# A DENDROARCHAEOLOGICAL STUDY OF LOG COFFINS: BO KRAI CAVE AND BAN RAI ROCKSHELTER IN PANG MAPHA DISTRICT, MAE HONG SON PROVINCE

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## ABSTRACT

This thesis documents the dendrochronological and radiocarbon chronology of log coffin head styles in the Log Coffin culture from Bo Krai Cave and Ban Rai Rockshelter at Pang Mapha District, Mae Hong Son Province. At Bo Krai Cave, 71 wood samples were taken from 36 coffin lids and 3 supporting posts. At Ban Rai Rockshelter, 116 wood samples were taken from 27 coffin lids and 26 supporting posts. These samples were taken for dendrochronological analysis and radiocarbon dating. Statistical analysis of the dates and log coffin styles was then undertaken to test the hypothesis that the style of coffin heads becomes increasingly complex over time.

At Bo Krai Cave, analysis of correlations between these samples resulted in five dendrochronological series. These series indicated that the cave has functioned as a burial site with the same styles of log coffins used over a relatively long period of time. It means the people of the Log Coffin culture probably used each log coffin style continuously and simultaneously. All three chambers of Bo Krai Cave were probably used at the same time because tree-ring crossdating of samples from the three chambers shows that they have overlapping date ranges. At Ban Rai Rockshelter, correlations of the tree-ring width crossdating resulted in seven dendrochronological series. These series show this area was used as a burial site in several periods. The chronology of the log coffin head styles indicate that different styles of log coffins were used at the same time, similar to the pattern of coffin use at Bo Krai Cave. Different styles of log coffins, including 1A, 1B, 2A, 2B and 2C styles were used in several periods at this site. The different styles of log coffin do not show a pattern of increasing design complexity over time and or correspond with any cultural changes in this area.

Radiocarbon dates were obtained for 15 samples of wood from the coffins at Bo Krai Cave and Ban Rai Rockshelter. The radiocarbon data show that the log coffins in the study area date to between 1090±210 and 2330±230 yrs BP. This age is similar to other log coffin sites in Pang Mapha that date from the Late Holocene period. Moreover the radiocarbon data confirms the dendrochronological data because it shows overlapping between the simple styles and complex styles of coffin heads. This means that the chronology of log coffins styles in this area do not represent a development from simple styles to complex styles. These results have important implications for an understanding of the archaeology and cultural history of this area. The simultaneous use of different coffin styles suggests that style may be related to the status of the buried individual or their ethnic affiliation rather than cultural changes over time.

KEY WORDS: DENDROCHRONOLOGY / RADIOCARBON DATING / TEAK (*Tectona grandis* L.) / LOG COFFINS

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การศึกษาวงปีไม้ของโลงไม้จากแหล่งโบราณคดีถ้ำบ่อไคร้และแหล่งโบราณคดีเพิงผาบ้านไร่ อำเภอปางมะผ้า จังหวัดแม่ฮ่องสอน (A DENDROARCHAEOLOGICAL STUDY OF LOG COFFINS: BO KRAI CAVE AND BAN RAI ROCKSHELTER IN PANG MAPHA DISTRICT, MAE HONG SON PROVINCE)

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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อต้องการทราบถึงพัฒนาการของรูปแบบหัวโลงและอายุสมัยของโลงไม้ในวัฒนธรรมโลงไม้จากแหล่งโบราณคดีถ้ำบ่อไคร้และแหล่งโบราณคดีเพิงผาบ้านไร่ อำเภอปางมะผ้า จังหวัดแม่ฮ่องสอน ตัวอย่างไม้จากแหล่งโบราณคดีถ้ำบ่อไคร้รวมทั้งสิ้น 71 ตัวอย่าง จากโลงไม้ 36 ฝาและเสาไม้ 3 ต้น และตัวอย่างไม้จากแหล่งโบราณคดีเพิงผาบ้านไร่รวมทั้งสิ้น 116 ตังอย่าง จากโลงไม้ 27 ฝาและเสาไม้ 27 ต้น นำมาใช้ในการศึกษาด้วยวิธีการทางด้านวงปีไม้และกำหนดอายุด้วยวิธีธาตุกัมมันตรังสี (คาร์บอน 14)

ผลการศึกษาทางด้านวงปีไม้สามารถเชื่อมความสัมพันธ์ระหว่างโลงและเสาไม้จากแหล่งโบราณคดีถ้ำบ่อไคร้ได้ 5 ชุดข้อมูล แสดงให้เห็นว่า กลุ่มคนในวัฒนธรรมโลงไม้ใช้ถ้ำแห่งนี้เป็นสถานที่ฝังศพและมีการใช้รูปแบบหัวโลงแต่ละแบบอย่างต่อเนื่อง จากการซ้อนทับรูปแบบการเจริญเติบโตของต้นไม้ของตัวอย่างไม้อาจไปได้ว่าพื้นที่ภายในถ้ำทั้ง 3 คูหาถูกใช้เป็นพื้นที่ฝังศพในช่วงเวลาเดียวกัน ส่วนผลการศึกษาของแหล่งโบราณคดีเพิงผาบ้านไร่สามารถเชื่อมความสัมพันธ์ระหว่างโลงและเสาไม้ ได้ 7 ชุดข้อมูล พบว่า พื้นที่ส่วนต่างๆ ของเพิงผาถูกใช้เป็นสถานที่ฝังศพรวมทั้งมีการสร้างหัวโลงรูปแบบต่างๆ ในช่วงเวลาเดียวกัน หัวโลงรูปแบบต่างๆ คือ 1A, 1B, 2A, 2B และ 2C ถูกนำมาใช้ในหลายช่วงเวลา จึงทำให้ไม่สามารถใช้ลักษณะของหัวโลงที่แตกต่างกันเพื่ออธิบายถึงลำดับหรือเปลี่ยนแปลงทางวัฒนธรรมในพื้นที่ศึกษา

ผลจากการกำหนดค่าอายุด้วยวิธีคาร์บอน 14 จากโลงไม้จำนวน 15 ตัวอย่าง พบว่า โลงไม้ในพื้นที่ศึกษามีช่วงอายุ 1090±210 ถึง 2330±230 ปีก่อนปัจจุบัน และเมื่อเปรียบเทียบกับการกำหนดอายุของวัฒนธรรมโลงไม้ที่ได้จากแหล่งโบราณคดีอื่นๆในพื้นที่อำเภอปางมะผ้า พบว่าค่อนข้างจะอยู่ในช่วงเวลาเดียวกัน คือ สมัยโฮโลซีนตอนปลาย และผลการศึกษาทางด้านวงปีไม้และค่าอายุสมัยของโลงไม้ในพื้นที่ศึกษา พบว่า รูปแบบของหัวโลงในพื้นที่ศึกษาไม่ได้จัดลำดับจากรูปแบบอย่างง่ายไปเป็นแบบที่มีความซับซ้อนมากขึ้น แต่มีการใช้หัวโลงแต่ละแบบอย่างต่อเนื่อง ซึ่งการใช้หัวโลงที่มีลักษณะแตกต่างกันในระยะเวลาเดียวกันนี้ อาจสัมพันธ์กับสถานะทางสังคมหรือกลุ่มคนมากกว่าการเปลี่ยนแปลงตามช่วงเวลา

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# ACRONYMS

| | |
|---|---|
| A.D. | Anno Domini |
| ANU | Australian National University |
| B.C. | Before Christ |
| B.E. | Buddhist Era |
| cm | centimeter(s) |
| $^{14}C$ | carbon 14 |
| $^{14}CO_2$ | radioactive carbon dioxide |
| ENSO | El Nino and Southern Oscillation |
| g | gram(s) |
| km | kilometer(s) |
| m | meter(s) |
| min | minute(s) |
| ml | milliliter(s) |
| mm | millimeter(s) |
| yrs BP | radiocarbon years before present |
| σ | standard deviation |
| % | per cent |

# CHAPTER I
# INTRODUCTION

## 1.1 Introduction

Pang Mapha, an area of cultural and biodiversities, is a small district of Mae Hong Son Province in Northern Thailand (1). Archaeological evidence suggested that many of the caves and rockshelters in this area have been continuously occupied from 10,000 years ago up to present. Many of Thai and foreign researchers are interested in Pang Mapha but specific topics of interest have been scattered among the researchers, and no systematic research has been carried out prior to 1988 (2,3).

One of the major attractions is the remains of the Log Coffin culture generally found in many caves and rockshelters in this area. These represent the special burial practice of coffin culture in Pang Mapha District. Log coffins were typically made of a teak log splitting in half and dug-out inside. Both ends of the coffins, called heads, were decorated with carving of different styles. Generally, the log coffins were usually found in pairs and were placed on wooden posts or beams in the caves. Other associated items are also associated with the coffins, such as stone tools, small metal artifact, fragments of animal bones, human skeletons, ashy layers and pottery. In some cases, rock paintings are also found (2,3,4,5,6,7). Previous radiocarbon dating of coffins suggested that they date ranging from 2,200 years ago to 9$^{th}$ century A.D. (2,8). In other words, this dates to Iron Age to historical period of northern region (1).

Teak (*Tectona grandis* L.) was widely used and valued during the time of the Log Coffin culture. This is one of the few tropical tree species that forms clear annual growth rings (9,10). This means that dendroarchaeology can be used on the log coffins to establish tree-ring dates. Currently, many research questions about log coffins found at archaeological sites lack evidence to provide convincing answers; for example the different styles of coffin heads may show the evolution of culture when they are arranged by age. Although some pieces of log coffins have been radiocarbon dated to provide ten dates (8,11) this does not yet suggest a convincing relationship between the styles of coffin heads and their ages because of the small number of samples dated.

The hypothesis of this study is the different styles of coffin heads arranged by age and show changes over time. If this hypothesis is correct, the different styles of coffin head will have different age range when crossdated by dendrochronological and radiocarbon dating methods. Similarly, log coffins of the same style will have similar dates. In this case, Bo Krai Cave and Ban Rai Rockshelter are important and interesting research areas because the head forms of coffins from the both sites have twelve styles and resemble each other in five styles and the both sites have abundant of log coffins. It is important to study the relationship and arrange an evolutionary sequence of head form. Finally, these types of data could be very valuable to understand the Log coffin cultural period at Pang Mapha, Mae Hong Son Province.

## 1.2 Research Questions

1. What is the dating of the teak log coffins at Bo Krai Cave and Ban Rai Rockshelter in Pang Mapha, Mae Hong Son Province?
2. What is the chronology of log coffins' head style at Bo Krai Cave and Ban Rai Rockshelter in Pang Mapha, Mae Hong Son Province?

## 1.3 Research Objectives

1. To examine the chronology and the relationship of the log coffin styles by applying tree-ring technique.
2. To explain the date of log coffins from Bo Krai Cave and Ban Rai Rockshelter by using radiocarbon dating technique ($^{14}C$ method).

## 1.4 Scope of the study

1. The study area was focused on two sites: Bo Krai Cave and Ban Rai Rockshelter in Pang Mapha, Mae Hong Son Province in order to control a

microclimate. Environmental conditions are an important influence on tree growth and tree-ring width. Therefore, tree growth in the same or similar environmental conditions and time interval will have uniform ring structure. In addition, both sites have a lot of log coffins that show variation in the styles of coffin heads. This variation is necessary to study the evolution and the relationship of the log coffin styles by tree-ring series.

2. This study examined 187 samples of teak log coffins and posts from Bo Krai Cave and Ban Rai Rockshelter as part of "The Highland Archaeology Project in Pang Mapha, Mae Hong Son". At Bo Krai Cave a total of 71 samples were taken from 36 log coffin lids (68 cores) and 3 posts (3 cores) on 25 and 27 December 2001. At Ban Rai Rockshelter, a total of samples 116 samples were taken from 27 log coffin lids (64 cores) and 26 posts (52 cores) during 12-13 May and 29 December 2001.

## 1.5 Expected result

1. The chronology style coffin heads from Bo Krai Cave and Ban Rai Rockshelter in Pang Mapha, Mae Hong Son Province.
2. The age of log coffins from Bo Krai Cave and Ban Rai Rockshelter in Pang Mapha, Mae Hong Son Province.
3. A Teak chronology database from archaeology sites in Thailand.

## 1.6 Definition of terms

1. The Log Coffin culture is a distinct mortuary practice in highland Pang Mapha District, Mae Hong Son Province, Northern Thailand. Log coffins were located either in chambers or at the mouths of caves and rock-shelters in this area. The coffins are made from a longitudinal half of a teak log that has been hollowed out. The log coffins often place on posts and cross beams inside caves or under cliff overhanging. Human skeleton and grave goods were probably placed in these log coffins. Unfortunately, no coffin was discovered completely intact (2,5).

2. Annual rings or tree rings are formed in varying physiological conditions that influence cell formation throughout the growing season (6-7 months per year). The wood cells produced early in the growing season are large, thin walled, and less dense (earlywood), while the cells formed at the end of season are smaller, thick-walled, and more dense (latewood). An abrupt change in cell size between the last-formed cells of one ring and the first formed cells of the next marks the boundary between annual ring (12). The beginning of earlywood formation and the end of the latewood formation result in one annual ring, which usually extends around the entire circumference of the tree (13).
3. Dendroarchaeology is the science that use tree rings to date wood material found in archaeological site or artifact (14).
4. Radiocarbon dating is one of the most widely used and best known absolute dating methods. This method is used in a wide range of scientific disciplines including archaeology, geology, soil science, climatic reconstruction and oceanography (15).

## 1.7 Conceptual Framework

Debate over the meaning of differences in styles of material cultural has been part of archaeology for many years (16,17,18,19). Style has been considered by many writers to be the result of a choice between more than one way of doing something (20). It has been interpreted as many things, including evidence of ancient symbolism and as chronological markers. Much recent work on style in ethnoarchaeology and archaeology is based on Wobst's proposal (17) that style is a form of information exchange (18). In many cases, differences of material culture are associated with differences in ethnicity and style is a means of displaying this difference.

In this thesis the style of log coffins in Pang Mapha District, Mae Hong Son Province is the recorded as way that the coffins are decorated. This thesis is concerned with how coffin styles relate to each other chronologically and how the styles change over time. Although log coffins spend most of their time in a dark cave, they are produced and used in public funerary contexts. This means that variation is the style of coffins is likely to indicate variation in ethnic identity as well as ritual systems.

Previous studies of log coffin styles have suggested a simple chronological progression from simple styles to more complex styles and have tended to minimize the function of the coffin styles. This thesis attempts to put the style of coffins into a more anthropological framework by producing a fine-grained chronological relationship between different coffin head styles. High resolution chronological information is obtained by crossdating patterns of tree-ring growth of samples taken from the coffins. This is intended to show if coffins were made from trees growing at the same time or at different times, and the chronological order of coffin styles. Radiocarbon dates were also obtained from the samples to provide absolute date ranges for the different coffin styles.

Using these methods it will be possible to how the different styles of coffin heads are arranged by age and how the styles changes over time. It will also be possible to show if different styles are used at the same time, and how many different styles are used at the same time. This is important because in some cases increases in differences in material culture are associated with increases in social tension and competition (21,22). By building a detailed chronology of log coffin styles this thesis can then propose an anthropological explanation for one element of the Log Coffin culture.

# CHAPTER II
# LITERATURE REVIEW

This chapter consists of two parts. The first part attempts to explain the characteristics of teak (*Tectona grandis* L.), the environmental factors that influence the growth of teak, geographical distribution, and the general principles of dendrochronology, and radiocarbon dating. Also, the discussion will cover previous dendrochronological studies in Thailand, including Bo Krai Cave and Ban Rai Rockshelter, Pang Mapha District, Mae Hong Son Province.

The second part discusses the archeological investigations of the Log Coffin culture at Pang Mapha District. At first, there was setting up period of time for studying refers to the Log Coffin culture period. The next phase describes the collection of data about the forms of log coffins and posts, archeological evidence found with log coffins, and environmental conditions in Pang Mapha District, Mae Hong Son Province from the past to present. However, it is necessary to refer to some relevant information from other study areas because they include some interesting and relevant points that have never been studied before in the study area examined here.

## PART I

### 2.1 The characteristics of teak (*Tectona grandis* L.)

This teak once formed major component of moist deciduous forests (23) and is one of the most valuable timbers of the tropics (24). Teak trees can reach an age of 400 years. Teak heartwood is one of the most well known and highly regarded in the world and it has a wide range of uses. It is used for construction in contact with water (docks, rails, latches, etc.), house building, furniture and numerous other purposes (23,24). The properties of teak that make it so valuable are its lightness, strength, stability, durability, ease of working without cracking and spitting, resistance to termites, resistance to fungi, resistance to weather and non-corrosive properties (24).

The species is a member of the family Labiatae (25,26). The genus *Tectona* consists of three species and is well known through *Tectona grandis*, which yields the valuable teakwood widely used since early historical times. The other species are *Tectona hamiltoniana* and *Tectona philippinensis* (27). Teak is a medium to large-sized tree. It reaches to about 50 m high with an irregularly formed crown and with low buttresses. It reaches to about 50 m high with an irregularly formed crown and with low buttresses. In natural stands, the trunk is generally straight and branchless up to 20 m with diameters of up 250 cm at breast height. Sometimes small branches sprout on the main trunk. The bark is light brown to grey, the dead outer bark grayish black and drops off in short longitudinal flakes (Figure 2-1). The young twigs are four-angled in cross-section. The leaves are simple oppositely in pairs and alternately at right angles with each pair forming four rows (decussate) and some are in three (ternate). The flowers are loosely set in the flower clusters. The fruits are somewhat fleshy when green, more or less rounded, slightly four-angled, when dry woody. The seeds are without albumen (nutritive material stored in seed), i.e., endosperm (28). Teak Sapwood is yellowish white and heartwood dusky red (29). Sapwood is 2 to 5 cm. wide (23). It has been observed that teak grown in wetter areas has wider sapwood than teak grown in drier areas (23,30).

