked increase in the number of bronzes. There was also a modest number of iron ornaments, weapons, and tools, including knives, spears, and socketed hoes. Fish were often placed in the graves. The GC rose to 0.433, slightly higher than during the preceding BA 5 phase.

There were insufficient later IA graves at Ban Non Wat to provide reliable data, so we move about 2 km to the west to the moated Iron A settlement of Noen U-Loke. Here, there are three IA phases labeled IA 2, 3, and 4. There was a steep rise in the number and variety of mortuary offerings that was particularly notable with IA 3. Now, graves were filled with rice. Compared with the nucleated set of graves seen at Ban Non Wat during the initial IA, graves during IA 2 through 3 formed tight clusters on a checkerboard layout (*SI Appendix*, Fig. S3). Some individuals, particularly during IA 3, were spectacularly wealthy, one man being interred with 224 bronze ornaments, agate pendants, glass beads, and gold and silver ear discs.

Table 1. GCs for Northeast Thailand

Site	Phase	Dates	Sample size	Unadjusted GCs	Adjusted GCs
(1)	(2)	(3)	(4)	(5)	(6)
Ban Kao	Neolithic	2000–1250 BC	27	0.340	0.310
Khok Charoen	Neolithic	1500–1150 BC	22	0.477	0.435
Khok Phanom Di	Neolithic	2000–1600 BC	53	0.363	0.329
Ban Non Wat	Neolithic 1	1800–1250 BC	14	0.524	0.478
Ban Non Wat	Neolithic 2	1250–1050 BC	26	0.532	0.484
Ban Non Wat/Ban Lum Khao	BA2	900–800 BC	43	0.724	0.657
Ban Non Wat	BA 3	900–800 BC	25	0.596	0.542
Ban Non Wat	BA 4	800–700 BC	87	0.663	0.603
Ban Non Wat	BA 5	700–420 BC	25	0.383	0.350
Nong Nor	BA	700–420 BC	42	0.562	0.510
Non Nok Tha	BA	1000–500 BC	37	0.526	0.478
Ban Non Wat	IA	420–100 BC	70	0.477	0.433
Noen U-Loke	IA 3	200–400 AD	13	0.612	0.557
Noen U-Loke	IA 4	300–500 AD	12	0.668	0.608
Non Ban Jak	IA	300–600 AD	44	0.526	0.477

The estimates in column (5) and (6) show, respectively, the GC computed before and after the adjustment procedure explained in the text.

Another man wore four bronze belts, and a man beside him was accompanied by a pottery vessel containing a socketed iron plowshare. Women, too, were buried with impressive exotic ornaments including gold and agate beads and silver bangles. A rising trend of social inequality is detected during the IA (Fig. 2) when the GC rose to 0.557 in IA 3.

IA 4 at both Noen U-Loke and the third significant site, Non Ban Jak, saw a further change in burial practice, with the dead now interred within the rooms of domestic houses. Although less spectacularly endowed than during IA 3, the GC for IA 4 at Noen U-Loke rose to 0.608, and at the smaller nearby site of Non Ban Jak, the GC is 0.477. Significantly, two more iron plowshares were found at Non Ban Jak but not in graves.

Discussion

The lack of any social distinctions in the Neolithic graves of Ban Non Wat may be compared with three other Neolithic settlements: Ban Kao (13), Khok Charoen (14), and Khok Phanom Di (15). The dead at Ban Kao were interred in a diffuse group with pottery vessels and stone adzes but very few exotic ornaments. Their GC is the lowest that we encountered at 0.310 (Table 1). At Khok Charoen, we again find that pottery vessels predominated, with a scattering of bivalve shells, stone adzes, and shell ornaments. The GC is 0.435. Khok Phanom Di is a special case with its seven mortuary phases. Phases 2 through 4 comprised superimposed clusters on a checkerboard pattern (*SI Appendix*, Fig. S2), in which the dead were accompanied by fine pottery vessels and, on occasion, an impressive number of shell beads. Most were sprinkled with red ochre, and some women were associated with clay anvils for shaping pots and burnishing stones. The GC for these three phases is 0.329. However, with the phase 5, there was a spectacular burst of mortuary wealth with a woman potter interred wearing over 120,000 shell beads, two shell discs, a shell bangle, and superb pottery vessels. This same phase also included a male and three infants of very great wealth. There was no interdict on social elitism in this Neolithic site, situated as it was on an estuary we see as a central node in an extensive riverine and coastal exchange network.

