



Teak Log Coffins in Northwest Thailand: Dated by Dendrochronology and 14Cwiggle Matching

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Abstract

Log coffins have been discovered in caves and rockshelters in the Pang Ma Pha district, Mae Hong Son province, Northwestern Thailand. Most are made of teak wood. Many researchers have used the 14C method to determine their age. However, 14C cannot provide as precise a calendar age as dendrochronology. In this paper, we therefore applied dendrochronology analysis to a number of teak log coffins at the Ban Rai Rockshelter to establish a floating chronology and to cross-date the coffins relative to each other. Then, wiggle matching was used for one log coffin to derive an approximate but absolute calendar age. The findings indicated that cutting of this teak tree occurred around AD 265. The analyses also revealed a close association between coffins of the same head style.

Keywords: Dendrochronology; archaeology; teak; log coffins; wiggle matching

Introduction

There is a long history of archaeological activity in Thailand [1, 2, 3]. However, little information is available on the wood which ancient peoples used in their daily lives, and which can now be found as artifacts at archaeological sites. Log coffins are examples of such artifacts, and are indeed the most outstanding remains from the Iron Age. Numerous such coffins made from teak trunks have been discovered in dry caves

in the Pang Ma Pha district, Mae Hong Son province [4, 5]. Teak is well known for its wood texture, color, and natural durability against wood-destroying fungi and insects. In subtropical northwest Thailand, teak wood is ring-porous with clear annual rings, thus offering great potential for dendrochronological research [6, 7, 8]. In other areas around the world, dendrochronology has successfully been applied to provide more information than a date for

archaeological artefacts; that is to say, information about past human cultures and behavior, and sometimes even on the contemporary socioeconomic environment [9, 10, 11]. There are however, few examples of the use of dendrochronology for dating of log coffins [12, 13, 14]. In our recent study, we aimed to explore whether teak log coffins in northwest Thailand could reveal information on the log-coffin culture and its people and on the environment of that time.

Study area

The Pang Ma Pha district is located at 19° 31' N latitude and 98°14' E longitude in Mae Hong Son province, northwestern Thailand, and is part of the mountain ranges extending south-north from the Malaysian peninsula to the Shan state in Myanmar. The district ranges in altitude from between 400 m to 1,200 m above sea level. The region climate has three distinct seasons: a wet season from June to October, a cool and dry season from November to February, and a hot and dry season from March to May. According to meteorological data recorded by the Mae Hong Son Meteorological Station, the average annual mean temperature is 25 °C. During the hot and dry season, average mean temperature is 33°C. In the cool and dry season, the temperature in the highlands often falls below 10 °C. The total sum of annual rainfall is 1,260 mm.

The Ban Rai Rockshelter, situated under a large overhanging rock, contains numerous log coffins and some spectacular rock paintings. It is located approx. 793 m above sea level and 150-200 m above a plain. The rock shelter is horseshoe-shaped, about 105 m wide and 142 m long; its height is on average 30 m. In its centre is a forested sinkhole. The entrance to the rockshelter faces north, and the Lang River runs nearby (Figure 1).

Material and methods

Almost all log coffins exhibit signs of deterioration due to fire, insect attack or human activities, such as looting and cutting for firewood. Each log coffin was made from a single tree cleaved into halves. Each half was hollowed out, and the top (head) and end of the coffin were carved. We collected wood samples from either the heads or the ends of the log coffins which consist of sufficiently remaining solid wood.

A total of 121 wood cores were taken from 30 coffin lids and from 27 posts, using an engine-driven increment borer with a diameter of 10 mm; the bore holes were filled with pieces of wood. Wood samples were divided into six groups according to archaeology excavation [15].

The cross-sectional surface of each core was sanded with a rotary-sanding tool until the tree-ring borders became visible. Then, the tree-ring widths were measured to the nearest 0.01 mm using a moving stage and a microscope interfaced to a computer that served as data recorder. On a lighted table, the radii of each coffin lid or post were visually cross-dated for measurement errors. To identify locally absent or false rings and to eliminate measurement errors and ensure dating accuracy, the quality of the cross-dating was finally checked using the COFECHA programme [16]. Problematic samples, such as samples with a distorted growth pattern, were removed from the data set.

After floating chronologies were successfully assembled, we selected samples from one core of one coffin for 14Cwiggle matching [17] because of logistic constraints. For this purpose the 217-year long core BR05A, 22 consecutive decadal sub-samples were taken, which provided the material for the 14Cwiggle matching.

Wiggle matching is a technique to calibrate the radiocarbon ages of a series of samples in one object with certain intervals, e.g., ten years [18]. Matching the multiple results to the wiggles in the 14C-calibration curve can effectively

reduce errors in radiocarbon dating. Therefore, wiggle matching is very useful to date floating tree-ring chronologies. Wiggle matching was performed by the OxCal v3.10 program, using

the IntCal04 calibration curve for the northern hemisphere [17, 18, 19]. The performance of wiggle matching was determined by Bayesian statistic [17].