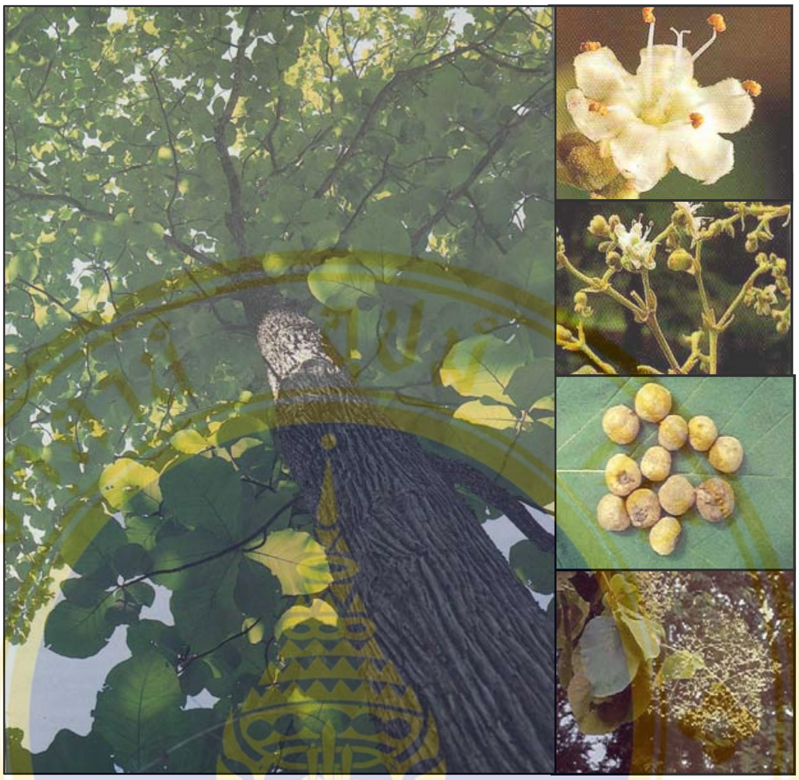


**Figure 2-1** Teak (*Tectona grandis* L.) (31,32)

**2.1.1 The environmental factors affecting of teak growth**

There are many factors controlling growth of teak and the distribution but the most important factors include climate (rainfall and temperature), soil and topography. These factors influence both the distribution and growth pattern of this species, particularly in Thailand. Teak naturally occurs over a wide range from very dry localities to very moist localities (24,33). It thrives in forests often exposed to fire. The range of annual rainfall in Thai teak region is 1,000-1,800 mm. The most favorable range of rainfall for better growth and timber qualities of this species is about 1,200 mm. The optimum temperatures for growth and development of teak seeding is between 27/22$^{o}$C to 36/31 $^{o}$C (day/night temperature) with the most favorable temperatures of 30/25$^{o}$C. It grows well on limestone soil. The most suitable soil for teak is deep and well drained alluvial soil with an optimum range of soil pH between 6.5 and 8.0 and with a relatively high calcium (Ca) and phosphorous (P) content. Teak is light-demanding species and the optimum light for its growth and development is between 75 to 100 per cent of the full sun light (33).

### 2.1.2 Geographical distribution

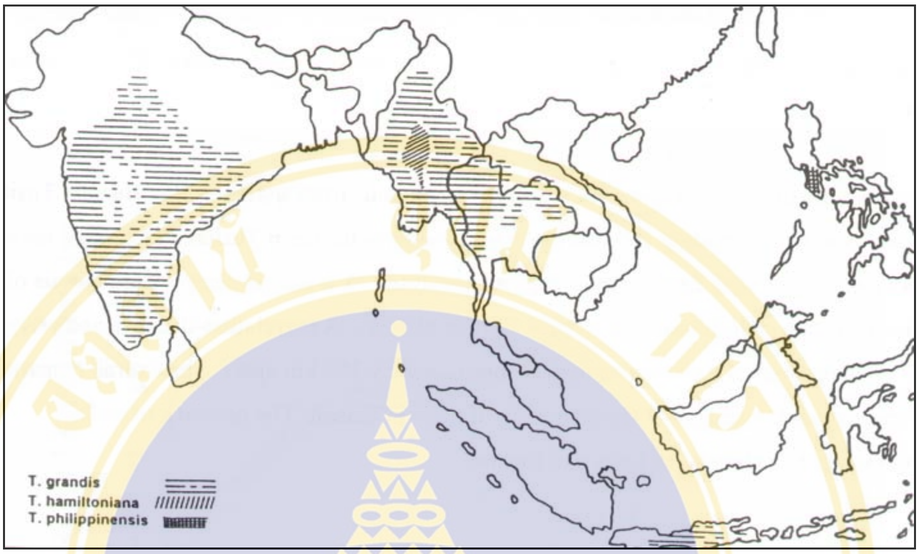



**Figure 2-2** The natural distribution of teak (27)

The genus occurs naturally in various tropical deciduous forest of Asia (Figure 2-2). The natural distribution of teak is limited to the Southeast Asian region. The species range from India to Myanmar, Laos and Thailand (23,24). *Tectona grandis* L. covers a much wider range than the other species (*Tectona hamiltoniana* and *Tectona philippinensis*) within its natural area of distribution teak can constitute the numerically dominant tree species at 400 to 800 m above sea level (27). At these altitudes teak occurs in tropical deciduous forests with a pronounced dry season. It is cultivated in many other parts of Asia due to its high quality and beauty. Teak was introduced into Indonesia several hundred years ago and has also been planted in Latin America and Africa (23).

## 2.2 Dendrochronology

Dendrochronology is a method that uses tree-ring analysis to establish chronology. A major application of dendrochronology in archaeology is as a tool for establishing tree-ring dates. This method makes it possible to date individual ruins to within a year, or even a season, of the day they were built. Often, the tree-ring analysis from sites can give strong clues about the length of occupation, certain periods of building or repair activities at the site, as well as demonstrate practices of reuse or stockpiling by early inhabitants (34).

The annual ring cycle of tree-ring formation has been known for long time and for many years tree rings were counted to establish the ages of growing of dead trees. However, the modern science of dendrochronology was pioneered by A. E. Douglass, an astronomer who had set out to investigate sunspot cycles by tracing climatic factors reflected in the growth of trees. From his earliest studies, which were purely climatic in their objectives, he went on to establish, in a systematic manner, an absolute chronology for the southwestern United States (34).

Thus, the study that started as an aid in the investigation of climate, and used archaeological data to extend the chronology, has provided an important tool for archaeologists in their efforts to solve archaeological problems. Since the discovery of the technique, hundreds of prehistoric ruins have been dated. Current research in dendrochronology is concerned with establishing chronologies for other species of trees and different parts of the world where it can be applied. Efforts are being made to simplify the method of recording and standardize ring sequence with the aid of computers (34).

### 2.2.1 The Underlying Process in Dendrochronology

Tree-ring analysis is based on the phenomenon of formation of annual growth rings that occurs in many trees (Figure 2-3). These rings can be recognized most clearly in trees that grow in areas with regularly alternating seasons. Usually trees produce one ring in every year from the cambium. Cambium is the layer of soft, cellular tissue that lies between the bark and the old wood (34).

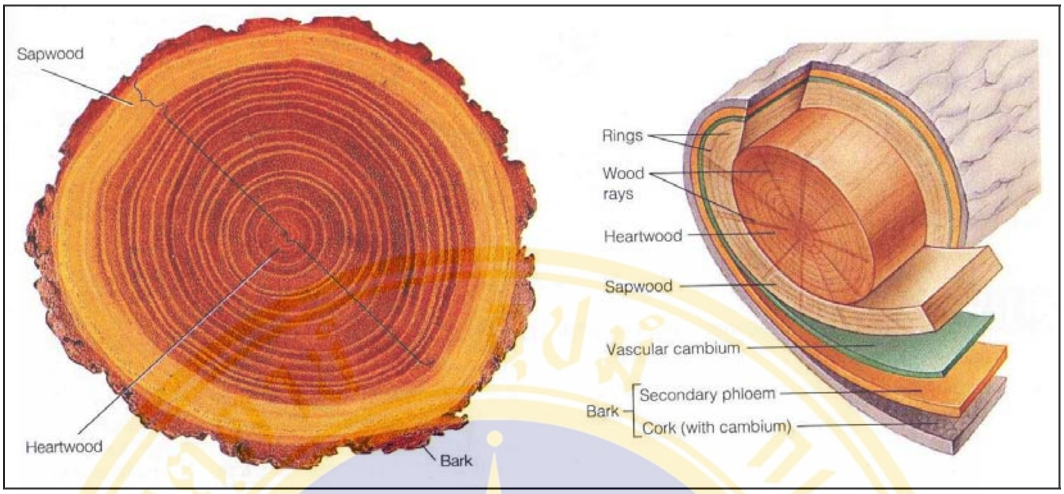



**Figure 2-3** The biology of tree growth (35)

This growth occurs in a very thin layer of cells that completely shrouds the tree called the vascular cambium. Here, cambial cells divide, with the outer cells contributing to the formation of phloem tissue, which helps transport nutrients downward from the crown of the tree. As phloem cells become older and die, they contribute to the protective outer layer of the tree (the bark).The inner cambial cells contribute to the formation of woody tissue called xylem. The xylem is divided into sapwood, which transports water and sap upward, and darker colored heartwood at the interior of the tree trunk, consisting of xylem cells where waste substances have accumulated (14).

In the spring, or generally at the start of growing season, groups of large, thin-walled, light-colored cells are added to the existing wood. As the season progresses these cells merge gradually with new cells which become increasingly smaller, darker, and more thickly walled, until the production of cells stops abruptly at the end of the summer or the wet season. The process is repeated the following year, and a clear line thus is formed between the summer growth of one year, with its small dark cells, and the new spring growth of following year with its large, light-colored cells. Growth rings thickness varies throughout the year. This variation is caused by two major factors. First, ring thickness varies with the age of the tree and the rings becoming narrower as the tree gets older. The inner rings of tree are therefore wider than its outer rings. This factor is independent of climate and location, and must be considered and taken into account when the rings are analyzed. The second source of variation in the thickness of growth rings is the change in climate from one year to another. In year with unfavorable weather, such as drought, the growth rings will be unusually narrow. On the other hand, during years with exceptionally large amounts of rain, the tree will from much wider growth rings. Most of the trees in a given area will show the same variability in the width of their growth rings because of the climatic fluctuations they have all endured. Such trees are said to be sensitive; those that do not exhibit variability are said to be component (34).

### 2.2.2 The Principles of Dendrochronology

As with any science, dendrochronology is governed by a set of principles. These principles have their roots as far back as 1785 (the Principle of Uniformitarianism) and as recent as 1987 (the Principle of Aggregate Tree Growth). Some are specific to dendrochronology while others, like the Principle of Replication, are basic to many disciplines. All tree-ring research must adhere to these principles or the research could be flawed. However, before one can understand the principles, one needs to know basic definitions of terms used in tree-ring research (13).

#### 2.2.2.1 The Uniformitarian Principle

This principle states that physical and biological processes that link current environmental processes with current patterns of tree growth must have been in operation in the past. In other words, “the present is the key to the past”, as originally stated by James Hutton in 1785. When applying this principle to dendrochronology, it means that the variations in conditions present today must have been present in the past. This does not mean that the conditions are exactly the same but that similar kinds of influences affected the similar kinds of processes. However, dendrochronology adds a new twist to this principle: “the past is the key to the future” In other words, by knowing environmental conditions of the past through the analysis of tree rings use may be able to predict or manage similar environmental conditions in the future (12,13,36,37).

**2.2.2.2 The Principle of Limiting Factors**

This principle states that rates of plant processes are constrained by the primary environmental variable that is most limiting. For example, precipitation is often the most limiting factor to plant growth in arid and semiarid areas. In these regions, tree growth cannot proceed faster than that allowed by the amount of precipitation, causing the width of the rings to be a function of precipitation. In some locations, rainfall is not the most limiting factor. For example, in the higher latitudes, temperature is often the most limiting factor that influences tree growth rates. In addition, the factor that is most limiting is often acted upon by other non-climatic factors. While precipitation may be limiting in semiarid regions, the effects of the low precipitation amounts may be compounded by well-drained soils (12,13,36,37).

**2.2.2.3 The Principle of Aggregate Tree Growth**

$$\mathbf{R_t = A_t + C_t + \delta D1_t + \delta D1_t + E_t}$$

This principle states that any individual tree-growth series can be decomposed into an aggregate of environmental factors, both human and natural, that affected the patterns of tree growth over time. For example, tree-ring growth (R) in any one year (indicated by a small "*t*", where *t* could be "1" for year 1, and "2" for year 2, etc.) is a function of an aggregate of factors:

A = the age related trend due to normal physiological aging processes.

C = the climate that occurred during that year.

D1 = the occurrence of disturbance factors within the forest stand (for example, a blow down of trees).

D2 = the occurrence of disturbance factors from outside the forest stand (for example, an insect outbreak that defoliate the trees, causing growth.

E = random (error) processes not accounted for by these other processes (13).

**2.2.2.4 The Principle of Ecological Amplitude**

This principle states that a tree species will be more sensitive to environmental factors at the latitudinal and elevational limits of its range. This principle is important because tree species useful to dendrochronology are often found near the margins of their natural range (12,13,36,37).

**2.2.2.5 The Principle of Site Selection**

This principle states that sites useful to dendrochronology can be identified and selected based on criteria that will produce tree-ring series sensitive to the environmental variable being examined. For example, trees that are especially responsive to drought conditions can usually be found where rainfall is limiting, such as rocky outcrops, or on ridgecrests of mountains. Therefore, a dendrochronologist interested in past drought conditions would purposely sample trees growing in locations known to be water-limited. Sampling trees growing in low-elevation, mesic (wet) sites would not produce tree-ring series especially sensitive to rainfall deficits. The dendrochronologist must select sites that will maximize the environmental signal being investigated (13,37).

**2.2.2.6 The Principle of Crossdating**

Crossdating is the most important principle of dendrochronology and refers to both a principle and practice. This principle states that matching patterns in ring widths or other ring characteristics (such as ring density patterns) among several tree-ring series allow the identification of the exact year in which each tree ring was formed. For example, one can date the construction of a building, such as a barn or Indian pueblo, by matching the tree-ring patterns of wood taken from the buildings with tree-ring patterns from living trees. Crossdating is considered the fundamental principle of dendrochronology without the precision given by crossdating, the dating of tree rings would be nothing more than simple ring counting (13).

**2.2.2.7 The Principle of Replication**

This principle states that the environmental signal being investigated can be maximized, and the amount of noise (environmental factors not being studied, such as air pollution) minimized, by sampling more than one stem radius per tree, and more than one tree per site. Obtaining more than one increment core per tree reduces the amount of intra-tree variability, in other words, the amount of non-desirable environmental signal peculiar to only tree. Obtaining numerous trees from one site, and perhaps several sites in a region, ensures that the amount of noise is minimized (13,37).

**2.2.3 Dendrochronological studies in archaeology**

The value of dendrochronology is its use as a tool that can be applied to a variety of research questions, all of which concern to some degree changes in the environment over time. Interestingly, the practice of tree-ring dating would be impractical unless it was applied to help answer a research hypothesis. For example, dendroarchaeology is the science that uses tree rings to date the wood material found in archaeological sites or artifacts, and has been most often applied in the Southwestern United States and Europe. In fact, dendrochronology came of age when A.E. Douglass was able to connect his ring chronology obtained from living trees with those chronologies he had developed from trees used in archaeological sites in the American Southwest, effectively dating the construction to the year of many of the Southwestern pueblos. The use of tree rings is still a major application in the American Southwest today. In Europe, dendrochronologists are often employed to date the period of construction of barns, manors, cathedrals and churches, Roman bridges, wells and fountains, pile dwellings in lakes, and Neolithic settlements. In 1996, dendrochronologists from Cornell University announced the development of a multimillennial tree-ring chronology that helped rewrite Mediterranean archaeological history. Dendrochronology is also useful for dating the likely construction period of any piece of wooden artwork or musical instrument (14). In this study used the dendrochronological dating to examine the chronology and relationship of the log coffin styles from Bo Krai Cave and Ban Rai Rockshekter and building the Teak chronology database from Thailand.

**2.2.4 Dendrochronological studies in the tropical forest**

Dendrochronological studies in the tropical and subtropical forest belt were for a long time believed impossible and impractical (38) because of frequent heavy rain and high temperatures in rainy season and dry but steady high temperatures in the hot season, most trees are growing at the same rate all year (39). Consequently, many tropical tree species have little or no discernible ring structure (40). However, the increasing demand for palaeoclimatic information stimulated dendrochronologists to extend their study areas from the southern and northern temperate zone towards the equator (38). One of the key phenomena for climatologists is the palaeomonsoon in Southeast Asia. Dendrochronological research could contribute to a better understanding of dynamic of this Southeast Asia monsoon (41,42).

A few species such as teak (*Tectona grandis* L.), pine (*Pinus kesiya* and *Pinus merkusii*) and Podocarpaceae have been proven to produce distinctive ring growth, which are possible to work with dendrological purposes (39).

Some of the earliest studies on periodic tree growth in the tropics extend back to Brandis in 1890 in India (43). Later, Coster (1927) investigated the periodicity of diameter growth for more than 200 tree species in Southeast Asia (41). A dendrochronological approach was first applied by Berlage (1931) to teak in Java, teak in Indonesia (9), and with various tropical tree species in India (44).