Two sites beyond the upper Mun Valley provide comparanda for the BA. Non Nok Tha is located remotely in the northern Khorat Plateau. Bronzes were cast there, but few were found with the dead (16). The GC is a modest 0.478. The 42 intact

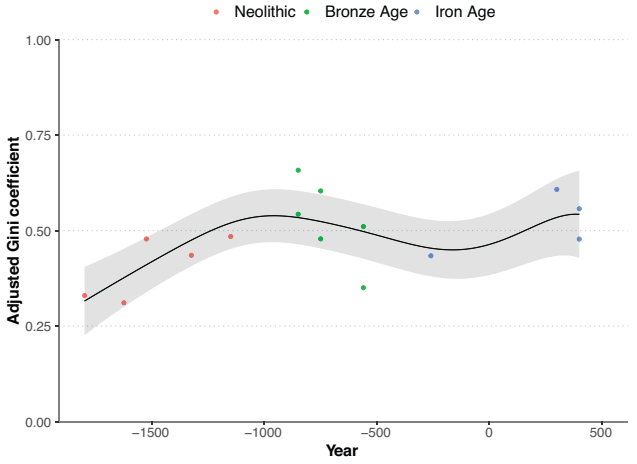

Fig. 2. Adjusted GCs over time and time trend. The solid line shows the time trend estimated through a second-degree local polynomial regression with a kernel smoothing bandwidth parameter equal to 400 y. The light-gray area delimits the 95% CIs of the time trend. Dates are midpoints of the year intervals by phase-site shown in Table 1. Year "0" indicates beginning of AD/CE (Table 1).

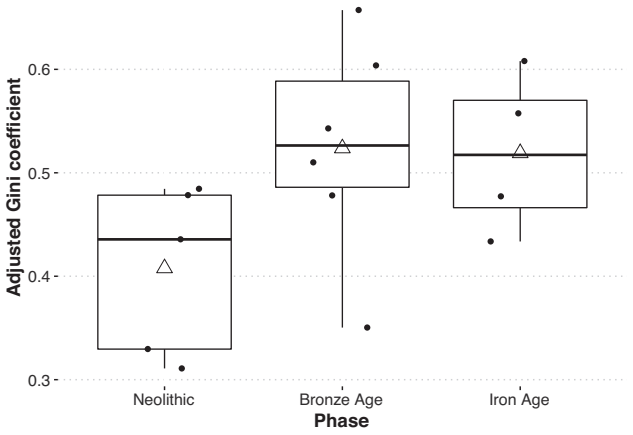

Fig. 3. Adjusted GCs by phase. The boxes show, for each phase, the 95% CIs of the median GC (shown by the black line within the box). The triangles indicate the mean wealth inequality by phase (Table 1).

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burials at Nong Nor were found in two groups. Although some individuals were associated with exotic jade, carnelian, and serpentine jewelry and bronze and tin ornaments were sporadically worn, none matched in wealth the elites of Ban Non Wat. The GC for this site is 0.510.

We have identified three episodes of greatly increased social inequality during the 2,500-y sequence. The first occurred ca. 1800 BC at the Neolithic site of Khok Phanom Di, the second ca. 1100 to 800 BC at Ban Non Wat during the early BA, and the third ca. AD 200 to 400 during the later IA (the last two episodes are also captured by the peaks of the time trends of social inequality shown in Fig. 2). These raise the fascinating issue of whether there was a tendency in Southeast Asian rice farming communities for aggrandizer individuals or specific kin groups to seek social prominence. Khok Phanom Di was located on an exchange choke point, the estuary of the Bang Pakong River. Graves representing about 20 generations were found in a stratified sequence, a unique finding virtually worldwide. During the first 12 generations, there were rare instances in which an individual was interred with far more than the norm in terms of personal ornaments. A specialist female potter was then interred in a grave larger than necessary to contain her body under a stack of clay preforms for making pots, covered in red ochre, and adorned with a spectacular assemblage of exotic shell jewelry. Her clay anvil for shaping pottery vessels and two burnishing stones in a shell container lay beside her right ankle. Two infants interred on either side of her grave were also extremely wealthy, one also under clay preforms, with thousands of shell beads and a miniature clay anvil beside her right ankle. It does not take a leap of imagination to visualize a mother–daughter relationship, the 18-mo-old infant already learning how to make ceramic vessels. A very wealthy male was also present. Intriguingly, a headless male buried in a shallow grave adjacent to the wealthy matriarch was accompanied by just two pots. This occurred as the environment changed rapidly to marine conditions as the sea level rose higher. We suggest that this transformation reflected her standing as a highly skilled artisan who fed her output into a major exchange network. Nor was she unique to the site. During the ensuing phase, very wealthy women were found interred under the floor of a building raised on a platform.