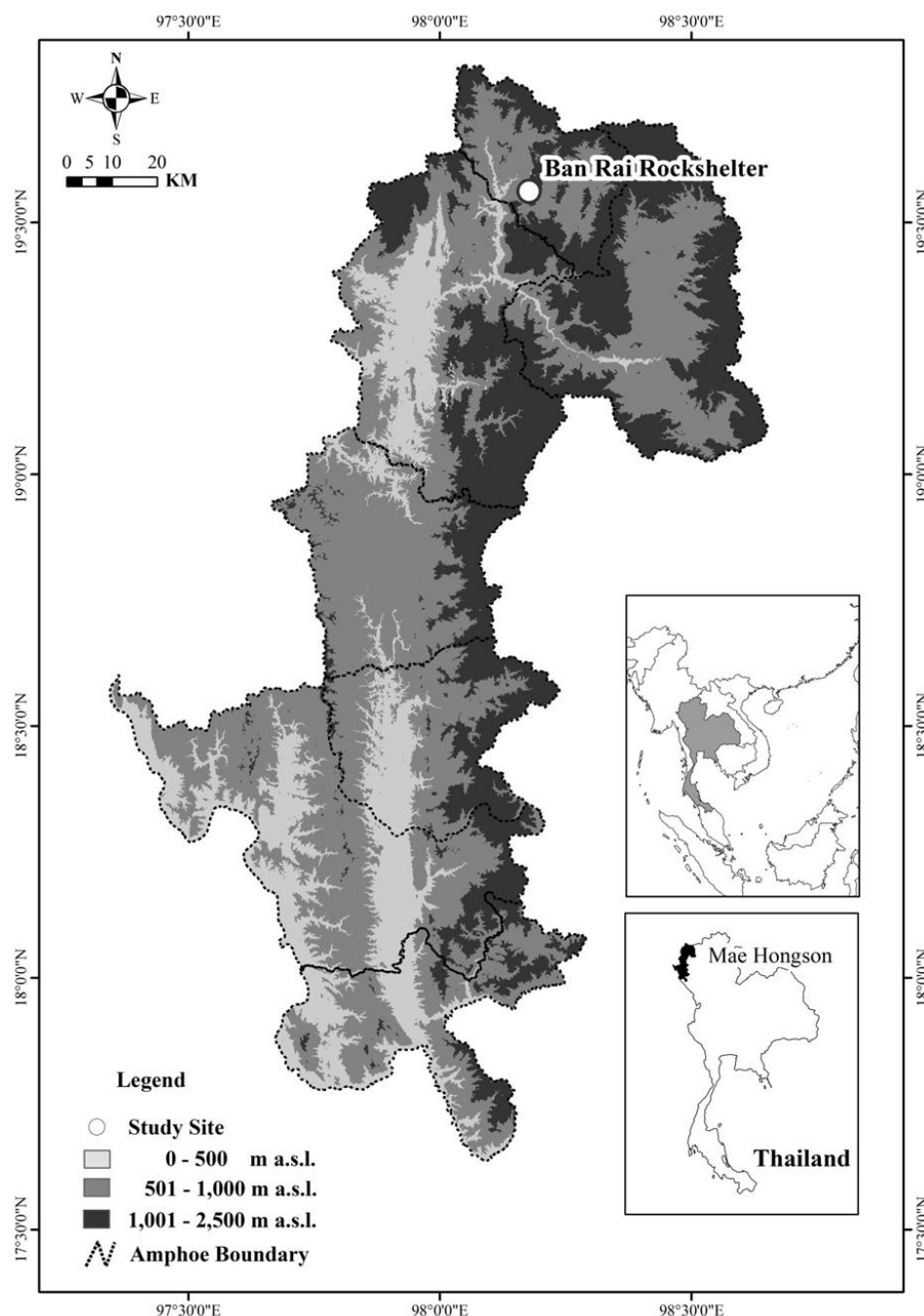


Figure 1 Map of Thailand and of the study area

Results

By combining dendrochronological and archaeological research, we found that the log coffins were made of trees, of which 90% were

teak. It appears that the natural resources around the study area were once plentiful and included different forest types, especially dense mixed-deciduous forests with teak species dominant.

During the Iron Age [20], people had excellent skills in selecting wood, particularly teak, and in making log coffins. They must have had tools to fell trees, considering the large size of the log coffins, which have an average diameter of approximately 0.5 m and a length of approximately 4.0-5.0 m. We assume that these people were living in large communities and that they held death ceremonies. Whether they believed in a life after death or just celebrated an individual's life, cannot be decided yet.

At the Ban Rai Rockshelter, most of the log coffins were made from teak but sometimes other tree species such as *Syzygium cumini* were used. The various styles of the log-coffin heads are of a simple form with no facial features (Table 1, Figure 2). The styles in our study area are not as varied as the head styles (from all the investigated caves in the Pang Ma Pha district) classified by Treerayapiwat [20].

Tree-ring width measurements and cross-dating were successfully made for 13 log-coffin lids (39 cores) and 6 posts (15 cores). The longest tree-ring series of a log-coffin lid and from a post covered 265 and 152 years, respectively; the shortest tree-ring width series were 21 (log-coffin) and 45 (post) years.

In total, we assembled six floating tree-ring chronologies. Later we were able to combine the Ban Rai floating chronologies series 1-2-3 into one series. The locations of the collected samples and styles of log-coffin heads are shown in Figure 3. The Ban Rai chronological series 1 (BRS1) is described in detail whereas the remaining five floating chronologies are illustrated only by bar charts to show the time periods spanned by the respective set of relatively dated samples.

Table 1 Styles of log-coffin heads in the Ban Rai Rockshelter ^[21]

Style	Drawing	Description	Number of pieces of log coffin heads
IA		A long piece of solid wood that is curved at the protruding end	6
IB		A short piece of solid wood that is curved at the protruding end	8
IIA		A long piece of square solid wood that is curved at the protruding end and pierced through to the flat back of the bottom and has a small hole	18
IIB		A short piece of square solid wood that is curved at the protruding end and has a flat back on the bottom	7
IIC		A short piece of square solid wood that is curved at the protruding end and pierced through to the flat back of the bottom	2

Note: The lid of each log coffin has two heads.