In Thailand, promising results were reported for various tree species including *Pinus* and *Podocarpus* in Thailand (40), after a correlative study of pine tree-ring width and climatic variables at Nam Nao and Phu Kradung National Parks (45). Research has also investigated on *Pinus merkusii* tree ring response to climatic factors (rainfall and temperature) and compared growth patterns of *Pinus merkusii* and ecological characteristics in Northern Thailand at Doi Tum Mak Keang in Mae Hong Son Province, in central Thailand, at Phu Toei National Park in Suphan Buri Province and in the upper southern part of Thailand at Pha Chum Chon in Phetchaburi Province (46). Moreover, Sukkosol (47) studied another view of dendrochronological investigation through drought and flood events of Thai historical documentary records with rainfall data and tree rings indices of *Pinus Kesiya* from Nam Nao and Phu Kradung National Parks. The result of the study showed some tree rings of drought and flood years matched both historical data and rainfall data.

In Southern Thailand, Peeranart studied correlation of surian (*Toona febrifuga* M. Roem) tree-ring widths at Khao Pu-Khao Ya National Park with climate (rainfall and temperature) and El Nino-Southern Oscillation (ENSO) with the Japan Meteorological Agency (48).

For teak (*Tectona grandis* L.) dendrochronological studies in Thailand, Pumijumnong et al. (42) established a network of teak chronologies in northern Thailand (Mae Hong Son, Lamphun, Phrae, Tak and Lampang Provinces). The purpose of this study was to present the output of dendrochronological research on teak to reconstruct climatic data in Northern Thailand over the last 200 years in relation to annual rings and describe the cambial activity of teak during the growing season for a better understanding of climate-growth relationships. A total of 425 cores from 288 teak trees were taken at breast height (1.3 m), and processed dendrochronologically. The longest site chronology, from Maetuen, Tak Province has a length of 312 years. The results revealed that the correlation between the annual rings of teak and both monthly rainfall and average temperature was significant. The temperature and rainfall could be reconstructed back to 1870 from 1990 (or 120 years) with good data quality. Valuable information about cambial activities such as the start of the growth period could be observed (41,42,49,50,51).

Long-term trends of ENSO in Thailand have been reconstructed from teak and pine (*Pinus kesiya* and *Pinus merkusii*) tree-ring width. Teak and pine chronology index are significantly positively correlated with rainfall for only half of rainy season, and there are no significant correlations with temperature. The Teak Index shows significant negative correlations with the ENSO index from May-October in current year and the Pine Chronology Index shows significant negative correlations with the ENSO index from September to December in previous year and January to April in the current year (10). For the study on paleomonsoon climate in Southeast Asia (northern part of Thailand and Myanmar) samples were taken from 183 teak trees in the areas included the upper and lower northern part of Thailand which covered Mae Wong National Park (Nakorn Sawan and Tak Provinces), Khlong Wang Chao National Park (Tak and Kampaeng Petch Provinces), and Pai Wildlife Sanctuary (Mae Hong Son Province). In Maynmar, samples from 187 Teak trees were collected from Seinye Research Station (humid mixed-deciduous forest), Moswe Research Station (arid mixed-deciduous forest), and Pyinoolwin Reserve Forest (lower northern part of Myanmar). The new 11 teak chronology indices from Thailand have been constructed. The longest index is 255 years during 1742-1996. The study revealed that for teak growth in the lower northern part of Thailand, rainfall in July and September of the current year has a significant positive correlation with the tree-ring width. Temperature in August and September of current year shows significant negative correlation with tree-ring width. Teak from upper northern part Thailand, rainfall in May-July of current year has significant positive correlation however temperature does not show any significant correlation with tree-ring width. In contrast, teak vessel data (cross-section area of vessel, vessel diameter, vessel density, and vessel conductive area) has negative correlation with rainfall and positive correlation with temperature (52).

The new 13 teak chronology indices from Myanmar have been constructed. The longest teak chronology from Moswe Research Station is 248 year (1750-1997). Teak growth in arid areas with rainfall in September-October of current year has a positive correlation with tree-ring width. Temperature in February, April and May of current year has a significant positive correlation with tree-ring width. For teak growth in humid areas, only temperature in August and September of current year has a significant positive correlation with tree-ring width. Teak in the lower northern part of Myanmar and rainfall in April of current year has a significant positive correlation with tree-ring width. Temperature in December of current year has a significant positive correlation with tree-ring width (52).

The ecological dynamics study of mixed deciduous forest used tree rings of teak at Mae Wong National Park. The correlation between teak growth patterns and climate data from the Tak weather station showed a positive relationship with the amount of rainfall in September of current year, at the end of rainy season but it showed an unclear relationship with temperature (53). Teak at the regional plantation of Saraburi in central Thailand is being used to clarify teak reaction on various external factors as climate and the ambient air particulate matter content (54).

These studies also pointed out that the growth of teak in Northern Thailand have been, and still are, influenced by the amount of rain during the beginning of the wet period. These suggest the potential of receiving a broader knowledge on the dynamics of monsoon palaeoclimate from teak annual rings.

It is difficult to make long chronologies from living trees in Thailand. To extend tree-ring chronologies, Sumitra Phanijkul (55) studied the first pioneering of tree-ring analysis on old teak timber in Thailand used material from houses in Ban Koh Noi and living trees in Srisatchanalai National Park. The result showed distinctly narrow ring in the same year and suggested that further research could be conducted on teak stumps, other objects made from teak, or historical buildings.

Dendroarchaeological study in Thailand started in 2001 as part of "The Highland Archaeology Project in Pang Mapha, Mae Hong Son". This is a interdisciplinary research project involving archaeology, physical anthropology, and dendrochronology. The project studied tree ring and ancient environment from wood samples and the log coffins in archaeological site that were primarily used for burials during the Late Holocene or Log Coffin culture period (2,200 years ago – 9$^{th}$ century A.D.). Craft specialization in wood and metal occurred during this time. Wooden coffins are diagnostic of this period (2). The chosen sites were Mae Lang Jun Cave (56). In 2001, Pipad Krajaejun (57) studied the log coffins and posts in Ban Rai Rockshelter for his

BA's thesis. Dendrochronological study at Bo Krai Cave by Sineenart Wannasri (58) and other sites such as Lod Cave, Umong Cave, Phadang Cave and Loangyuk Cave by Nathsuda Pumijumnong (59) were also conducted applying different approaches including archaeology, dendrochronology and ethnology. It has been shown that there were skilled carpenters with an elaborate knowledge of local timbers, particularly teak and the outstanding characteristics of difference type of wood (60). In terms of paleoenvironment, results of the tree rings, analyses of fauna remains and palynology indicate the Late Pleistocene and Early Holocene climate was slightly colder and moister than at present. During the Late Holocene, particularly the Log Coffin cultural period, the vegetation may have been much denser than at present. Finally, the vegetation changed rapidly after the forest concessions of the past 150 years (2).

However, previous studies have not extensively used dendrochronological techniques to compare the relationship between log coffins found at archeological sites. To understand the log coffins, which are the most outstanding remains of that period, it is necessary to understand the meaning of the variations in coffin head styles, which may indicate a cultural sequence. Hence, it is necessary to find and fill the blanks of knowledge in archeological science because it is hardly possible to understand the past through stories without supporting evidence. It is necessary to use an integrated study method to compile knowledge to find the answer.

**2.3 Radiocarbon dating**

Another application of tree-ring analysis is the analysis is the inference of past environmental conditions (12,36). This type of data could be extremely valuable to archaeologists. The accuracy of the chronometric scale established by tree-ring analysis has resulted in an effort to use these scales for calibrating dates obtained using other dating methods (61,62). In this study, the chronology of the wood sample will be calibrated with radiocarbon dates ($^{14}C$ method) to check the accuracy of tree-ring chronological series and establish the age of wood sample from Bo Krai Cave and Ban Rai Rockshelter.

Carbon-14 ($^{14}C$) dating techniques were first developed by the Willard F. Libby who received the Nobel Prize in Chemistry in 1960. $^{14}C$ is a low energy beta emitter with a radioactive range in air of ten inches. It is created in the upper atmosphere by the capture of cosmic produced neutron on nitrogen resulting in the emission of proton and the creation of a $^{14}C$ atom. The $^{14}C$ is then oxidized to radioactive carbondioxide ($^{14}CO_2$) and distributed evenly through out the global atmosphere (63).

From the cosmic space a continuous flux of particles that primarily high energy proton enters the atmosphere. Through collisions with the nuclei of the atmospheric gas molecules, a broad spectrum of particles is produced, amongst which are neutrons. During collisions with air molecules these neutrons which have high energies when first formed slow down. The Result of low energy neutrons has a fair change of causing the nuclear action (64).

Plants assimilate $^{14}C$ during photosynthesis so all living terrestrial creatures maintain their $^{14}C$ input during life. Similar, $^{14}CO_2$ dissolves in the oceans and is available to plankton so that all creatures during their life continuously replenish their $^{14}C$ content. At death of plant or animal $^{14}CO_2$ input ceases. Time of death can be establish by residual $^{14}CO_2$ content of the remains, since without fresh input, $^{14}C$ decay with a half life of 5,730 years (63).

The $^{14}C$ age is based primarily on the assumption of constancy of $^{14}C$ concentration in the past. This means that the concentration of radiocarbon in a sample at the time of its death (deposition) is assumed to be the same as in contemporary sample derived from the same environment (63). In principle, the log coffins were made from wood in the same time and area should have the same value of radiocarbon concentration in a sample.

Dendrochronological dating and $^{14}C$ dating have occasionally completed with each other. Nowadays these methods jointly provide precise dates of prehistoric culture, from which date of prehistoric cultures from which large dimensioned timber constructions have been preserved. Although, the $^{14}C$ dating cannot only provide with estimates of the absolute age of sample but it give initial and terminal dating for culture phase. However the differential duration in the same area can explain about the direction of cultural change. In other hand, the differential duration in different areas can answers to the direction of cultural movement.

## PART II

### 2.4 Log Coffin culture

Evidence of the Log Coffin culture has been found in caves and shelters. This was the special ceremony of coffin burials in Pang Mapha District. Generally, the log coffins were usually founded in pairs and were put on posts or wooden beams in the caves (Figure 2-4). Other items are also found with the coffins, such as human skeletons, cord-marked potsherds, glass beads, iron implements and bronze implements (4).

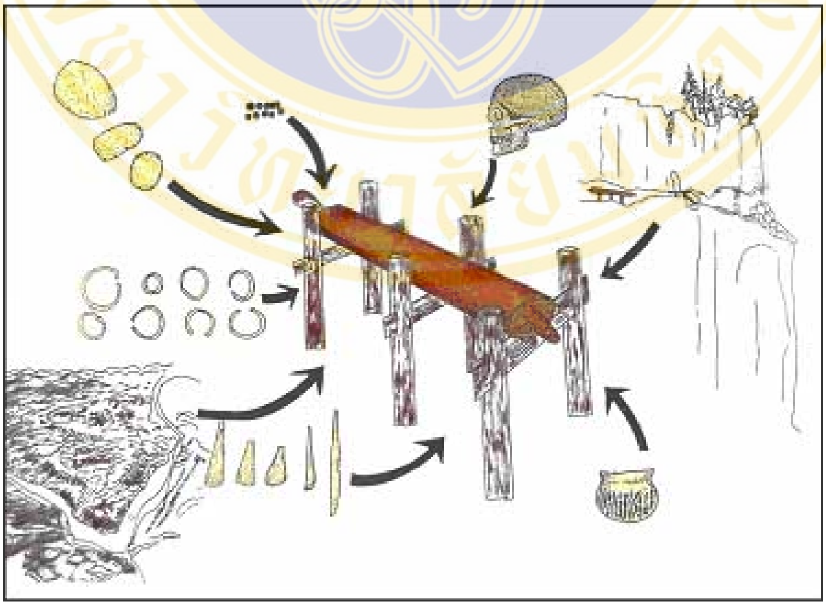


**Figure 2-4** The characteristic of Log Coffin culture in Pang Mapha, Mae Hong Son (4)

During the Log Coffin culture period or Iron Age (2200 yrs BP to 9$^{th}$ century A.D.), the sites were located almost on the top of the limestone cliffs and were primarily used for burial. No evidence of habitation has been found. Wooden coffins with various head styles are diagnostic of this period (1).

Archaeological research indicates that log coffin burials are a widespread mortuary practice in Southeast Asia (65,66,67,68). Typically preserved in caves of limestone karst formations, the distribution of log coffins ranges from southern China through the uplands of Vietnam, Myanmar and northwestern Thailand to the islands of Borneo, Sarawak and the Philippines. While the practice has continued into the modern period in some parts of Southeast Asia, for example among the Lua hill tribe, dated remains indicated that log coffins burial is a practice of considerable antiquity in the region (69).

In Thailand, log coffins have been discovered in many areas such as Mae Hong Son, Kanchanaburi, Tak, Chumphon in West mountain and other sites; Chiangmai, Sukhothai, Ubonratchathani (11,70,71,72,73,74). Log coffins are called various names because of differences in styles and functions. The Cave Survey and Database System Project in Mae Hong Son Province (3) and the Highland Archaeology Project in Pang Mapha: Phase I (2) indicate that log coffins were used for burial and the inhumation of human remains.

In 1969, the earliest then known site was investigated by American archaeologist Chester Gorman who wrote a doctoral thesis at the University of Hawaii on his findings from the Late Pleistocene through Early Recent periods. At Spirit Cave, Gorman found evidence of human habitation from about 11,500 years before present until 7,500 years before present. He also found carbonized plant remains that he thought may have been cultivated. But these studies were based specifically on the interests of the researchers involved and the individual work was not complied so as to create a full picture of the lives of the people who inhabited the area (75).

During 1998 and 1999, Dr. Sittipong Dilokwanich from Mahidol University conducted a Project titled “An Exporation and Database System of the Caves, Mae Hong Son Province”. In this project, the research team explored around 46 caves during the past of two years. This project collected data relating to caves in Lang and Khong river basin in Mae Hong Son Province and organized in database system (3). The archaeological sites in Pang Mapha were recorded in more detail and organize systematical for the first time. Moreover, the data system is useful for environmental management and further study in this area.

In 2002, Thai archaeologists led by Dr. Rasmi Shoocongdej from Faculty of Archaeology, Silapakorn University started the excavation works on Ban Rai Rockshelter which was the first site for an intensive study under the two-year Highland Archaeology Project: Phase I. This project studied the social and cultural development of ancient people who live on the mountain, foothills and valleys higher than 500 m above sea level. The log coffins around 30 pillars were found, as well as other evidence such as stone artifacts, small metal artifacts, fragments of animal bones, a human skeleton, ashy layers and wall paintings (2).

In 2003, the research team of Highland Archaeology Project: Phase I started excavating the second site near Lod Cave. They found several fragments of stone artifacts and other evidence as animal bones, human skeletons, ash layers, broken pieces of earthernware. The stone artifacts provide evidence that this area once was a manufacturing ground, as well as a temporary shelter for group of people. The skeleton discovered a meter or so above the artifacts suggests that these ancient people had their own funeral rituals involving laying stone around and over the corpses. Excavations have revealed the oldest skeletal remains of *Homo sapiens sapiens* in Northern Thailand. Two skeletons from the Tham Lod Rockshelter date to the Late Pleistocene (13720 and 12160 years ago, respectively). The skeleton found in a foetal position, much like an Early Holocene skeleton discovered at Ban Rai Rockshelter (9770 years ago). In addition, results from the teeth analyses suggest that the log coffin people shared similar traits with present day Southeast Asian population (2).

**2.4.1 Form and components of log coffins at Pang Mapha**

These caves that found log coffins are called "Tham Pi Man" by the local Shans. "Tham" means cave, "Pi" is spirit and "Man" is large. The Shans, closely related to the Northern Thailand, have lived in the area for about 200 years after moving from the Shan State in Burma. They believe the coffins were used by tall, cave lurking spirits (7,69).

The log coffins have the shape like a half timber that is dug-out inside like a pig drain and sculpted with individual designs at the both ends. Almost of them are laid on a pair of posts and beams which raise them above cave's floor. Posts and beams are put together in the "H" shape for bearing a load of log coffins. Beam planks hold up each side by piercing through each fitting perforated hole on each post. Occasionally, there are small and medium sizes of log coffins in the cave's corner. Cave geology and dimensions such as floor size, hall size, number and size of corners, wall size and roof height are all related to the distribution of log coffins (6,76).

The log coffins consist of two components, body and head. The body separates into two parts, one seems to be a cover for closing and another seems to be a body for padding. The head usually is sculpted both sides on the same form. However sometimes there are different form between head and rear or there are sculpting animal head on one side and a tail on another side (6,76).

**2.4.2 Form and individual head style of log coffins at Pang Mapha.**

The forms of the head were arranged into 12 groups based on the different patterns of decoration styles at the end of log coffins and size by Jakkarinrat Niyomkha (6) and Cherdsak Treerayapiwat (76). The similar styles are arranged into sub-sets using geometric model to show relatedness and English alphabet labels for the designs (Table 2-1).