The introduction of copper-based artifacts into Southeast Asia took place toward the end of the second millennium BC as part of the southward expansion of the necessary technical knowledge, a move that almost certainly involved long distance exchange and the movement of copper prospectors and founders (17). At least three copper sources were identified and exploited, one of which was located on the western side of a pass over the Petchabun range that linked Central Thailand with the upper Mun River valley. Ban Non Wat lies on a choke point for the exchange not only of copper-base items but also marble and marine shell. On the economic foundation of dry-rice farming, the raising of domestic pigs and cattle, and hunting and gathering, we suggest that it was by securing control over the ownership of and access to these exotic goods, including the novel and remarkable first metal, that an aggrandizer segment of Ban Non Wat society secured elite status. This was not confined to this one site; we know of rich elite graves at the nearby site of Ban Prasat. However, at more dispersed sites such as Non Nok Tha without control over exchange routes, all the BA dead were comparatively poor.

Nor was the early rise of a social elite at Ban Non Wat permanent. It endured for about eight generations before there was a sharp decline in mortuary wealth, as doubtless, bronze became more readily available to the point that bronze bangles were being cast on site employing a novel technique of multiple molds.

The sharp rise in elite wealth during the later IA is best measured in the proliferation of bronzes and exotic glass, carnelian, agate, gold, and silver ornaments. There may have been multiple stimuli, not least the evidence we have for salt production on an industrial scale that, like land, was a potential source of material wealth that could be monopolized and passed between generations. Unlike the situation during the preceding early BA, however, we cannot invoke an exchange choke point in this case, because numerous large sites ringed by moats are found throughout the Mun River valley. Multiple factors have been identified to explain the IA case of increased social inequality. It occurred when the strength of the monsoon rains faltered, and there was a need to maintain rice productivity (18). The onset of aridity was contemporary with the construction of moat/reservoirs. These were linked by distributaries to banked permanent rice fields. At this same juncture, iron plowshares replaced hoes, and domestic water buffaloes were corralled within the settlement of Ban Non Wat presumably to prepare the rice fields. These remain the principal source of tractive power for plowing rice fields. Dryland weeds that dominated until ca. AD 100 were replaced by species adapted to wetlands (19). During the period of transition, we find that both dryland and wetland farming systems were practiced concurrently and eventually irrigated wetland rice prevailed. We conclude that there was a transition from labor-limited dry rice cultivation by hoe to land-limited, wet-rice, plow-based farming as climatic conditions deteriorated, a situation that advantaged those owning the best irrigated land. One manifestation of increased rice production and the wealth that it represented is seen in the deposition of large quantities of grain in graves. As a consequence, wealth inequality also increased. For example, our estimations allow us to compare the GC in the labor-limited Ban Non Wat in BA 5 with the ones in the two closest and temporally subsequent land-limited sites, Noen U-Loke (IA 3 and IA 4) and Non Ban Jak IA (the sites are only a few kilometres from Ban Non Wat). Our estimates show that after the shift from labor- to land-limited cultivation, wealth inequality increased on average by more than 50% (Table 1). We conclude that this mirrors our results from an earlier study in western Eurasia, where social inequality expressed in the GC rose, although to a larger extent, in tandem with the rise of land-limited farming (1).

In Southeast Asia, the impact of this agricultural revolution was profound. The creation of wet-rice fields generated a habitat riven with dangers to human health. It would have encouraged the proliferation of malarial mosquitoes. The many fish and shellfish found in the middens at Non Ban Jak harbor deadly pathogens, as does regular proximity to domestic farm animals for those wading through waterlogged fields to transplant weed and harvest rice. This had a serious impact on health, particularly for women, seen in the doubling of infant mortality with the adoption of wet-rice farming, many of the dead being preterm or neonates. This agricultural revolution was also seminal to an astonishingly rapid rise of state societies during the sixth century AD. The archaeological signature in the upper Mun Valley was the trebling in area of Muang Sema, with the construction of a Buddhist monastery and epigraphic evidence for a royal lineage (20). Both in Northeast Thailand and adjacent Cambodia, as might be predicted, we encounter a society that comprised wealthy elite landowners and tied agricultural laborers ancestral to the civilization of Angkor (21). Our study has revealed in this last case, a permanent rise in social inequality stimulated by adaptability to climate change. The two prior instances have incorporated more nuanced inputs that had in common an apparent tendency toward aggrandizing behavior by individuals or kin groups.

Data Availability. Data and replication codes have been deposited in OPEN ICSR, https://doi.org/10.3886/E153082V1.

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