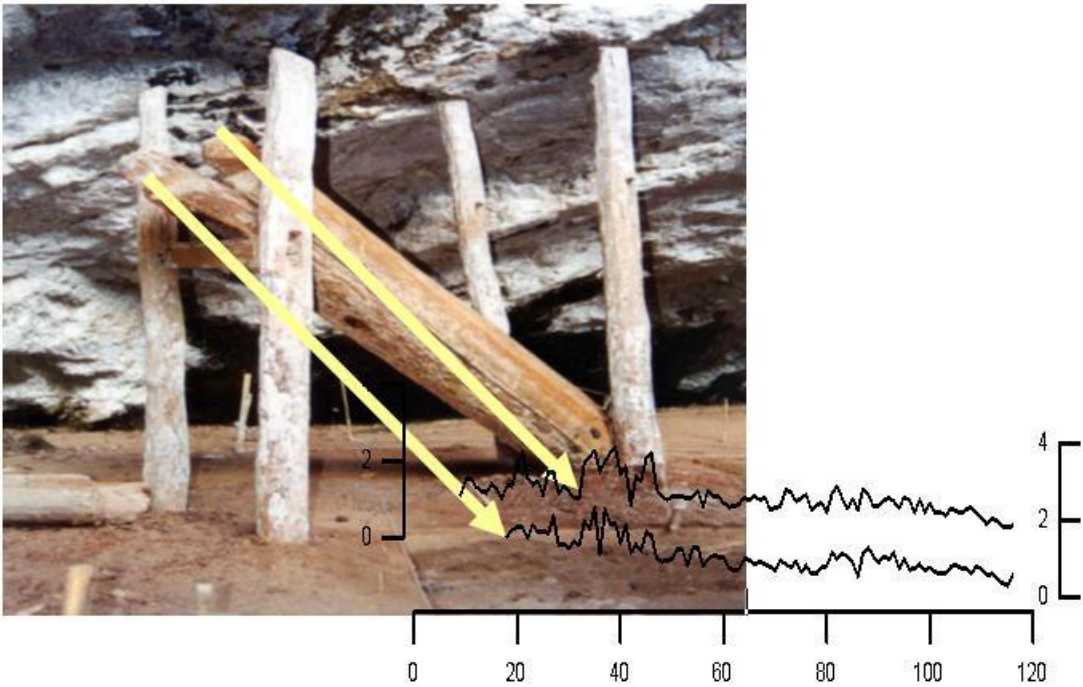


Figure 2 A log coffin and the two tree-ring width series derived from it.

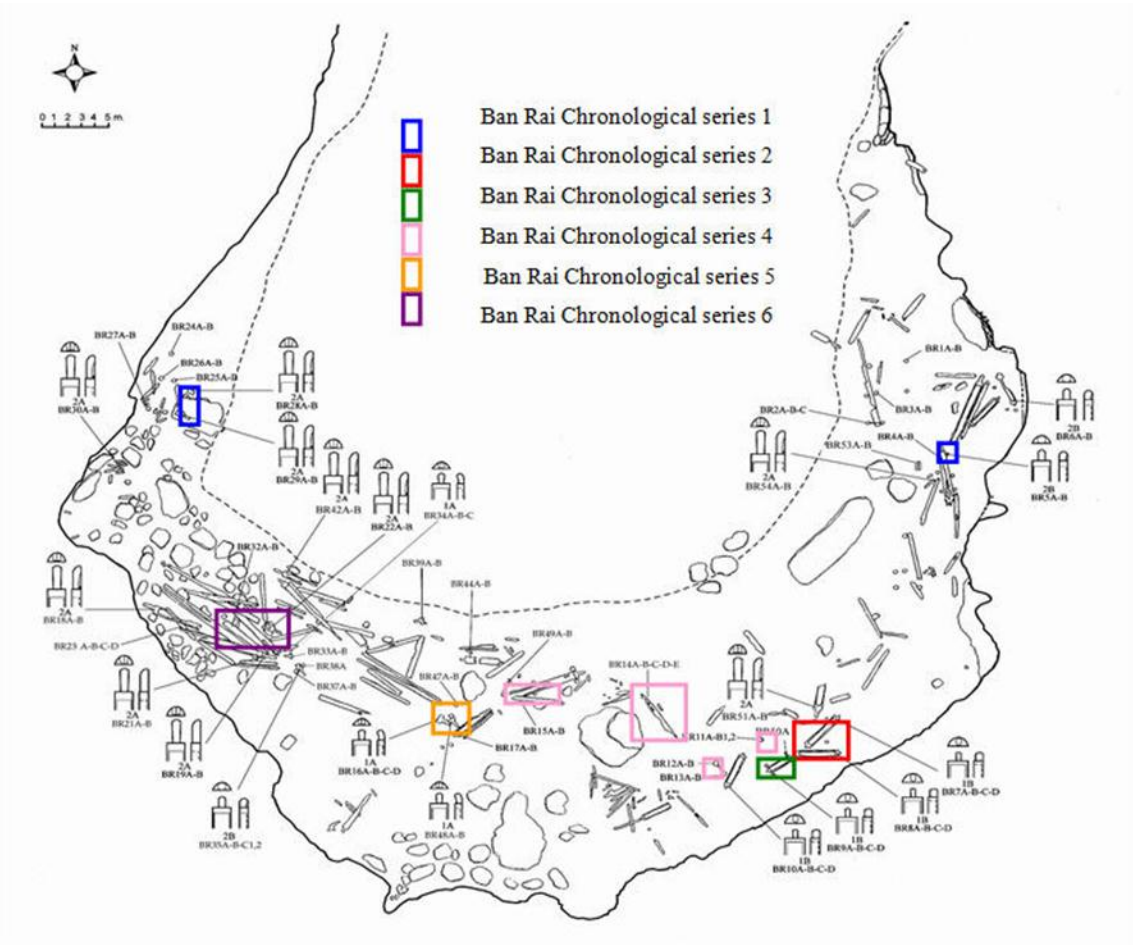


Figure 3 Samples in the Ban Rai Rockshelter collected for dendrochronology [22]

Ban Rai chronological series 1 (BRS1)

The Ban Rai tree-ring chronology 1 (BRS1) was built from ten cores (Figure 4). Samples BR05A+B were from a log coffin head (IIB style) supported by two posts (BR04A+B). BR28A+B and BR29A+B were from log coffins head (style IIA). BR52A+B were taken from a

log coffin with an unidentified head style. The BRS1 floating chronology covers 278 years. The ten tree-ring series included correlated highly among each other (Figure 4, Table 2) suggesting that the teak trees grew in a similar climate.