**Table 2-1** The styles of coffin heads in Pang Mapha District, Mae Hong Son Province (4)

| Style | Image | Description |
|---|---|---|
| 1A | | A long solid wood with curved at the end stick out. |
| 1B | | A short solid wood with curved at the end stick out. |
| 2A | | A long square solid wood with curved at the end stick out and pierced flat back at the bottom. |
| 2B | | A short square solid wood with curved at the end stick out and flat back at the bottom. |
| 2C | | A short square solid wood with curved at the end stick out and pierced flat back at the bottom. |
| 3A | | A solid wood sculpted look like a pig’s head. |
| 3B | | A solid wood sculpted look like reptiles : snake |
| 3C | | A solid wood sculpted look like a small quadruped animal: cat, barking deer. |
| 3D | | A solid wood sculpted look like a large quadruped animal: horse, donkey. |
| 3E | | A solid wood sculpted look like a bird’s head. |
| 4A | | Two pieces of long square solid woods and the end sharp. |
| 4B | | A long flat solid. The top is slopped. This style usually find with 3C style. |
| 4C | | A long solid wood with curved at the end |
| 5A | | A topknot wood and bent at the end. |
| 5B | | A topknot wood and pointed at the end. |
| 5C | | A topknot wood. |
| 5D | | Two pieces of a topknot wood. |
| 5E | | A topknot wood and circle shape. |
| 5F | | A topknot wood. |
| 6A | | A long solid wood that look like matches. |
| 6B | | A large solid wood. |
| 6C | | A short solid wood with curved at the end stick out but smaller than the log coffin head 1B style. |
| 6D | | A long and small solid wood. The shape is a semicircle. |
| 6E | | A long solid wood. The shape is flat and expands at the end. This style is similar to the log coffin head 4B style. |
| 6F | | A long solid wood and oval at the end This style is similar to the log coffin head 5C style. |
| 7 | | A long solid wood and square ridge. |
| 8A | | A flat solid wood |
| 8B | | A flat solid wood and curve at the end. |
| 8C | | Two pieces of solid wood that curve at the end. |
| 8D | | Two pieces of square and flat solid wood. |
| 9A | | A solid wood sculpted look like loop. |
| 9B | | A square solid wood |
| 9C | | A square solid wood |
| 9D | | A solid wood and pointed at the end |
| 9E | | Two pieces of very short solid wood. |
| 9F | | A wood sculpted look like human or animal face. |
| 10 | | Plain: no sculpted in the end of log coffin lid. |
| 11 | | A square solid wood and bent, carve the edge of log coffin lid. |
| 12 | | A lid has oval shape. One of the ends has sculpted head style. |

This table is arranged by shape and forms of the head without reference to the ages of the log coffin heads. This method can use for studying log coffins from their appearance in the present and record data from log coffins at Pang Mapha, Mae Hong Son Province.

### 2.4.3 The age of the Log Coffin culture at Pang Mapha

Previous evidence suggests that caves and rockshelters that are exposed to light may have been inhabited for more than 10,000 years ago. Since 3,000-2,000 years before present these place have been used for burial ceremonies. Radiocarbon analysis of samples of wood from coffins from archeological sites, using both conventional and AMS (Acceleration Mass Spectrometry) methods, has been conducted by Australian archaeologists, Peter Grave and Mike Barbitte. The age of 9 samples from posts and log coffins in 6 archaeological sites including Umong Cave, Namlang Jum (Lang Chan), Lahu Pot Cave, Lahu Village Cave, Sri Soppong Cave (Tham Sri Sophon) and Lod Cave. They are found that log coffins have dated of 2080±60 to 1240±90 yrs BP or Iron Age period (4,77,78).

Likewise, Brendan Buckley, an American dendrochronologist, analyzed a sample of wood from Chanrong Cave to scientifically establish its age. He sent samples to Beta Analytic Ltd. These samples had an age of between 700 years before Christ Era to 5$^{th}$ century A.D. This is harmonious with the data Peter Grave and his group presented. An Exporation and Database System of the Cave: Mae Hong Son Province sent 2 samples of human bones from Tham Pangkham to Waikato Laboratory, New Zealand to find their age. These samples had ages of between the 3$^{th}$ and 9$^{th}$ centuries A.D. which is younger than the samples of posts and log coffins. It is concluded that age of the log coffins culture are between ca 2000 years before present to 9$^{th}$ century A.D. (4).

**Table 2-2** The radiocarbon determination of samples from archaeological areas in the Log Coffin culture period (4)

| Site | Sample number of laboratory | Detail of samples | Age (Calibrated) (2 sigma) | $^{14}C$ age (yrs BP) |
|---|---|---|---|---|
| Tham Pangkham 1* (Nam Khong) | WK-7224 (AMS) | Palatine bone covered by limestone | AD 590-850 (BE1133-1393) | 1343±59 |
| Tham Pangkham 1* | WK-7225 (AMS) | A piece of long bone of human is 50 cm. from the cranium and covered by limestone | AD 180-510 (BE 723-1053) | 1698±59 |
| Tham Kao Chin** (Nam Khong) | Beta-166060 | A piece of log coffins' head 1A style | BC160-AD130 (384 before BE-BE 673) | 1990±60 |
| Tham Kao Chin ** | Beta-166061 | A piece of log coffins' head 1A style | AD110-410 (BE 653-953) | 1770±60 |
| Umong Cave*** (Nam Lang) | AMS381 | A piece of log coffins' head 5D style | AD200-700 (BE 743-1243) | 1600±110 |
| Lang Chan Cave*** (Nam Lang) | AMS382 | A piece of log coffins' head 2A style | AD180-620 (BE 723-1163) | 1640±90 |
| LahuVillage Cave*** (Mae Lana) | AMS383 | A piece of log coffins' head 6C style | AD100-650 (BE 643-1193) | 1700±110 |
| Lahu Pot Cave *** (Nam Lang) | AMS384 | A piece of log coffins' head 1A style | AD290-780 (BE 833-1123) | 1540±120 |
| Lahu Pot Cave *** | AMS385 | A piece of log coffins' head 1A style | BC600- AD50 (57 before BE-BE593) | 2080±60 |
| Tham Sri Sophon*** (Nam Khong) | AMS386 | A piece of log coffins' head 2B style | AD400-700 (BE 943-1243) | 1120±80 |
| Lod Cave*** (Nam Lang) | AMS387 | A piece of log coffins' head 2B style | AD590-990 (BE1133-1533) | 1240±90 |
| Lod Cave*** | AMS388 | A piece of log coffins' head 2A style | AD300-740 (BE 843-1283) | 1450±110 |

**Note** *Sittipong Dilokwanich 2000 ** Brendan Buckley 2002 ***Peter Grave et al 1994

AMS = Accelerator Mass Spectrometry.

WK = Waikato Laboratory, New Zealand.

In Ongbah at Khae Yai, Kanchanaburi Province, more than ninety wooden coffins were found piled up at various places but no coffin was discovered completely intact. The coffins are boat shaped and both ends have stylized animal heads. The coffins are made of hardwood, one of the abundant *Dalbergia sp*. The average total length of the coffin is between 3 and 3.5 m, and $^{14}C$ dating yield a result of 2180±100 yrs BP (79).

In Southeast Asia, a log coffin at Niah Cave gave a $^{14}C$ date of 2460±65 yrs BP, while a coffin from Kuruswanan Ledge, Tabon Cave, The Philippines was dated by other means to the late 13$^{th}$ or 14$^{th}$ century A.D. In Szechwan boat-coffins burials are known from Chia-ling-kiang, and from Chungking on Yangtze-kiang. These burials obviously owe their origin to the wooden chamber graves of the Ch'u state and are not earlier than the 6$^{th}$ century B.C. The latest of these burials is dated by the presence of Pan Liang coins, which were first issued after the unification of China under Ch'in in 221 B.C. (79).

The comparison of log coffin age data from archaeological sites at Mae Hong Son Province with other sites in Southeast Asia implied a cultural chronology in table 2-3. The oldest date may refer to the start of the tradition and the youngest date probably indicates the final period of the Log Coffin culture. However the small sample size suggests that there will be some variance between the radiocarbon dates and the actual start and end dates of the Log Coffin culture.

**Table 2-3** The age of the Log Coffin culture in Southeast Asia (72)

| Site | Age (yrs BP) * | |
|---|---|---|
| | Oldest | Youngest |
| Southern China | 2600-2300 | 100 |
| Kanchanaburi | 2300 | - |
| Mae Hong Son | 2100 | 1200 |
| Ubonratchathani | - | - |
| Sarawak | 1200 | - |
| Sabah | 1000 | 500 |
| Philippines | 900-800 | - |

**Note** This is the combination data of age value from documents which reference to the age of the Log Coffin culture.

* Bring the different of age value from research document to compute the period time until now.

Table 2-3 indicates that the chronology of the beginning and end of the Log Coffin culture is not well understood in Southeast Asia. There are only two places, Southern China and Borneo Island that have clear data about the timing of the Log Coffin culture. This case study of age values at Mae Hong Son Province does not add much clarification because of the small number of dates (4,72).

### 2.4.4 Chronology of coffin's head style

Without a data base of ages from the study area: Bo Krai Cave and Ban Rai Rockshelter) it is necessity to bring together the results of previous studies to general pattern of the evolution of individual coffin head styles by $^{14}C$ method (Figure 2-5) (4).

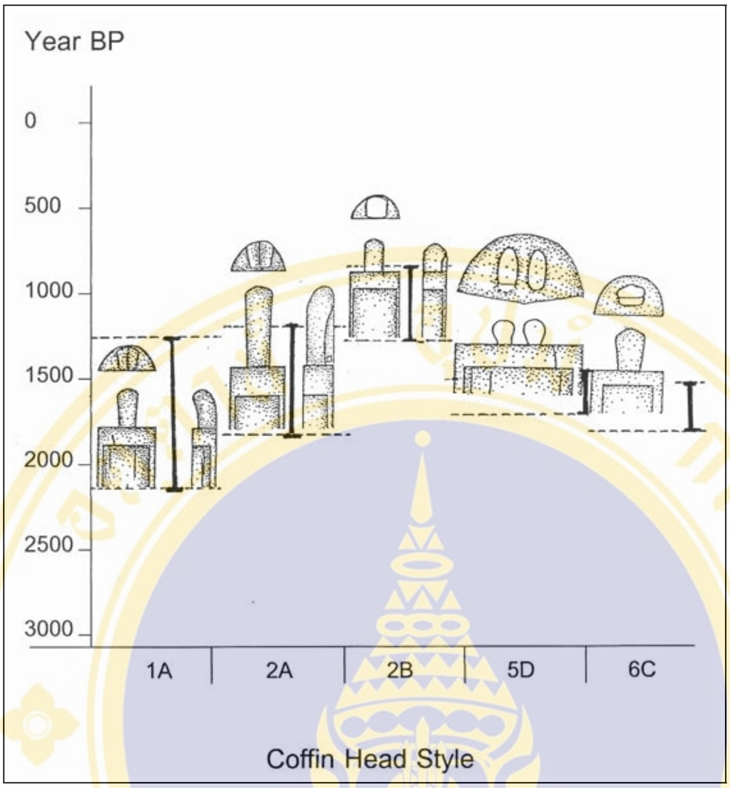



**Figure 2-5** The chronological distribution of individual coffin head styles according to radiocarbon data (4)

Even though these data are limited and inconclusive, they suggest that 1A is probably the oldest style. The 1A style made between 2080±60 to 1540±120 yrs BP. Later there appeared other individual styles such as 6C style at 1700±110 yrs BP and 2A style since 1640±90 to 1450±110 yrs BP. After that was 5D style at 1600±110 yrs BP which may have developed from 6C. Two hundred and ten years later there had been 2B style that date 1240±90 yrs BP (4).

This study aimed to establish the age of log coffins in the study area (Bo Krai Cave and Ban Rai Rockshelter) using the $^{14}C$ method which shows the period of log coffins at both sites. Importantly, this is the first date of log coffins' head in complex style that one end carved animal head (3C style) but one end carved tail (4B style) in the Log Coffin culture.

### 2.5 Paleoenvironment in the Log Coffin culture period

A view of the present environment in the study site was conducted to provide a baseline of the palaeoenvironment reconstruction and to make a comparison between present and past environments.

#### 2.5.1 The present environment

Thailand is located in the tropical zone near the equator. Thus, there are two types of monsoon that regularly influence the climate: the northern monsoon (cold and dry wind) and the southwest monsoon (warm and humid wind) (80). Northern Thailand has tropical savanna climate. The southwest monsoon brings rain with a monthly average of 167 mm from April/May to October, while November to March, the weather is dry with only 23 mm of rainfall per month (81).

Pang Mapha District is located at 19$^{o}$N latitude and 97$^{o}$E longitude in Mae Hong Son, Northern Thailand. This area covers 924.8 km$^2$. The district is well known for its beautiful and dramatic landscapes, a topography that ranges from 400 m to over 1,200 m above sea level. This area forms parts of the mountain ranges that line up in the north-south orientation from the Malaysian peninsular to Shan state in Myanmar. This region has three distinct seasons. The wet season, from June to October; the cool dry season, lasting from November to February; and the hot dry season is lasting from March to May. According to climatological data from Mae Hong Son weather station, the average mean temperature is 25$^{o}$C. In the summer, the average highest temperature is 33 $^{o}$C while during the coldest months of the year, the temperature in the highland regions often falls below 10 $^{o}$C. The total annual rainfall in this area is 1,260 mm (82).

The seasonal climate of Northern Thailand with its complex topography has resulted in a natural vegetation pattern consisting of an intricate mosaic of both evergreen and deciduous forest patches which has been further complicated by a long history of human interaction (Figure 2-6). The balance of tree species in a particular forest patch depends on three main factors; moisture, altitude and disturbance (83).

Generally, dry dipterocarp and mixed deciduous forest can be found in the lower lying area and on the lower hill slopes (lower 1,000 m from sea level). Within this habitat, the co-dominant species of teak (*Tectona grandis* L.) can be found, as well as frequent patches of different species of bamboo forest. At higher elevations the mixed deciduous and dry dipterocarp forest blends into the lower montane and pine forest. Patches of evergreen forest occur around the depressions and outcrops of limestone.

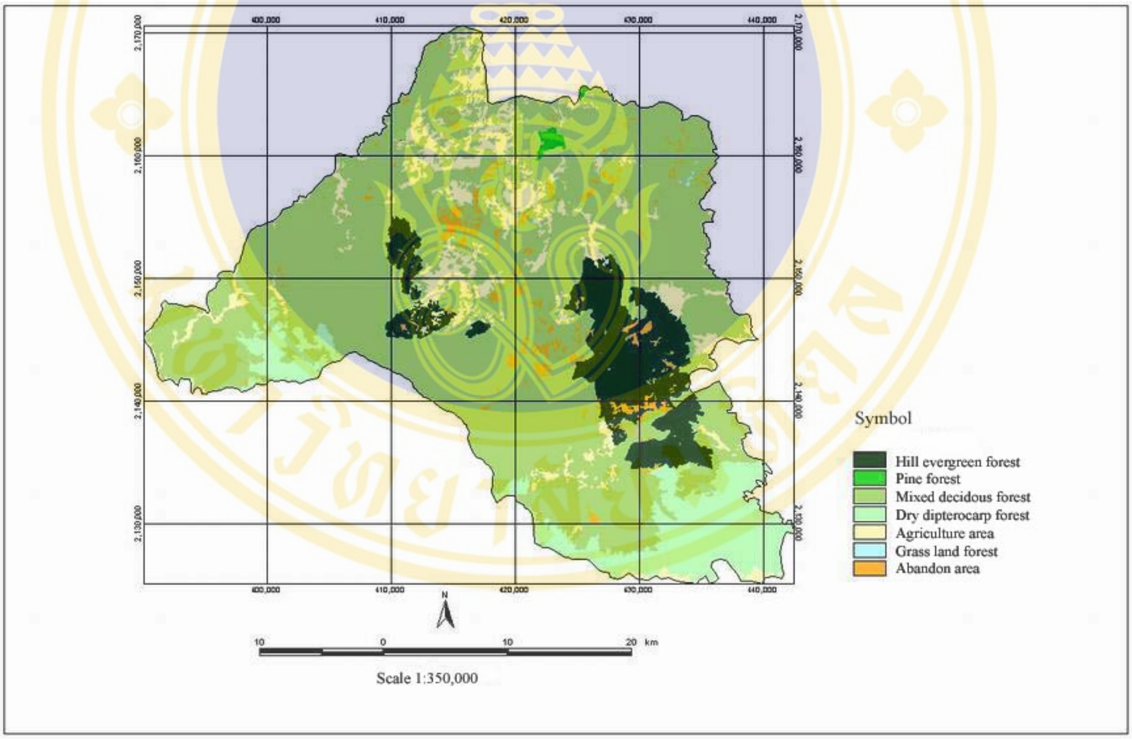



**Figure 2-6** Land use map of Pai Wildlife Sanctuary (84)

The Royal Forestry studied in both direct and indirect ways including surveyed at Pai Wildlife Sanctuary and previously collected data in 1996-1999. They found variety of wild animal especially 4 kinds of terrestrial vertebrates. The result presented more than 391 types, separated into mammal (67 types) birds (255 types) reptiles (46 types) and amphibians (23 types) (82). In addition Sompooch Srikomat et al.

(85) surveyed salt licks and wild animals at Mae Hong Son. They found many kinds of wild animals such as Barking Deer, Sambar Deer, Serow, Goral, Common Wild Pig, Civet, Palm Civet, Hog Badger, small and medium size of Jungle Cat, Ape, Langur, and Gibbon. Large animals such as Elephant, Guar, Banteng, Tigers and Leopards were already extinct. The group also found two salt lick sites. The other one was near Ban Mueang Pam (Pong Laung) where is a food source for birds and Barking Deer. Another one was Pong San Pig which was used by Barking Deer and Green Peafowl. Similarly, the study of Somsak Laoyeepa (86) found wild animals for example mammalians such as Squirrel, Flying Lemur, Palm Civet, Barking Deer, Rat, bats, and many kinds of birds; Asian Palm-swift, Barn Swallow, Crested Serpent Eagle, *Anthus novaeseelandidae*, Black-crested Bulbul, and Robin. However, the big size animals were not found in their study area.