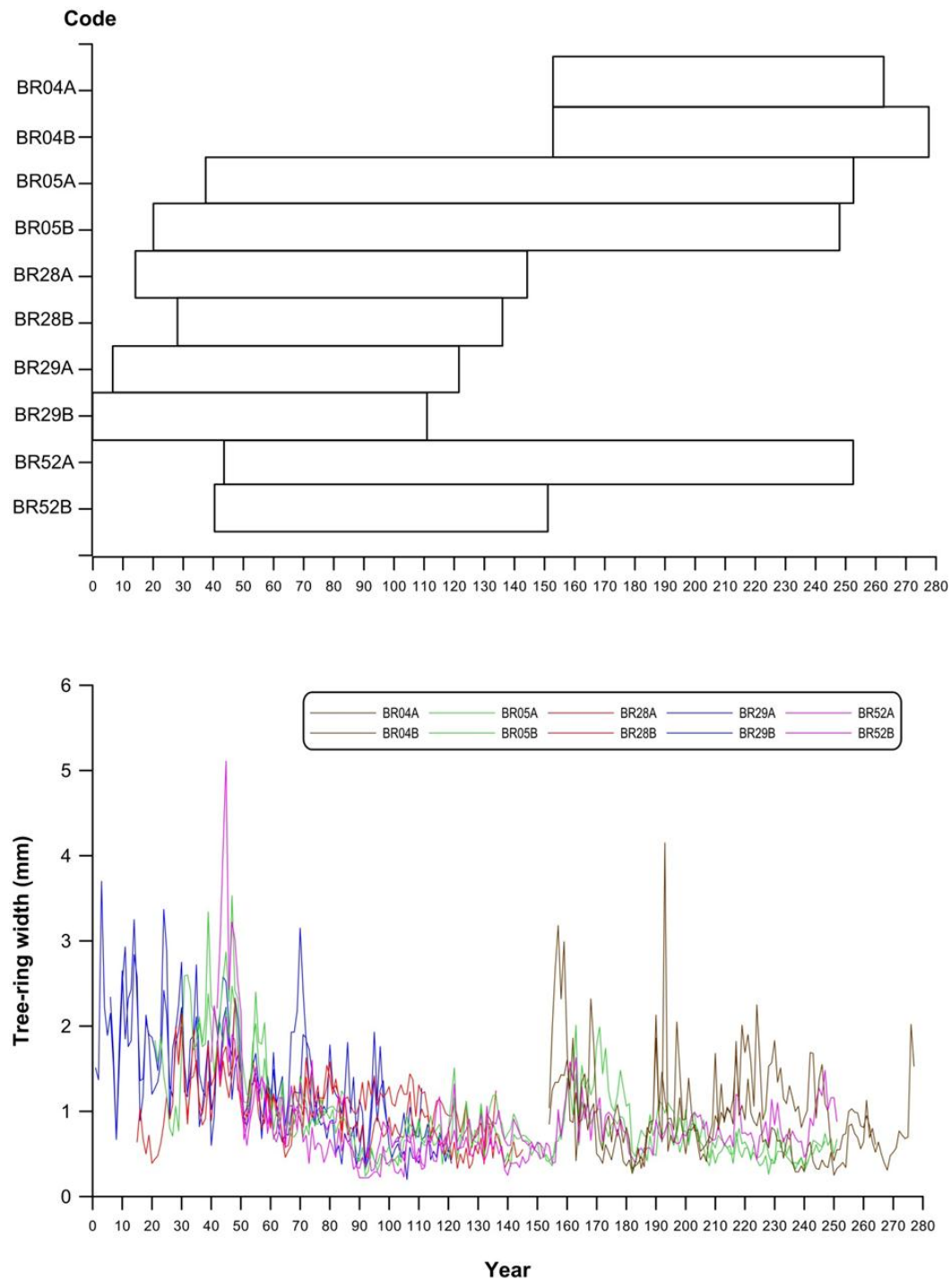


Figure 4 Ban Rai chronological series (BRS1); time spans (above) and raw measurements (below) of the ten tree-ring series in cross-dated position

Table 2 Descriptive statistics of the Ban Rai Chronological Series

Series	Cores (n)	Correlation with master	Mean tree-ring width (mm)	Standard deviation (mm)	Auto correlation	Mean sensitivity
BRS1	10	0.51	0.98	0.51	0.72	0.25
BRS2	8	0.72	1.86	0.82	0.79	0.24
BRS3	8	0.62	0.64	0.34	0.54	0.32
BRS4	12	0.53	1.13	0.84	0.72	0.31
BRS5	6	0.65	1.33	0.94	0.81	0.26
BRS6	10	0.64	1.09	0.56	0.72	0.27

BR28 and BR29 were from the head of a log coffin found on the floor in the eastern part of the rockshelter; BR05, from the head of the log coffin (style IIB), and BR04, from a post, were found in the western part of the rockshelter. The log coffin head of style IIA (BR28, BR29) was probably used prior to the log coffin of style IIB (BR05A+B); thus, the eastern part of the rockshelter was possibly used as a burial site before the western part of the rockshelter. There is a high correlation between the post (BR04) and the log coffin (BR05) that it supported, which means that both samples were made from trees that grew in a similar climate. These samples may have been cut in the same period because the last ring was built at a similar position in time. Similarly, BR28 and BR29 may be from the same coffin lid because they were very highly correlated and were found in the same area of the rockshelter.