Natural water sources in Pai Drainage area flow from the north at the Thailand and Myanmar boundary to the Pai River (Mae Nam Pai) at the south of the drainage area. There are four important rivers; Khong River (Nam Khong) which is the longest river with a length is around of 50 km. It runs through the west regions of the area, running almost north-south to the Pai River at Nam Who Rivulet (Huay Nam Who) in the south of the region (82). The Pong San Pig Rivulet (Huay Pong San Pig) is around 25 km long and 10 km from the Khong River to the east. It gets close to the Khong River at the north region of Ban Mae Suya. The Mae Lana Rivulet (Huay Mae Lana) is around 10 km long. It flows through Mae Lana Cave and cave systems then returns to above ground and combines with the Khong River. The Nam Lang Rivulet is long around 30 km and is in the east of the drainage area. It flows through Lod Cave at Ban Sop Pong then changes direction to the west parallel with highway no.1095. It goes underground at Lang Disappearing Stream (Kued Nam Lang), Ban Rai area. The Nam Lang Rivulet probably passes through the system to the canal at Soosar Waterfall or near the area at the south region. At that point, it flows close to the Pai River (87).

### 2.5.2 Holocene Environment in Thailand (10,000 years ago to present)

Previous archaeological research suggests that the Log Coffin culture at Pang Mapha District, Mae Hong Son Province, spanned of age between 600 years before Christ to the 9th century A.D. coincide with the Late Holocene period (88). The Holocene in this case means the climatic and geological period that extends back to the end of the Pleistocene or aged between 10,000 years ago to present. At this period the ice melted, the weather is warm and the physical features of the coast changed. The tropical forests were changing especially the trees that usually grow in a cold climate sledded to grew at the higher latitude and many types of animal became extinct (89). The Late Holocene that was divided by Sun Xiangjun and Chen Yinshou, the Chinese archeologists, is 2,500 years ago to present (90).

Limited knowledge of the ancient environment conditions in the study area means that it is necessary to compare with previously studied cases at other areas in Thailand. This approach is limited because sometimes there are some results that are restricted to only specific areas.

The reconstruction of Holocene sea levels is a very controversial issue within the framework of Late Quaternary studies. This issue raises debate regarding the timing or nature of Holocene sea level changes. The Holocene in Thailand has been the subject of numerous studies dealing with evidence for former sea levels (91,92,93,94,95,96).

The Holocene transgression beginning about 8,400 yrs BP was a steady rise in sea level up to about 6,000 yrs BP and a height of +4 m above local mean sea level. It is a regression down to or near present sea level at around 5,000 yrs BP. Sea level then rose again to an elevation of +2.0 m above local mean sea level where it remained from 3,700 to 2,700 yrs BP. Another regression occurred from then until present sea level was reached about 900-800 years ago (dating from shell and peat in central Thailand) (91,95).

The Holocene sea level is harmonious with the evidence of mangrove habitat dynamics during the Mid to Late Holocene on the south western coast of Thailand, Kosrae Island in Micronesia and Iriomote Island in south western Japan (97), the data of marine transgression in the Central Plain of Thailand from many Holocene marine shell (98,99) and Holocene pollens data and $^{14}C$ dating from several localities in Thailand including Doi Inthanon in northern Thailand (92), Khok Phanom Di (100,101), Nong Han Kumphawapi in northeast Thailand (93), Tha Mai in southeast Thailand (94), and Narathiwat in peninsula Thailand (102). These pollen records indicate local environmental effects of Holocene sea level change on vegetation communities.

In Pang Mapha District, Chester F. Gorman (1970) noted that the ancient environment in Pang Mapha area in the Late Pleistocene to Holocene period was similar to the environment at present (6). However, Gorman's study was quite limited as he interpreted data in comparison to evidence from archaeological sites in China (1).

To re-examine the ancient environment in this area, the Highland Archaeology Project in Pang Mapha, Mae Hong Son: Phase I (2001-2003) in which Dr. Rasmi Shoocongdej, Dr. Nathsuda Pumijumnong, Dr. Suppaporn Nakbanlung and the researcher team are studying a wide range of evidence found in the area (2).

The result of the analyses of faunal remains, tree rings, geomorphology and palynology from Ban Rai and Tam Lod Rockshelters indicate the Late Pleistocene and Early Holocene climate was slightly colder and moister than at present. The animal and pollen remains indicate use of a variety of habitats in the Late Pleistocene and Early Holocene, including evergreen forests, deciduous dipterocarp forests, and pine forests in the uplands. Later, particularly during the Log Coffin culture period, the vegetation may have been much denser than at present. Finally, the vegetation changed rapidly after the forest concession during the past 150 years (1).

### 2.6 Research Area

Environment is an important factor which has an effect on tree growth and tree-ring width. Tree growth in the same or similar environmental conditions and time will have uniform ring structures. The relationship of tree-ring widths between sites mean that sites in the same area should be studied before linking to other sites in different environments. In this case, Bo Krai Cave and Ban Rai Rockshelter were essential to study because the both sites located in the drainage area of the Lang River (Figure 2-7).

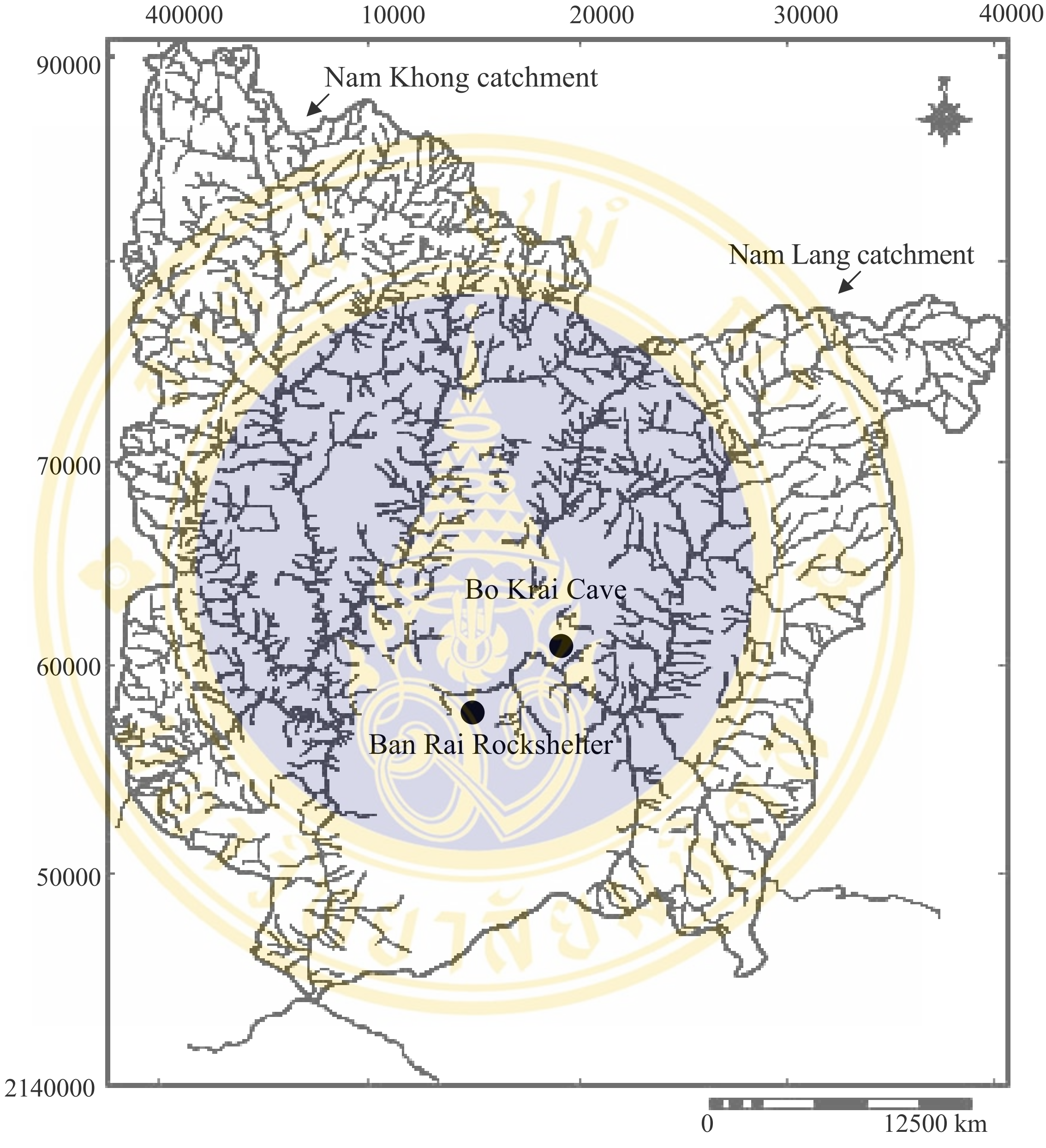



**Figure 2-7** Bo Krai Cave and Ban Rai Rockshelter site location,
Mae Hong Son, Northern Thailand (3)

**2.6.1 Bo Krai Cave**

Bo Krai Cave is located at 47Q 0419695 E 2161055 N UTM (lat.19$^{o}$32” 39’ long. 98$^{o}$ 14” 04’) in the hills is approximately 933.1 m. above the sea level (Figure 2-8). The site is elevated approximately 290 m above the Nam Lang plain which is located at the south of the cave. The entrance faces to the north. The cave has a mound of rock fall at the right hand side of the walk way and the dimensions of entrance are about 4 m wide and 2 m high (Figure 2-9) (76).

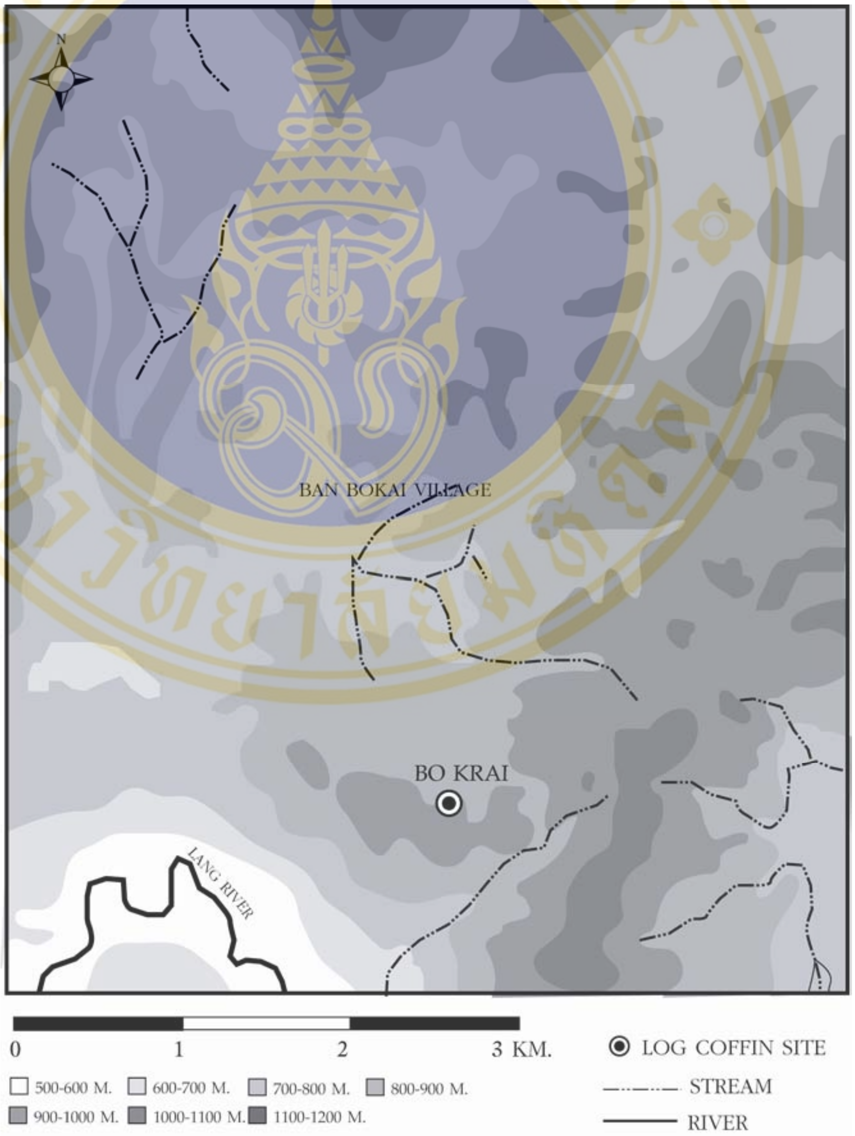



**Figure 2-8** Topographic map of Bo Krai Cave (103)

**Figure 2-9** The entrance of Bo Krai Cave.

Inside the cave, there are three chambers (Figure 2-10). In chamber 1 there are several coffins scattered and broken along the floor and six large posts standing. Chamber 2 is dark and located approximately 3 m lower than the entrance. A lot of log coffins were found in this area (76). They are two sets of log coffins supported on six large posts with cross beams which remain largely intact and in a good state of preservation. Unfortunately, the log coffin has a large hole along the base of the coffin (104). In chamber 3, the log coffin rests on the beams that are attached to the cave wall.

The log coffins in Bo Krai Cave have more than thirty lids of log coffins (that is, 15 couples). Altogether, the log coffins had no specific orientation. All of the log coffins and posts are made of teak (*Tectona grandis* L.). The average total length of the log coffin is between 3 and 4 m and width is between 35 to 50 cm. The longest coffin is 5 m (76). Unfortunately, no coffin was discovered completely intact. Moreover, they were found with other evidence such as stone and metal artifacts, sherds of cord-marked pottery, fragments of animal bone, a human skeleton, tooth with 3 holes drilled into the side and plugged with metal (2). These items may be grave goods for use in an after life.

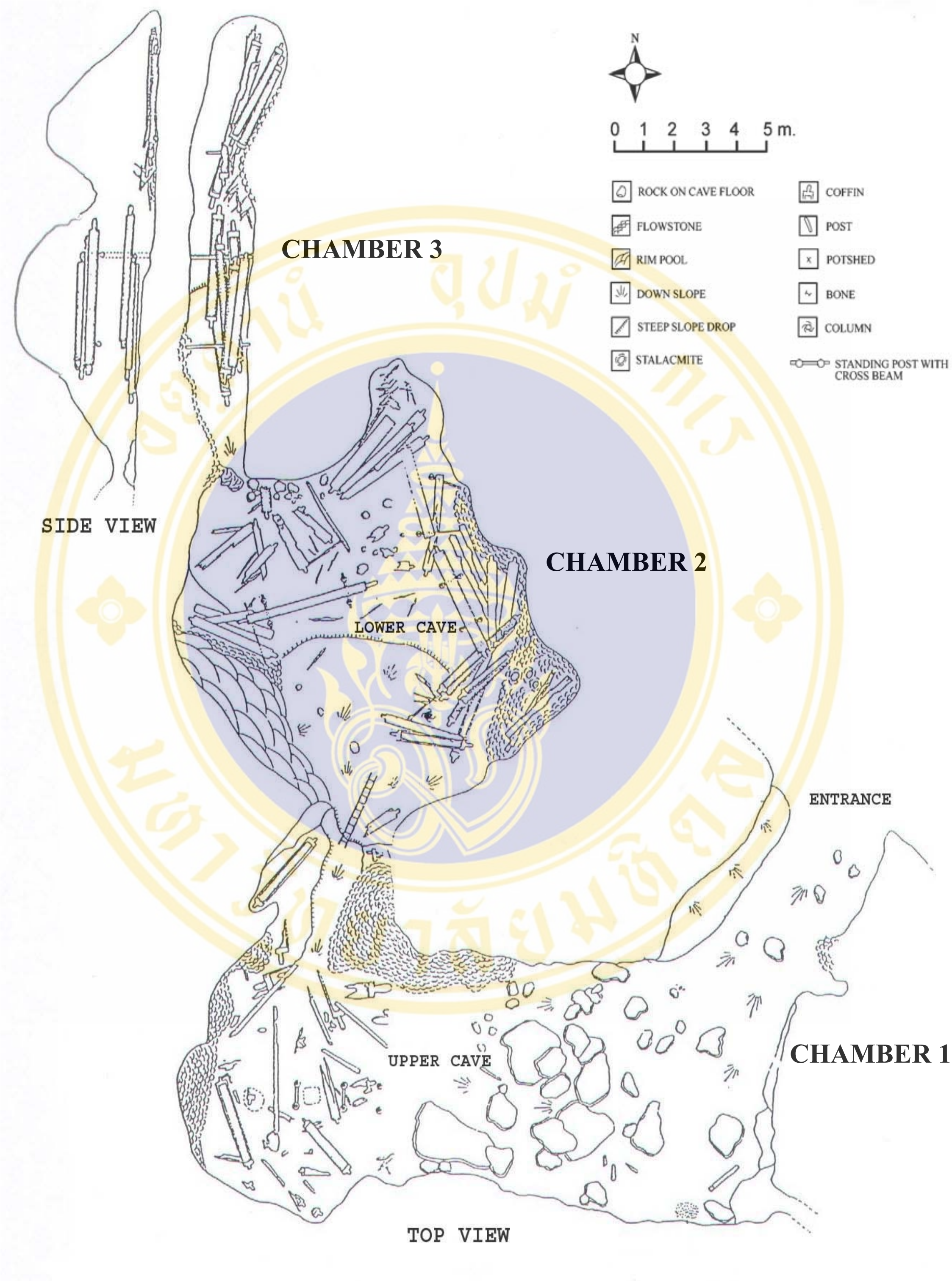



**Figure 2-10** Plan and cross-section of Bo Krai Cave (3)

There are two styles characteristic of the log coffin heads discovered in Bo Krai Cave. One style is of an animal head carved on one end and on the other end a carved animal tail. The second style is the geometric style that includes triangular, rectangular, and amorphous motifs. From the Cave Survey and Database System Project in Mae Hong Son Province (3), the archeologists, Jakkarinrat Niyomkha and Cherdsak Treerayapiwat, classified the log coffins from Bo Krai Cave into 11 different styles of coffins heads based on their pattern and size. Those are 1A, 1B, 2A, 2B, 3A, 3C, 4B, 5B, 5D, 6C and 10 styles. Usually there are many styles of laying coffins such as laying the coffin on posts and beams combined in a H form, laying the coffin on a skewing beam with one side pierced through post and another put on the cave wall or laying at the corner of cave. These observations suggested that there was not a uniform standard of laying but that the differences might result from the restrictions of the cave topography. It might be assumed from the ridges that some posts looked as if they were taken from earlier coffins and spilt for making the supporting posts for later coffins (76).