Ban Rai chronological series 2 (BRS2)

The Ban Rai chronological series 2 (BRS2) was built from two log coffin lids (8 cores) (Figure 5). The log coffin head of BR07 was carved in style IB and IIC. The log coffin head of BR08 was made of style IB. Both log coffins were located on the floor in the western part of the rockshelter near a cliff. Their lids were of similar size: BR07 was 3.57 m long, 0.54 m wide and 0.29 m thick, and BR08 was 3.58 m long, 0.54 m wide and 0.24 m thick. The ends of both log coffins are decorated in a similar style. The

BRS2 floating chronology covers 123 years. The individual tree-ring series were highly correlated (Table 2); thus, these specimens might have been taken from the same tree.

Ban Rai chronological series 3 (BRS3)

The Ban Rai chronological series 3 (BRS3) was built from two log coffin lids (7 cores) and one post (1 core) (Figure 5). BR09 and BR10 were from log coffin heads in style IB. Both lids were supported by post BR50. Another end of a log coffin lid (BR10) was supported by one beam and four posts. BR09 was located on the floor near this log coffin. After its excavation, log coffin BR09 was placed as a cover on BR 10. Both log coffin lids were put on a cross beam, but the beam that supported the other end of these coffins is damaged. The log coffins are of the same size (3.10 m long, 0.52 m wide and 0.22 m thick).

The individual tree-ring series were highly correlated (Table 2). Thus, specimens BR09 and BR10 might have been taken from the same tree. All of the log coffins have their last ring formed at a similar position in time. The younger tree was used to make the post and the older tree was used to make the coffin, meaning that the environment around the rockshelter was a mixed deciduous forest. If both lids were made from the same tree, it shows the high level of skill of the people of the Log Coffin Culture. Both lids were made from trees growing in a similar climate.

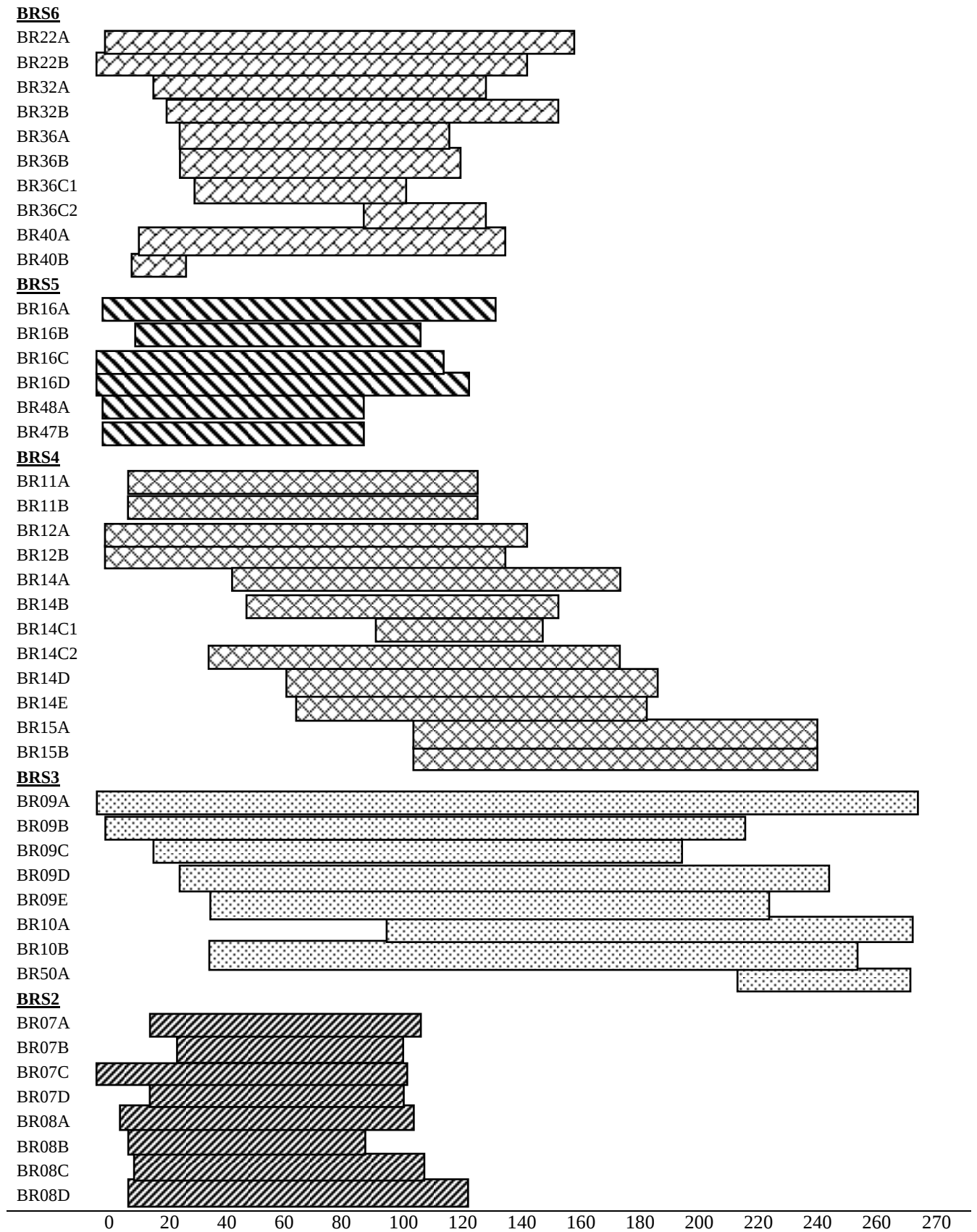


Figure 5 Ban Rai chronological series (BRS2-3-4-5-6);
time spans of the tree-ring series in cross-dated position

Ban Rai chronological series 4 (BRS4)

The Ban Rai chronological series 4 (BRS 4) was built from 12 cores from 4 large posts (Figure 5). The individual tree-ring series were highly correlated to each other (Table 2).

The large posts were located near each other. BR14 and BR15 were lying on the floor. The top of BR14 was carved in a human shape, and some sections were burnt. Based on a similar tree-ring pattern BR14 was probably in the same group with BR11A-B and BR12A-B.

Ban Rai chronological series 5 (BRS5)

The Ban Rai chronological series 5 (BRS 5) was built from six cores from two log coffin lids (Figure 5). BR16 and BR48 have log coffin heads of style IA. The individual tree-ring series were highly correlated (Table 2); thus, these specimens might have been taken from the same tree.

As the last ring in coffin BR16 was formed about 50 years earlier than in BR48, the coffin

head style IA was used at different times. However, the dates of felling cannot be determined because of missing bark.

Ban Rai chronological series 6 (BRS6)

The Ban Rai chronological series 6 (BRS6) was built from ten cores from four log coffin lids (Figure 5). The log coffin head of BR22 was of style IIA and of BR36 was of style IIB. The heads of the coffins BR32 and BR40 were damaged so that their style could not be identified. The individual tree-ring series were highly correlated (Table 2); thus, these specimens might have been taken from the same area.

Combining BRS1-2-3 into one floating chronology

We successfully combined the BRS1-2-3 floating chronologies into one 278 years long series (Figure 6).

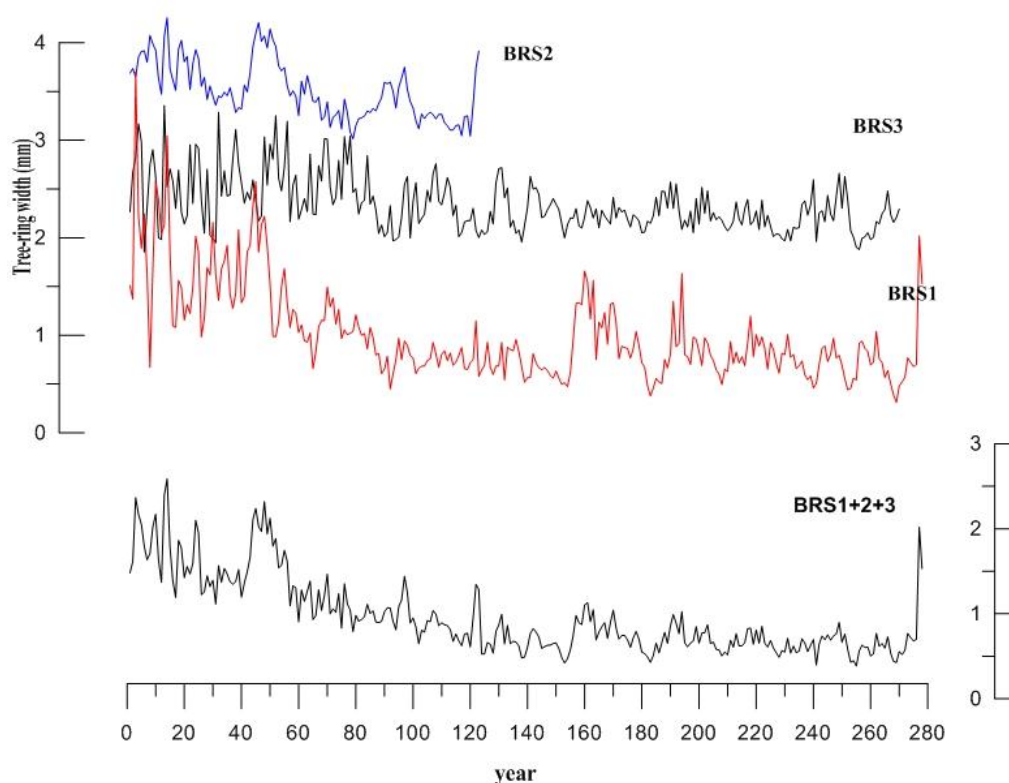


Figure 6 Combination of BRS1-2-3 floating chronology into a single series

Intermediate summary

The log coffins in our study area do not show an evolution but an overlap of their head styles. The three floating chronologies BRS1-2-3 come from log coffins with a simple head style. The log coffins and posts in the same group often could be cross-dated, such as BRS2 and BRS3, or cross-dated with a nearby group, such as BRS1. The results from BRS3 and BRS5 show that the same log coffin head style can be cross-dated to the same time range. These results indicate that the same style was used at the same time.

Moreover, the results of BRS1 show that style IIA was probably used before the IIB style; however, these log coffin styles can be cross-dated to the same age range since the last ring on the outside of the specimen ends at the same position as in BRS3. BRS 2 shows that the IIC and IB styles were used on the same lid; thus indicating that different styles of coffin heads were used during the same time period of the Log Coffin Culture.

We were able to combine the BRS1-2-3 floating chronologies into a single chronology, thus confirming that different head styles were constructed almost at the same time. BRS3B-

R09 (A+B+C+D+E) covers a time span of 265 years, including the head styles IB, IIB and IIA. However the remaining BRS4-5-6 floating chronologies could not yet be cross-dated to each other or to BRS 1-2-3.

Radiocarbon wiggle matching

The tree-ring series of the teak log coffins and posts from the Ban Rai Rockshelter cannot be dendrochronologically dated in terms of calendar years because the only long-term reference chronology for teak assembled from living trees in NW Thailand currently extends from the present time back to 1558 AD [8].

The wiggle matching method however, gives an assessment of a calendar date and can be used with wood samples that have enough rings (generally more than 100) [23, 24]. The well-preserved teak wood coffins allowed us to apply wiggle matching; using one core from a coffin, 5A (series BRS1). Twenty-two decadal samples from this wood, which had a total of 217 rings, were analyzed. The AMS measurements yielded dates in the range from 1650-2040 BP. They were plotted in the IntCal04 curve (Figure 7). The outermost samples of the 5A wood was formed around AD 265.