**2.6.2 Ban Rai Rockshelter**

Ban Rai Rockshelter is a large overhanging rock with a large number of log coffins and some spectacular paintings (Figure 2-11). The co-ordinates of this site are 47Q 0414112 E 2158402 N UTM (lat. $19^{o}$ 31' 12" long. $98^{o}$ 10' 53"). Ban Rai archaeological site is located at Ban Rai village, Soppong subdistrict, Pang Mapha District, Mae Hong Son Province. The site is approximately 793 m above the sea level and 160-200 m above the plain (Figure 2-12). The Lang River is about 300-400 m to the south. There is a sinkhole in the middle of shelter with many perennial trees. The rockshelter has an open horseshoe shape and includes an area of forest in the middle of the sinkhole. The rockshelter is about 105 m in width and 142 m in length. The entrance to the rockshelter faces north. The average height of the shelter is approximately 30 m (57,105,106).

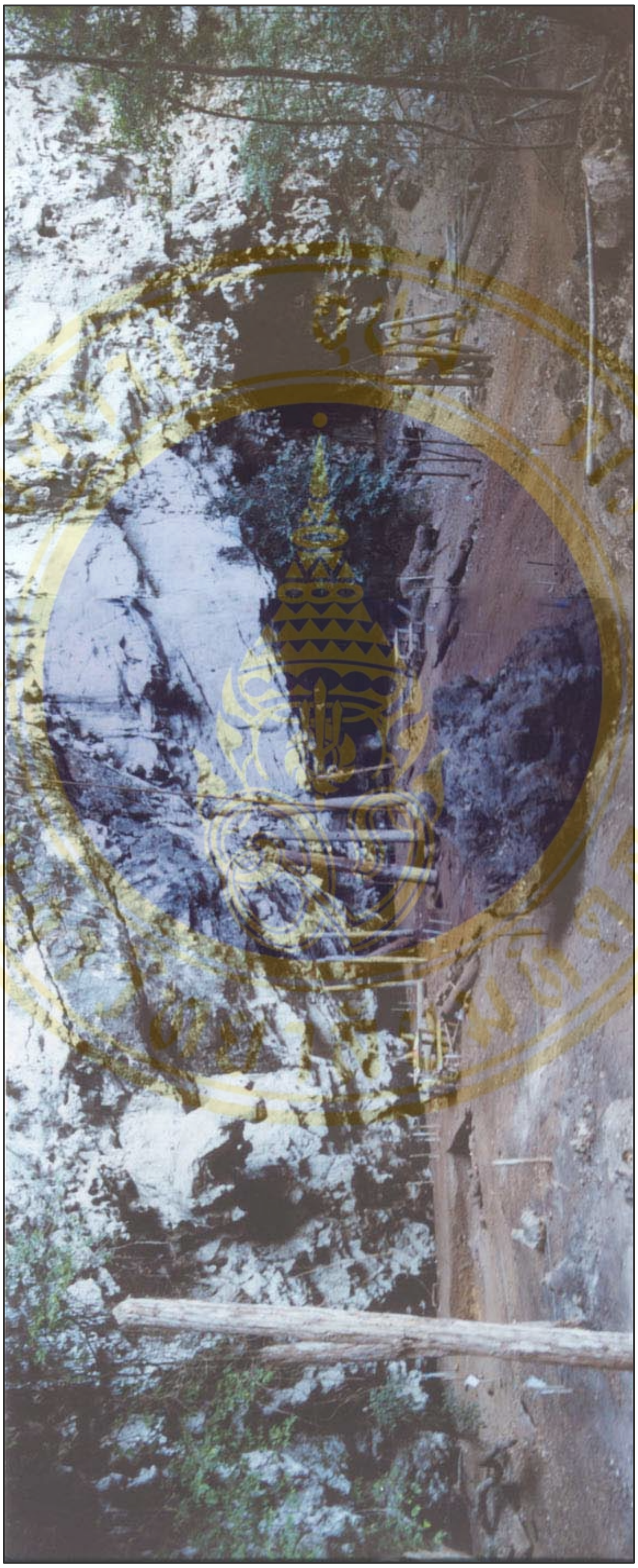


**Figure 2-11** The Log Coffin culture at Ban Rai Rockshelter in 2001 (2)

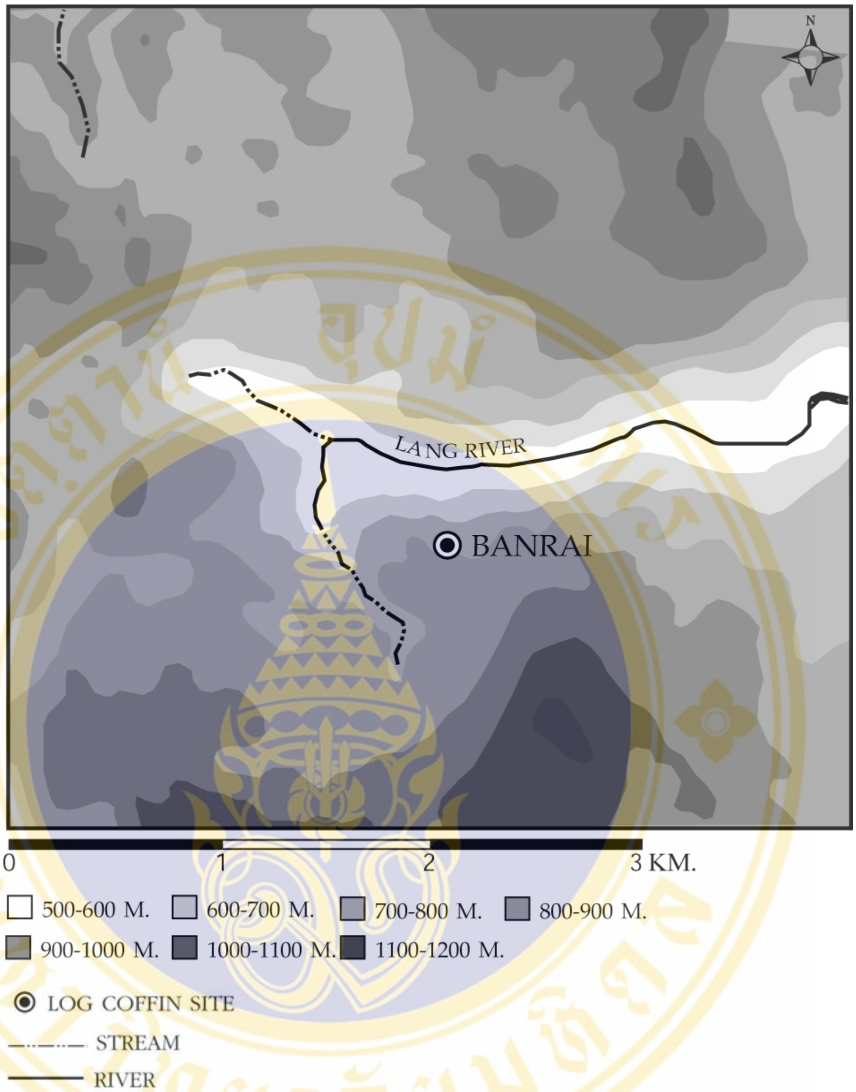



**Figure 2-12** Topographic map of Ban Rai Rockshelter (103)

The present forest surrounding this site is predominantly mixed deciduous forest (Figure 2-13). The dominant floras are teak wood, bamboo and are scattered with Lithocarpus, Bombax and Java Palm. Evergreen trees can also be found inside the area (Figure 2-14). Above the roof of the rockshelter there is a dry dipterocarp forest where *Shorea* sp. and *Dipterocarp* sp. are the dominant species. Additionally, in this region teak wood can be found together in dry dipterocarp forest (57).

**Figure 2-13** The forest type (mixed deciduous forest) around Ban Rai Rockshelter.

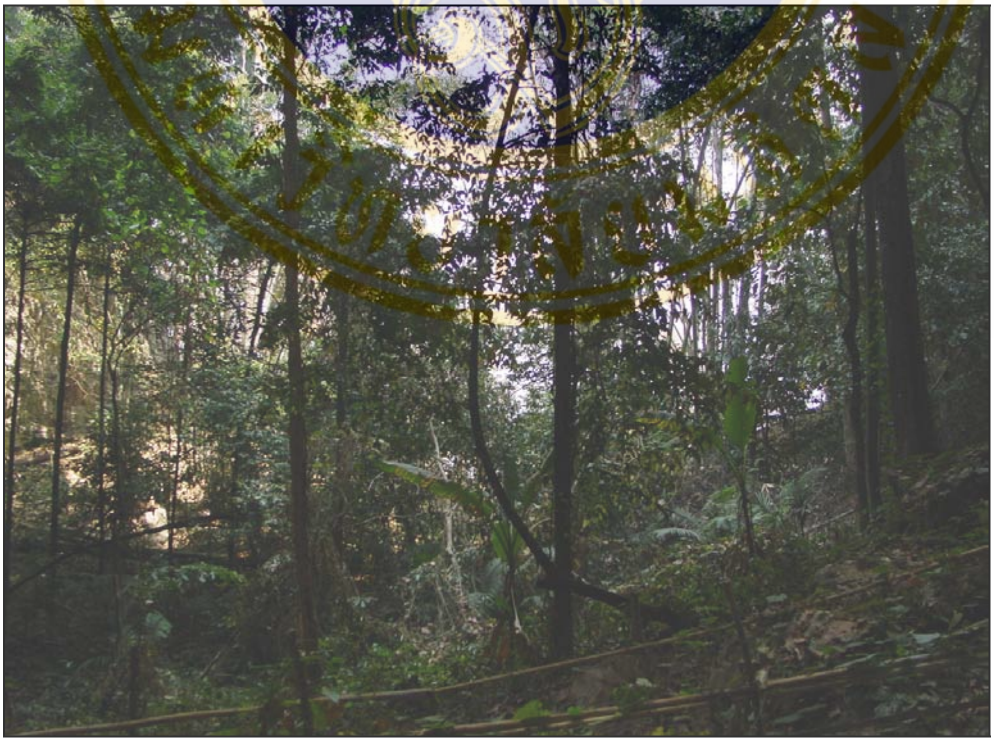


**Figure 2-14** The evergreen forest at sinkhole in the middle of Ban Rai Rockshelter.

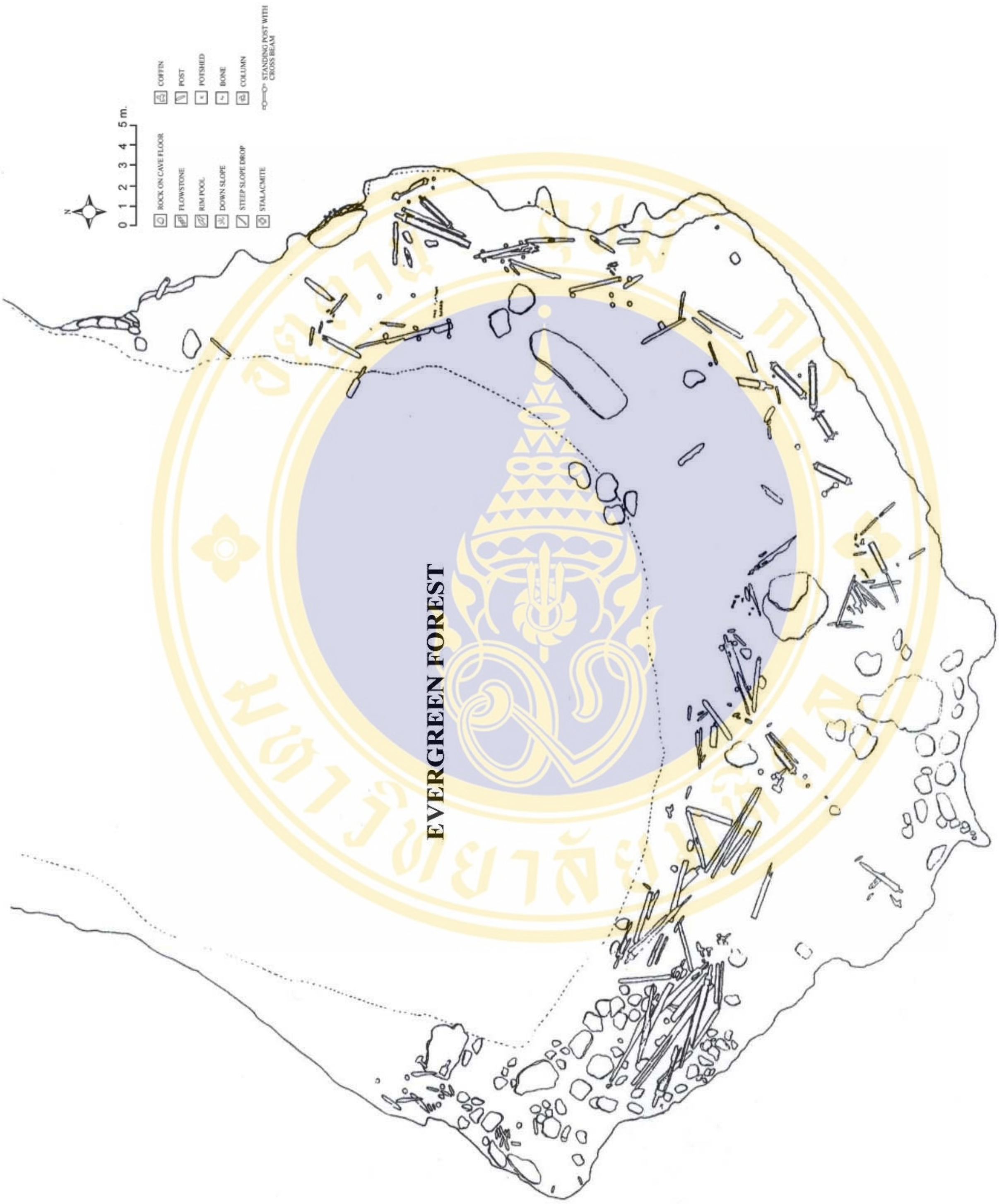
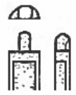
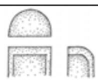



**Figure 2-15** Plan of Ban Rai Rockshelter (3)

There are many ancient remains, which are not only different in type but in age also, such as pebble artifacts, rock wall paintings, remnants of earthenware, shells, human bones, animal bones, a large number of log coffins and posts. Log coffins and posts have been protected from sunshine and rain by the overhang of the rockshelter. However, many log coffins and posts have deteriorated; some of them were burnt or covered with weeds. Some coffins and some logs have fallen on the floor. Posts and beams have been found with and without penetrations for joining with other beams. As for the large coffins, beams could be hewed for fitting and making the stronghold. It is assumed that the laying form of the coffins was related to coffin size. The coffins rest on beams and also directly on posts (105,106). Most of the log coffins and posts were made from teak wood and sometimes made from another wood such as jambolan (*Syzygium cumini*). The style of log coffin heads in this area including 1A, 1B, 2A, 2B and 2C styles (105).

The majority of coffins and posts are made from teakwood which has a high potential for dendrochronological study. The head form of coffins from the 2 sites resembles each other in 5 styles; 1A, 1B, 2A, 2B and 2C (Table 2-4). It is important to study the relationship and arrange an evolutionary sequence of head form to see if the head forms that were dated with $^{14}C$ techniques represent different periods of time. Even though the wood samples for dating did not come from Bo Krai Cave and Ban Rai Rockshelter the samples were extracted from the Log Coffin culture archeological sites at Pang Mapha District, Mae Hong Son Province. The result of finding age values will allow comparison with the form of log coffins throughout the study area. The samples of wood from Bo Krai Cave and Ban Rai Rockshelter were radiocarbon dated at the Office of Atomic for Peace (OAP), Bangkok, Thailand.