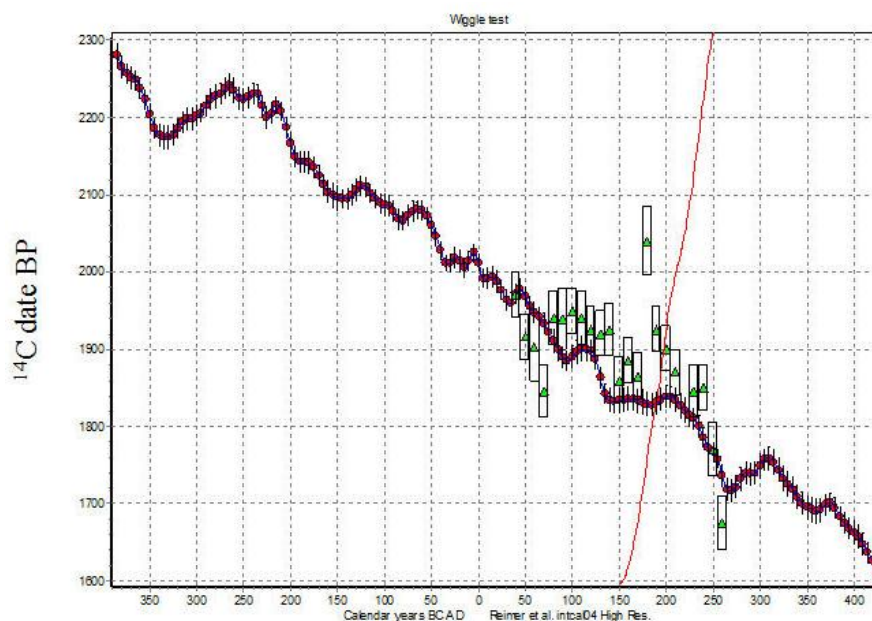


Figure 7 Radiocarbon dates of 22 consecutive decadal samples from the BR5A core and where they fit the IntCal04 calibration curve

The latest ring of the BRS1 series, which were obtained from the coffin BR05 and its supporting posts, was 25 years younger than the 5A wood (Figure 4). It belonged to a post with the bark ring (BR04B series1 in Figure 4). Therefore, we can conclude that the BR05 coffin woods were cut around 265 AD.

Based on the date of the 5A wood and the successful of combination RS1-2-3 floating chronology, it can be inferred that the Ban Rai Rockshelter was continuously used as a burial site. The log coffin head style 1B was perhaps used for a long time. The other log coffin head styles (IIC, IIA, IIB) were used interchangeably.

Discussion

Dendrochronology and archaeology are closely related, and have been used together since around 1914 when A.E. Douglass first collected prehistoric wood samples from Indian ruins in northern New Mexico and demonstrated that cross-dating between ancient wood and living trees is possible [25]. Most of such multidisciplinary work, involving dendrochronology and archaeology, has been conducted in temperate climate regions. In subtropical/tropical areas, dendrochronology has been and still is mostly applied in forestry and ecology [26]. However, teak has a great potential for dendroarchaeology as it is durable and has widely been used as construction timber in India, Myanmar and Thailand for more than 2,000 years.

One of our archaeological questions concerns the intensity and duration of episodes of human occupation of Southeast Asian caves and rockshelters, and the interaction between human and natural resources. Anderson [27] summarized three periods of archaeological cultures in Southeast Asia during the late Pleistocene and early Holocene. In the late Pleistocene, caves were used only as temporary campsites while dwellings were located in open spaces. In the early Holocene, caves were often used as dwelling sites, particularly less accessible caves and

rockshelters that provided protection from human or animal predators. During the Middle Holocene, more accessible caves and rockshelters were often used for burial purposes.

Archaeological research indicates that log coffin burials were a widespread mortuary practice in Southeast Asia [28, 29]. The distribution of log coffins, which were typically preserved in caves of limestone karst formations, ranges from southern China through the uplands of Vietnam, Myanmar and northwestern Thailand to the islands of Borneo, Sarawak and the Philippines. During the Log Coffin Culture period or Iron Age (2,200 years BP to 9th century AD), the sites were located almost at the top of the limestone cliffs and were primarily used for burial. No evidence of habitation has been found [15, 21]. Wooden coffins with various head styles are diagnostic of this period. In Southeast Asia, a log coffin at Niah Cave gave a 14C date of $2,620 \pm 220$ and $3,080 \pm 40$ BP [30], while a coffin from Kuruswanan Ledge, Tabon Cave on the Philippines was dated, using other means, to the late 13th or 14th century AD. An extensive archaeological excavation in Surigao del Norte on the northeastern coast of Mindanao found a stone structure enclosing a portion of an area with burial pits and a dug-out wooden coffin. The wood samples were identified and came from several tree species found in mixed-deciduous forest, such as *Lagerstroemia* sp., *Vitex parviflora*, *Pterocarpus indicus*, and in mangrove forest, such as *Ceriops* sp, which was mainly of medium size and used for posts. One coffin has been radiocarbon dated to $\text{AD}140 \pm 390$ [31].

For the Late Pleistocene to Holocene period, the most well-known archaeological cave sites in Thailand are as follows: For the Lang Rongrien Rockshelter in southwestern Thailand, used from 3,500 to 4,300 BP, there is a date from a wood coffin of $2,530 \pm 45$ [32]; the Ongbah cave in Kanchanaburi province, western central Thailand, with dates of $11,180 \pm 180$ BP and

9,350 $\pm$ 140 BP [33]; the Phaa Chan Cave in north Thailand, which dates from 7,500 to 5,100 BP [34]; the Banyang Valley Cave in northwest Thailand, which dates from the beginning of the Hoabinhian period of the late Stone Age up to the Metal Age (3,500–900 BC) [35]; the Moh Khiew Rockshelter in Krabi province, which dates from 25,800 $\pm$ 600 to 4,240 $\pm$ BP^[36]; the Ban Rai Rockshelter, which dates to 10,600 $\pm$ 40 and 7,250 $\pm$ 40 BP [37]; the Tham Lod Rockshelter, which dates from 35,000 to 2,900 BP [15] and the Spirit Cave in Pang Ma Pha, Mae Hong Son province, which has a time period spanning from 7,622 $\pm$ 300 to the oldest date of 11,690 $\pm$ 560 BP [1, 2, 38]. Later work by Lampert et al. [39] has clarified the Spirit Cave sequence through dating of the resinous coating on a potsherd. The uncalibrated date for the Spirit Cave resin samples were reported as 3,042 $\pm$ 37 BP and 2,995 $\pm$ 40 BP.

Only two of the above archaeological sites refer to wood log coffins: Ongbah Cave and Spirit Cave. However, at Spirit Cave, Gorman [38] makes little reference to wooden coffins. At Ongbah Cave [3], more than ninety wooden coffins were found piled up at various places but no intact coffin was discovered. The coffins are boat shaped and their ends are shaped as stylized animal heads. The coffins are made of hardwood, one of the abundant *Dalbergia* sp.; regrettably, this species cannot be used for dendrochronology. The average total length of the coffins is between 3 and 3.5 m, and 14C dating yielded a result of 2,180 $\pm$ 100 yrs BP [3, 40]. In 2001, the highland archaeology project excavated the Ban Rai Rockshelter and reported a wide range of archaeological artifacts, including log coffins, which were dated to approximately 2,100–1,200 BP, stone tools, shards of pottery, animal bones and rock paintings [37]. The log coffins at Pang Ma Pha have various forms of heads. Previous studies used samples for dating that were selected on the basis of the different log coffin head styles to prove cultural

change. Wannasri et al. [14] employed dendrochronological techniques, together with 14C dating, to support the hypothesis that log coffin head styles became increasingly complex over time. They concluded that the people of the log coffin culture used multiple log coffin styles continuously and simultaneously. The oldest log coffin in this area is possibly from the La Hu Pot cave and has dated to 2,080 $\pm$ 60 (C14 age BP) (calibrated, 2 sigma; BC 355 – AD 55) and 1,120 $\pm$ 80 (14C age BP) (calibrated 2 sigma; AD 400–700) [41]. Our log coffin at Ban Rai dates to about 265 AD. In addition, using dendrochronological techniques on the teak log coffins provide a deeper knowledge about the Log Coffin Culture and the evolution of the style of coffin heads. Since teak ring width is significantly and positively related to the amount of rainfall, the variability of the tree-ring index series will indicate previous rainfall patterns. If the number of samples analyzed by the wiggle technique increases, the length of the archaeological teak index series will possibly be extended.

In Thailand, log coffins have also been discovered in other areas, such as in Tak and Chumphon in the West Mountain, Chiang Mai, Sukhothai and Ubon Ratchathani [4]. Unfortunately, these sites are not dated.

Hotchkis et al. [42] measured the 14C content in the outermost part of 10 log coffin samples from different caves in Pang Ma Pha, Mae Hong Son, Thailand. Combining the previously dated log coffins in this area with those from Vietnam and the Philippines, we conclude that the age range of the Mae Hong Son sample group spans from 2,209 $\pm$ 97 to 1,323 $\pm$ 85 BP; this indicates that the practice of log coffin burial in Southeast Asia has a continuous regional history. Grave [43] has studied the shift to commodities, and one of his hypotheses proposed an interaction between the lowland people and upland people in northwestern Thailand. He collected 14 coffin samples from dif-

ferent topographies in Nam Khong, Pang Ma Pha district. 14C dating was used, and the results from the coffin samples ranged from 2,200 BP to 1,200 BP. The early date of 2,240 BP from the Lahu Pot Cave corresponds to the coffin in the Ongbah Cave ($2,180 \pm 100$ BP). The two dates for the spears from Tak (located south of Mae Hong Son province) are earlier, with calibrated ages of 1,020 BP and 725 BP. Grave [43] concluded that the end of the Nam Khong log coffin practice was possibly due to the expansion of lowland trade and exchange.

In summary, teak from log coffins has the potential to unearth climate patterns in monsoonal regions. Past climate patterns may better explain human cultures since the majority of people in monsoonal regions depend heavily on natural resources. Therefore dendrochronology could be an answer to archaeologists interested in ancient human culture. Further research, combining samples from teak disks, standing buildings and using radiocarbon dating as well as the wiggle technique has good potential to be more widely applied.

Conclusion

We can now describe the Log Coffin Culture in NW Thailand using information from teak log coffins. The Pang Ma Pha district was once covered with fertile land with rich wildlife. The society's log coffin culture was extensive. These communities settled close to one another and tried to find as much open space as possible (since dense forests were dangerous due to wildlife). However, settling in one and the same area over a long period of time decreased the available agricultural area. The Pang Ma Pha district consists of mostly steep hills with little flat land. A population increase caused some of them to migrate, and they brought with them their cultural beliefs, especially their burial ceremonies. Consequently, numerous, diverse, and large wooden coffins have been found in this area. The ability to access the area (which

is not overly steep as there are no very high mountains) may have been attractive. This residential area was the major social centre of the Log Coffin Culture in NW Thailand.

By using 13 teak log coffin lids (39 cores) and 6 posts (15 cores) from Ban Rai Rockshelter, Pang Ma Pha district, Mae Hong Son province, we created three floating chronologies. In each series, the tree-ring patterns cross-dated well. However, we combined only three floating chronologies into one single series; the remaining floating chronologies probably have a gap between them. We found that the log coffin head styles were designed or crafted in the same period of time. They did not refer to an evolution as archeologists had originally assumed (simpler head styles should be older than complex ones). We used the wiggle technique on a sample taken from one of the coffins to examine a precise calendar year. It was found that the wood from this particular coffin (samples BR05, head style IIB) were cut dating around AD 265.

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