**Table 2-4** The style of log coffin heads from Bo Krai Cave and Ban Rai Rockshelter (4)

| Style | Image | Description | Piece of log coffins' heads | |
|---|---|---|---|---|
| | | | Bo Krai | Ban Rai |
| 1A |  | A long solid wood with curved at the end stick out. | 4 | 6 |
| 1B |  | A short solid wood with curved at the end stick out. | 7 | 8 |
| 2A |  | A long square solid wood with curved at the end stick out and pierced flat back at the bottom and have small hole. | 26 | 18 |
| 2B |  | A short square solid wood with curved at the end stick out and flat back at the bottom. | 1 | 7 |
| 2C |  | A short square solid wood with curved at the end stick out and pierced flat back at the bottom. | 2 | 2 |
| 3A |  | A solid wood sculpted look like a pig's head. | 2 | - |
| 3C |  | A solid wood sculpted head of small four-legged animal: cat, barking deer. | 25 | - |
| 4B |  | A flat solid wood with turned up at the top. Always found with 3C style | 20 | - |
| 5B |  | A sharp topknot solid wood. | 1 | - |
| 6C |  | A short solid wood with curved at the end stick out. Similar to 1B style but smaller and more slender. | 1 | - |
| 5D |  | There are two topknot solid wood with cut at the end stick out. | 1 | - |
| 10 |  | Simple head without any sculpture. | 2 | - |

**Note** A lid of log coffin has two pieces of log coffins' head.

# CHAPTER III
# METHODOLOGY

The valuable teakwood in the Pang Mapha area has been widely used since prehistoric times. Teak is one of the few tropical tree species that forms clear annual rings. This means that log coffins made from teak logs can be fruitfully studied through dendrochronology. Archaeologist predicts that the simple type head (such as triangle, rectangular, and amorphous) in this area predate the complex type (such as deer, snake, and pig) (107). To test this prediction dendrological techniques and the $^{14}C$ method were applied to samples taken from coffins.

## 3.1 Dendrochronology

### 3.1.1 Collection of archaeological specimens

The materials for tree-ring dating were taken from teak log coffins and teak posts at Bo Krai Cave and Ban Rai Rockshelter. Great care must be taken that the sampling causes as little damage as possible to the objects.

It is possible to move the log coffins but the hypothesis of this study must record the in situ locations of log coffins, so this study has rules to select the sample:

1. A piece of log coffin is equal to a lid of log coffin.
2. The style of the log coffins were identified according to the archaeologists Jakkarinrat Niyomkha (6) and Cherdsak Treerayapiwat (76).
3. The samples were collected by a boring tool, which has 0.25 inch borer tube width.
4. Two specimens have been removed from each log coffin lid and post samples.

**Figure 3-1** Taking a sample from Ban Rai Rockshelter in 2001

During visits to the caves, the sample number, date, site number, location of the specimen within the structure, and the spatial relationship of the specimen to other objects were recorded. This is necessary for a meaningful interpretation of its date.

| 1 | 2 | 3 |
|---|---|---|
| BO | 01 | A |

The details of sample code:

1. Site Code

BO = Site: Bo Krai Cave

BR = Site: Ban Rai Rockshelter

2. The sample number

3. The location of the specimen within the structure

A = core A

B = core B

**Table 3-1** Details of log coffin samples collection from teak log coffins and teak posts at Bo Krai Cave and Ban Rai Rockshelter

| Site | Date | Log coffin | | Post | | Total |
|---|---|---|---|---|---|---|
| | | (lid) | (sample) | (post) | (sample) | (sample) |
| Bo Krai Cave | 25, 27 Dec 2001 | 36 | 68 | 3 | 3 | 71 |
| Ban Rai Rockshelter | 12-13 May 2001 | 11 | 22 | 12 | 27 | 116 |
| | 29 Dec 2001 | 23 | 45 | 15 | 31 | |

### 3.1.2 Sample data

Samples of Ban Rai Rockshelter were taken in two times and had repeatable samples. The information of study materials were taken from log coffins and teaks posts of Bo Krai Cave and Ban Rai Rockshelter in Pang Mapha District, Mae Hong Son Province illustrated in the table 3-2 and table 3-3.

**Table 3-2** Detailed sample data from Bo Krai Cave

| Code | Chamber | Post | Coffin | Number | Coffin head styles | Diameter (cm) | Remark |
|---|---|---|---|---|---|---|---|
| BO01A | 3 | | X | 1 | 2A | 17 | |
| BO02A | 3 | | X | 1 | 1B | 22 | |
| BO03A-B | 3 | | X | 2 | 2A | 18.5/22 | A half of lid |
| BO04A-B-C | 3 | | X | 3 | 2C | 13.5/14.5/7 | |
| BO05A-B | 3 | | X | 2 | 2A | 23/20.5 | Position near BO04 |
| BO06A-B | 3 | | X | 2 | 3A and 4B | 19/23 | The head looklike pig |
| BO07A-B | 2 | | X | 2 | 10 and 4B | 26.5/17 | |
| BO08A | 2 | | X | 1 | 4B | 17 | |
| BO09A-B | 2 | | X | 2 | 5B | 17.5/15.5 | |
| BO10A-B | 2 | | X | 2 | 4B | 25.5/21.5 | The end looklike tail but another end was damaged. |
| BO11A-B | 2 | | X | 2 | 3C and 4B | 17.5/14.5 | |
| BO12A-B | 2 | | X | 2 | 3C | 23/18 | Log coffin was damaged |
| BO13A-B | 2 | | X | 2 | 3C | 38/20 | Head coffin piece |
| BO14A-B | 2 | | X | 2 | 1A | 20/13.5 | |
| BO15A-B | 2 | | X | 2 | 3C and 4B | 17.5/14 | |
| BO16A-B | 2 | | X | 2 | 3C and 4B | 24.5/19.5 | Log coffin broken in middle of lid |
| BO17A | 2 | | X | 1 | 2A | 23 | Lower lid was supported by 4 posts |
| BO18A-B | 2 | | X | 2 | 1A | 23/18 | Log coffin was damaged |
| BO19A-B | 2 | | X | 2 | 3C | 15.5/13 | |
| BO20A-B | 2 | | X | 2 | 3C and 4B | 20.5/27 | |
| BO21A-B | 2 | | X | 2 | 3C and 4B | 17/18 | |
| BO22A-B | 2 | | X | 2 | 3C | 21/19 | Another end damage |
| BO23A-B | 2 | | X | 2 | 3C and 4B | 17.5/17 | |
| BO24A-B | 2 | | X | 2 | 3C and 4B | 17.5/18 | |
| BO25A-B | 2 | | X | 2 | 3C | 23/18 | Piece of head |
| BO26A-B | 2 | | X | 2 | 3C and 4B | 14.5/14.5 | Head has long neck |
| BO27A-B | 2 | | X | 2 | 3C and 4B | 14/14 | |
| BO28A-B | 2 | | X | 2 | 3C and 4B | 18/17.5 | |
| BO29A-B | 2 | | X | 2 | 3C and 4B | 23/18.5 | |
| BO30A-B | 2 | | X | 2 | 1B | 18.5/19 | |
| BO31A-B | 2 | | X | 2 | 2A | 25/25 | Upper lid was supported by 4 posts |
| BO32A-B | 2 | | X | 2 | 3C and 4B | 22/21 | |
| BO33A-B | 2 | | X | 2 | 3C and 4B | 19.5/22.5 | |
| BO34A-B | 1 | | X | 2 | 2B | 19/18 | |
| BO35A | 1 | | X | 2 | 2A | 23 | |
| BO36A-B | 1 | | X | 2 | 3C and 5B | 12.5/18 | |
| BO37A1-A2 | 1 | X | | 1 | Post | 23 | The same post group with BO38,39 |
| BO38A1-A2 | 1 | X | | 1 | Post | 19.5 | The same post group with BO37,39 |
| BO39A1-A2 | 1 | X | | 1 | Post | 19.5 | The same post group with BO37,38 |
| BO40 | 2 | | X | 1 | 5D | 25 | Piece of head |

**Table 3-3** Detailed sample data from Ban Rai Rockshelter

| Code | Post | Coffin | Number | Coffin head styles | Diameter (cm) | Remark |
|---|---|---|---|---|---|---|
| BR01A-B | X | | 2 | Post | 16/20 | |
| BR02A-B-C | X | | 3 | Post | 8.5/15/11 | Position near BR03 |
| BR03A-B | X | | 2 | Post | 19.5/19 | Position near BR02 |
| BR04A-B | X | | 2 | Post | 16.5/16.5 | Support BR05 |
| BR05A-B | | X | 2 | 2B | 27/29 | |
| BR06A-B | | X | 2 | 2B | 18.5/20 | |
| BR07A-B-C-D | | X | 4 | 1B and 2C | 29/26 | |
| BR08A-B-C-D | | X | 4 | 1B | 21.5/21/24.5/29.5 | |
| BR09A-B-C-D-E | | X | 5 | 1B | 32/19/14/21.5/12 | Position near BR10 (upper lid) |
| BR10A-B | | X | 2 | 1B | 17/18 | Position near BR09 (lower lid) |
| BR11A-B1,2 | X | | 2 | Post | 22/24.5/17 | Position near BR12 and BR13 |
| BR12A-B-A1-B1 | X | | 2 | Post | 16/23/20.5/24 | Position near BR11 and BR13 |
| BR13A-B | X | | 2 | Post | 24/15.5 | Position near BR11 and BR12 |
| BR14A-B-C1,2-D-E | X | | 5 | Post | 21.5/15.5/14/16/19/18.5 | The top of the post is carving look like sitting human |
| BR15A-B | X | | 2 | Post | 33/27.5 | |
| BR16A-B-C-D | | X | 4 | 1A | 21/18/21.5/19.5 | Head coffin piece near BR 49 |
| BR17A-B | | X | 2 | - | 20.5/21.5 | Head of log coffin was damage |
| BR18A-B | | X | 2 | 2A | | Jambolan (*Syzygium cumini* Skells) |
| BR19A-B | | X | 2 | 2A | -/18.5 | Jambolan (*Syzygium cumini* Skells) |
| BR20A1,2-B | X | | 2 | - | 5.5/14.5/12 | |
| BR21A-B | | X | 2 | 2A | | Jambolan (*Syzygium cumini* Skells) |
| BR22A-B | | X | 2 | 2A | 18/18 | |
| BR23A-B-C1,2-D | X | | 2 | Post | 19/14.5/10/25.5/35 | Position near BR19-21 |
| BR24A-B | X | | 2 | Post | 15.5/24 | |
| BR25A-B | X | | 2 | Post | 25/28.5 | Same post group with BR26,27 |
| BR26A-B | X | | 2 | Post | 12/14 | Same post group with BR25,27 |
| BR27A-B1,2 | X | | 3 | Post | 9.5/9/13 | Same post group with BR25,26 |
| BR28A-B | | X | 2 | 2A | 16/18.5 | Damaged, position near BR29 |
| BR29A-B | | X | 2 | 2A | 20/21.5 | Damaged, position near BR28,30 |
| BR30A-B | | X | 2 | 2A | 11.5/20 | Damaged, position near BR29 |
| BR31A1,2-B1,2 | X | | 2 | Post | 16.5/9.5/12/8.5 | |
| BR32A-B | | X | 2 | - | 22/19 | Position near BR35 |
| BR33A-B | | X | 2 | - | 19.5/14 | Damaged, position near BR34,35 |
| BR34A-B-C | | X | 3 | 1A | 19/15.5/23.5 | Position near BR33 |
| BR35A-B-C1,2 | | X | 3 | 2B | 22/17.5/15.5 | Position near BR 33,34 |
| BR36A-B | X | | 2 | Post | 12/25 | Same post group with BR37,38 |
| BR37A-B | X | | 2 | Post | 15/24.5 | Same post group with BR36,38 |
| BR38A1,2 | X | | 1 | Post | 8.5/11 | Same post group with BR36,37 |
| BR39A-B | | X | 2 | - | 20/11.5 | Head of log coffin was damage |
| BR40A-B-C | X | | 3 | Post | 15/14.5/16 | Half of post inhume in soil |
| BR41A-B | X | | 2 | Post | 30/29 | |
| BR42A-B | | X | 2 | 2A | 24/19 | |

**Table 3-3** Detail of sample data from Ban Rai Rockshelter (cont.)

| Code | Post | Coffin | Number | Coffin head styles | Diameter (cm) | Detail of samples |
|---|---|---|---|---|---|---|
| BR43A | | X | 1 | - | 12.5 | Head of log coffin was damage |
| BR44A-B | | X | 2 | - | 16/10 | Head of log coffin was damage |
| BR45A-B-C1,2 | X | | 3 | Post | 18/17/16.5/9.5 | |
| BR46A-B | | X | 2 | - | 23/23 | Position near BR 47 |
| BR47A1,2-B | X | | 2 | Post | 15.5/14/21.5 | |
| BR48A-B | | X | 2 | 1A | 19/18.5 | Position near BR 16 |
| BR49A-B | | X | 2 | - | 26/24.5 | Head coffin piece |
| BR50A | X | | 1 | Post | 15 | Support BR09,10 |
| BR51A-B | | X | 2 | - | 25/15 | A half of lid |
| BR52A-B | | X | 2 | - | 26/25 | Position near BR 53 |
| BR53A-B | | X | 2 | - | 24/23 | Position near BR 52 |
| BR54A-B | | X | 2 | 2A | 22/18.5 | Position near BR 05 |

### 3.1.3 Laboratory technique

#### 3.1.3.1 Sample preparation and measuring tree ring

3.1.3.1.1 Sample preparation.

Cores which are removed with a boring tool are often fragile and it is necessary to mount them before preparing the surface for analysis. The most important aspect of the mounting was the correct alignment of the cells in the core. If core was twisted when it was extracted, it must be twisted back to the correct alignment. If the cores are still moist, they have to be allowed to air dry for several days before mounting. When the cores are sufficiently dry, they are glued into a supporting wood. Cores were fixed to the mount using water soluble glue so that they could be realigned if necessary. After that they were clamped to the core to hold them in place with adhesive tape while the glue set. The cores were stored this way until the glue dried then the tape was removed. The quickest way to prepare the core surface for study is to sand the core with rotary-sanding tools or slice it with blade. The blade is held at an acute angle to the direction of slicing and a flat surface is cut on the top of the core until there is a clear view of the tree rings (Figure 3-2). If the orientation of the core in the mount was properly done, this cut will be at an angle to the tracheid cross-section (108,109).

**Figure 3-2** The sample preparation for tree-ring dating

3.1.3.1.2 Measuring tree rings. The specimens were measured to 0.01 mm accuracy, using a moving stage and microscope interfaced with a computer that serves as the data recorder and editor (Figure 3-3). The magnification of the microscope is 4x-40x, which is adequate for clear view of individual cells in each ring (109). The sample must not be held rigidly during the measurement stage because it is necessary to move the core during the process to keep the line of measurement parallel to the rays. In some cores this adjustment needed to be done between each ring. Cross hairs in the ocular lens serve as a reference point for the measurement of ring widths. The purpose of this study was to plot the ring width on a linear scale representing the years of growth for the x-axis and a logarithmic y-axis for the width of each ring (108). Graphs of ring widths were then created with a floating date scale.

**Figure 3-3** The moving stage and microscope interfaced with a computer

**3.1.3.2 Verification of data**

Crossdating involves matching tree-ring width patterns from different samples (40). This method was conducted exclusively on the light table with polled raw tree-ring series and with the cores under a binocular microscope. The accuracy of crossdating was subsequently checked by using COFECHA program (110), which was designed to be used to check the crossdating of a number of samples before they were combined into a chronology (108) that tested one of the series with the rest of the site by correlation statistics.

The COFECHA program is test segment by segment against the adjust master series for crossdating and general measuring accuracy. By calculating correlations for each segment of the series under examination with the master series matched at the point of crossdating. This study given a segment length of 40 years and lagged 20 years (giving 50% overlapping). The correlations of each segment of the series with master are printed in a table. The correlation values are underlined and flagged with "A" if they are less than 0.3665, representing the 99% confidence level of significance in a one-tail test of the distribution of the correlation coefficient. And the correlations are flagged with a "B" if a correlation at some position other than as dated gives a higher correlation with the master series (110).

**3.1.3.3 Correlation of tree rings with styles of log coffin heads**

This study used specimens from different styles of coffin head. Firstly, samples from the same style of coffin head were crossdated. Then samples from difference styles of coffin head were crossdated. Finally, the ring width patterns between Bo Krai Cave and Ban Rai Rockshelter were crossdated.

In this study, the log coffins' head style were consisted of two main styles after the style of the log coffins were identified according to the archaeologists Jakkarinrat Niyomkha (6) and Cherdsak Treerayapiwat (76). One type of head can be described as simple that has no facial features, merely a headlike shape such as 1A, 1B, 2A, 2B, 2C, 5B, 6C, 5D and 10 styles. By contrast, the complex type has animal-like features. The second style often animal head (3C style) carved on one end and the other end carved animal tail (4B style).

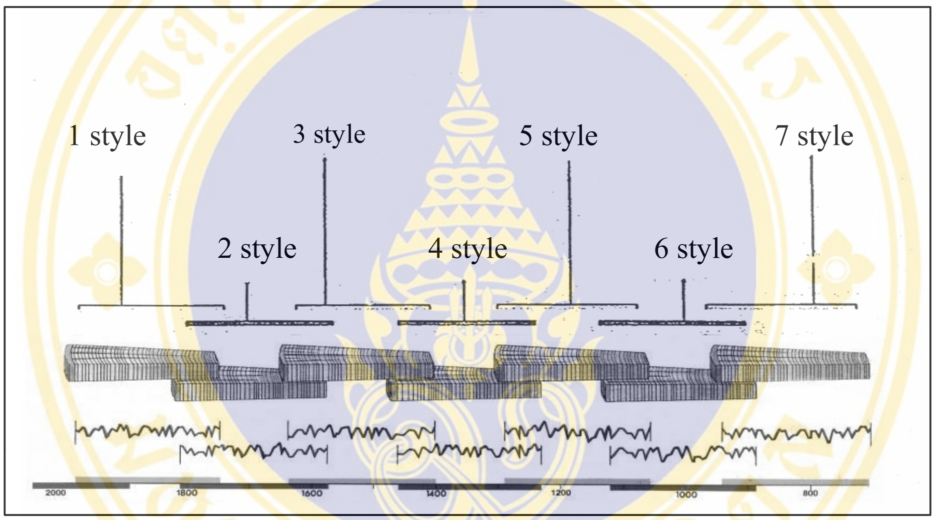



**Figure 3-4** Expected relationship of tree-ring series and log coffin styles (111)

The hypothesis of this study is that the different styles of coffin heads show the age and the development of coffin head styles. If this hypothesis is correct then different styles of coffin head will have different radiocarbon dates. Similarly, log coffins of the same style will have similar radiocarbon dates.

#### 3.1.3.4 Searching for the age of log coffins

The age of log coffins are considerably older than living trees and beyond the range of the tree-ring index of living teak. The explaining of this study is dependant on tree-ring patterns which are wide or narrow or explaining with the dates from $^{14}C$ method which show the period of log coffins.

## 3.2 Radiocarbon dating (Direct $CO_2$ absorption)

### 3.2.1 Selection of specimens

The materials for radiocarbon dating ($^{14}C$ method) were selected from teak log coffins specimens at Bo Krai Cave and Ban Rai Rockshelter that collecting for dendrochronological study as part of the Highland Archaeology in Pang Mapha, Mae Hong Son Province Project: Phase I in 2001 except sample code BO40. The BO40 sample from the outer layer of log coffin was collected in 2004. All of samples are stored in plastic boxes at the Tree Ring and Climate Change Laboratory, Faculty of Environment and Resource Studies, Mahidol University.

These samples were scanned with the WinDENDRO™ 2003a,b program to store the tree-ring width pattern which has important database for tree-ring method in further studies before date the age by radiocarbon method. The precise dendrochronological age (overlapping of tree-ring data) is supported by $^{14}C$ determination. For each tree-ring chronological series, two samples were selected to dating age by radiocarbon dating.

However, the measurement of sample activity by scintillation counting is required approximately 5 g of carbon. For wood sample, the minimum dry weight that will yield 5 g of carbon is 30 g. This weight is the minimum quantity of wood material that is necessary to avoid dilution of the sample and the consequential reduction accuracy to date. In this case, some tree-ring series cannot be dated if the wood samples in the series weigh lower than 30 g. of dry weight (112).

### 3.2.2 Physical pretreatment

The physical techniques used on a sample depend on the nature of the sample and its intended pretreatment. The physical techniques employed fall into two categories, the removal of obvious contaminants and the reduction in particle size of the sample (63).

3.2.2.1 The removal of contaminants

The presence of intrusive contaminants depends on the nature of the sample and its environments. The wood specimens are hard and quite large. To purify a sample, the surface layer and contaminants such as plant roots, soil and sand were removed (63).

3.2.2.2 Reduction in particle size

The specimens are reduced in size after they have been inspected. This is carried out to increase the overall surface area of the sample so that the maximum area of sample can be further chemically pretreated (63).

### 3.2.3 Chemical pretreatment

Wood consists of various fractions: resins, sugar, lipids, hemicellulose, lignin (up to 30 %) and cellulose (up to 70 %). The latter two are the most stable compounds. The others are more or less soluble and mobile and may infiltrate radially into the tree (64). $^{14}C$ calibration studies, on tree ring in particular, may require the preparation of pure cellulose. This procedure consists of a number of steps (113):

1. Extractions with 4 % hydrochloric acid (HCl) solution at 80$^{o}$C during 24 hours to remove resinous compounds including sugars, soil carbonate and infiltrated humic (fulvic) acid and to make the wooden chips more accessible to the further bleaching reagents.
2. Bleaching of the residue with sodium chlorite ($NaClO_2$) and acetic acid (114), with the subsequent addition, over 12 hours, of ten 15 g portions of $NaClO_2$ powder and 1 ml of 100 % acetic acid per 200 g of wooden chips in 2 liters of water at 70$^{o}$C.
3. Extraction of residue with 4 % NaOH solution at 80$^{o}$C during 24 hours to remove infiltrated tannic acids and part of the lignine, thus isolating the (α) cellulose.

4. Treatment with 4 % HCl solution at 80$^oC$ during several hours to remove $CO_2$ possibly absorbed during step 3.
5. Dry sample in the oven at 60-80$^oC$ overnight.

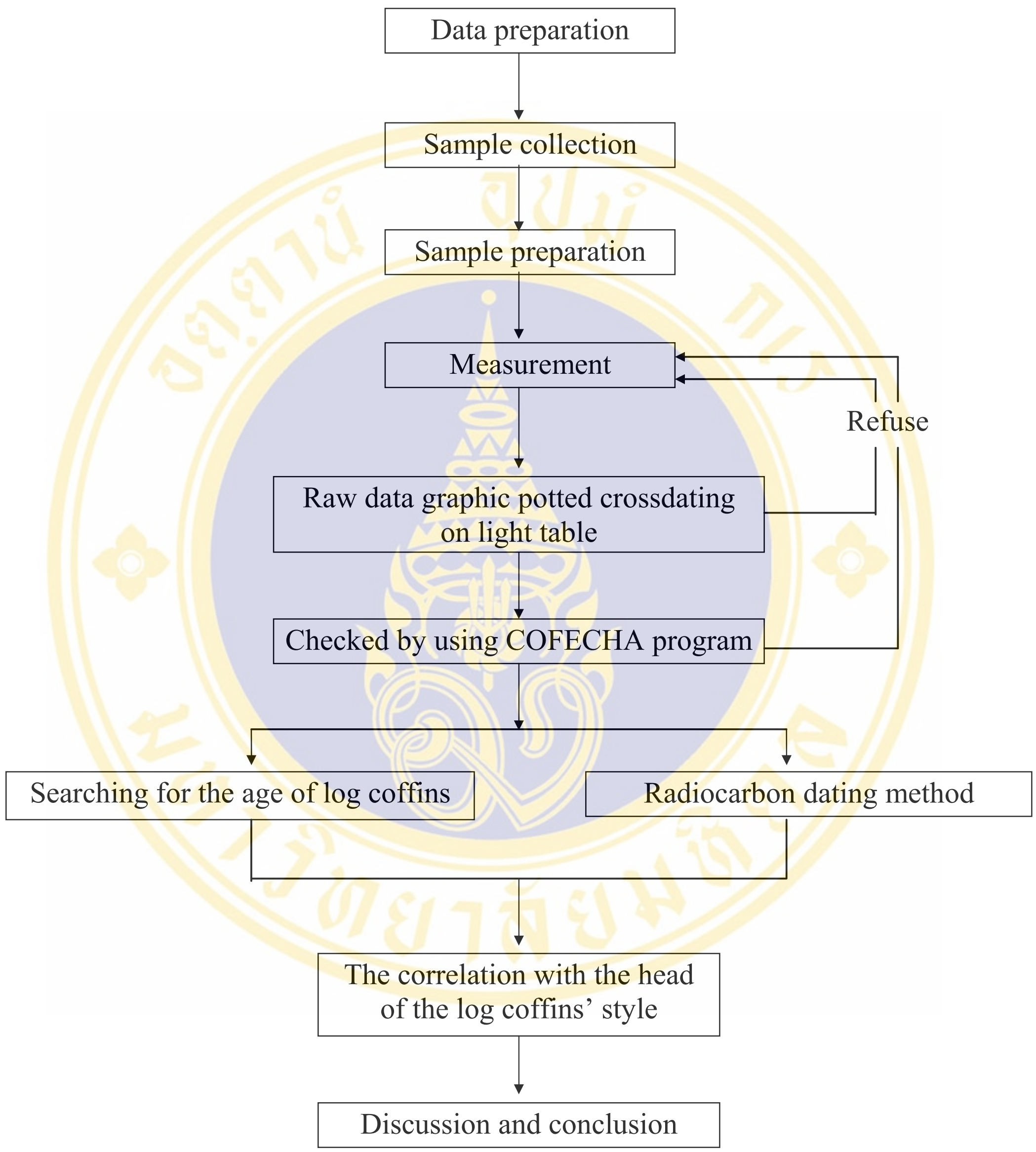
The steps 2 to 4 are separated by washing with determineralized water to pH ≅ 7.

### 3.2.4 Counting with Liquid Scintillation Counter

The specimens of this study had been pretreated in form of pure cellulose. The followings are the processes of converting the pure cellulose to $CO_2$ and absorb $CO_2$ by direct absorption at the radiocarbon laboratory, the Office of Atomic for Peace (OAP), Bangkok, Thailand. Then, the radiocarbon specimens were analysis using a Liquid Scintillation Counter (LKB Wallac 1220 Quantulus). The measurement was usually conducted under temperature-stabilized conditions at 20 $^oC$ and set counting with 20 cycles and period of 50 minutes for each sample. The standard reference of $^{14}C$ was used ANU sucrose and set $^{14}C$ half life 5,568 years. The data are statistically analyzed by computer (Appendix I) (115).

Because of the radioactive decay is random (Poisson) process, a repeated measurement of the same sample under similar conditions will not give the same result. The uncertainty is the measured activity is given by the standard deviation (σ). The change that the true activity in this study is within ±2σ is 95 %. Finally, the uncalibrate $^{14}C$ age and %MODERN used for calibrate (2 sigma) with OxCal v 3.9 (116) at probability 95.4 %.

### 3.3 Steps of methodology



# CHAPTER IV
# RESULTS

The district of Pang Mapha, Mae Hong Son Province in the Northern Thailand has many caves rich in archaeological interest. In certain dry caves, many teak coffins have been found. An interesting feature of these coffins is the carved teak heads at both ends. And archaeologist hypothesis that the simple head type predated the complex head type. To test this hypothesis, the methods used in this study are explained separately below under the headings dendrochronological dating and radiocarbon dating.

## 4.1 Dendrochronological dating

Dendrochronology is the science of dating events and variations in the environment of former period by the comparative study of growth rings in trees and aged wood. There are several prerequisites to the successful application of dendrochronology in an archaeological site such as there must be sufficient wood specimen and preserved tree-ring structures. This method makes it possible to date individual ruins to within a year, or even a season, of the day they were built. Often, the tree-ring analysis from sites can give strong clues about the length of occupation, certain periods of building or repair activities at the site, as well as demonstrate practices of reuse or stockpiling by early inhabitants.

In this study used the tree-ring analysis to build the chronology of log coffins' head style in the study area (Bo Krai Cave and Ban Rai Rockshelter). This method has provided an important tool to understand about the different style of log coffin heads in study area. The materials for tree-ring dating were taken from teak log coffins and teak posts at Bo Krai Cave and Ban Rai Rockshelter, Mae Hong Son Province. The both sites are important and interesting places for dendrochronological study in archeological sites because the majority of coffins and posts are often made from teakwood which has a high potential for dendrochronological study.

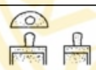
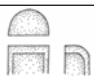
Generally, a tree-ring date is the year in which the last ring present on a specimen was formed. The term cutting date is applied to specimens possessing the last exterior ring that grew on the tree before it died, regardless of whether the tree was killed by human activity or died of natural cause. The specimens in Bo Krai Cave and Ban Rai Rockshelter are not finding bark or bark cell on the outside of the specimen. The tree-ring date is referred to a noncutting date and estimate the number of rings lost.

The tree-ring width was measured on 71 cores from Bo Krai Cave, 116 cores from Ban Rai Rockshelter. Firstly, samples from the same piece of wood were crossdated (Appendix II). After that samples in each site from the same style of coffin head were crossdated. Then samples from difference styles of coffin head were crossdated. Finally, the ring width patterns between Bo Krai Cave and Ban Rai Rockshelter were crossdated.

**4.1.1 Bo Krai Cave**

Inside Bo Krai Cave, there are three chambers. The log coffins in cave have more than thirty lids of log coffins. Altogether, the log coffins had no specific orientation. All of the log coffins and posts are made of teak (*Tectona grandis* L.). One style is the geometric style that includes triangular, rectangular, and amorphous motifs. One style is complex style that an animal head (3C style) carved on one end and another end a carved animal tail (4B style). The style of log coffin heads which dendrochronological study in this area include 1A, 1B, 2A, 2B, 2C, 3A, 3C, 4B, 5B, 6C, 5D and 10 styles (Table 4-1).

**Table 4-1** The style of log coffin heads from Bo Krai Cave (4)

| Style | Image | Description |
|---|---|---|
| 1A |  | A long solid wood with curved at the end stick out. |
| 1B |  | A short solid wood with curved at the end stick out. |
| 2A |  | A long square solid wood with curved at the end stick out and pierced flat back at the bottom and have small hole. |
| 2B |  | A short square solid wood with curved at the end stick out and flat back at the bottom. |
| 2C |  | A short square solid wood with curved at the end stick out and pierced flat back at the bottom. |
| 3A |  | A solid wood sculpted look like a pig's head. |
| 3C |  | A solid wood sculpted head of small four-legged animal: cat, barking deer. |
| 4B |  | A flat solid wood with turned up at the top. Always found with 3C style. |
| 5B |  | A sharp topknot solid wood. |
| 6C |  | A short solid wood with curved at the end stick out. Similar to 1B style but smaller and more slender. |
| 5D |  | There are two topknot solid wood with cut at the end stick out. |
| 10 |  | Plain: simple head without any sculpture. |

The tree-ring width measured from Bo Krai Cave was conducted on 36 log coffins (68 cores) and 3 posts (3 cores). After crossdating between cores (A, B and other) in the same piece of wood, the longest log coffin chronology has a length of 270 years and the shortest has a length 41 years. The posts have a longest length of 68 years and the shortest has a length 35 years. The tree-ring numbers of specimens from Bo Krai Cave given in table 4-2.

**Table 4-2** The tree-ring numbers of specimens from Bo Krai Cave

| Code | Chamber | Head styles | Pith | Tree-ring numbers | | | |
|---|---|---|---|---|---|---|---|
| | | | | Core A | Core B | Core C | Total |
| BO01A | 3 | 2A | NP | 52 | - | - | 52 |
| BO02A | 3 | 1B | NP | 145 | - | - | 145 |
| BO03A-B | 3 | 2A | NP/**P** | 44 | 28 | | 44 |
| BO04A-B-C | 3 | 2C | **P**/**P**/NP | 31 | 49 | 27 | 52 |
| BO05A-B | 3 | 2A | NP/**P** | 104 | 111 | - | 119 |
| BO06A-B | 3 | 3A and 4B | NP/NP | 49 | 97 | - | 101 |
| BO07A-B | 2 | 10 and 4B | NP/NP | 154 | 142 | - | 188 |
| BO08A | 2 | 4B | NP | 106 | - | - | 106 |
| BO09A-B | 2 | 5B | NP | 97 | 92 | - | 97 |
| BO10A-B | 2 | 4B | **P**/NP | 174 | 149 | - | 204 |
| BO11A-B | 2 | 3C and 4B | NP/NP | 115 | 109 | - | 115 |
| BO12A-B | 2 | 3C | NP/NP | 59 | 44 | - | 59 |
| BO13A-B | 2 | 3C | **P**/NP | 102 | 86 | - | 102 |
| BO14A-B | 2 | 1A | NP/NP | 39 | 31 | - | 42 |
| BO15A-B | 2 | 3C and 4B | NP/NP | 61 | 44 | - | 62 |
| BO16A-B | 2 | 3C and 4B | NP/NP | 89 | 99 | - | 99 |
| BO17A | 2 | 2A | NP | 148 | - | - | 148 |
| BO18A-B | 2 | 1A | NP/NP | 133 | 145 | - | 145 |
| BO19A-B | 2 | 3C | NP/**P** | 106 | 116 | - | 127 |
| BO20A-B | 2 | 3C and 4B | NP/NP | 93 | 79 | - | 94 |
| BO21A-B | 2 | 3C and 4B | NP/NP | 100 | 95 | - | 100 |
| BO22A-B | 2 | 3C | NP/NP | 84 | 85 | - | 108 |
| BO23A-B | 2 | 3C and 4B | NP/NP | 123 | 114 | - | 122 |
| BO24A-B | 2 | 3C and 4B | NP/NP | 103 | 128 | - | 130 |
| BO25A-B | 2 | 3C | NP/NP | 98 | 98 | - | 103 |
| BO26A-B | 2 | 3C and 4B | NP/NP | 124 | 125 | - | 126 |
| BO27A-B | 2 | 3C and 4B | NP/NP | 111 | 107 | - | 111 |
| BO28A-B | 2 | 3C and 4B | NP/NP | 145 | 123 | - | 163 |
| BO29A-B | 2 | 3C and 4B | NP/NP | 135 | 136 | - | 146 |
| BO30A-B | 2 | 1B | NP/NP | 96 | 89 | - | 98 |
| BO31A-B | 2 | 2A | NP/NP | 210 | 201 | - | 270 |
| BO32A-B | 2 | 3C and 4B | NP/NP | 60 | 36 | - | 60 |
| BO33A-B | 2 | 3C and 4B | NP/NP | 40 | 41 | - | 41 |

**Table 4-2** The tree-ring numbers of specimens from Bo Krai Cave (cont.)

| Code | Chamber | Head styles | Pith | Tree-ring numbers | | |
|---|---|---|---|---|---|---|
| | | | | Core A | Core B | Total |
| BO34A-B | 2 | 1B | NP/NP | 109 | 152 | 153 |
| BO35A | 1 | 2A | NP | 157 | - | 157 |
| BO36A-B | 1 | 3C and 5B | NP/NP | 68 | 97 | 104 |
| BO37A1-A2 | 1 | Post | **P** | 33 | 19 | 35 |
| BO38A1-A2 | 1 | Post | **P** | 61 | 68 | 68 |
| BO39A1-A2 | 1 | Post | **P** | 29 | 35 | 35 |

**Note** P = The inner rings either contained the pith or were close to the pith.
NP = No-pith.
Total tree-ring numbers = Tree-ring numbers after crossdated between core A, B and C.

The result of the tree-ring width crossdated of specimens from Bo Krai Cave, five dendrochronological series were built from 51 cores. The sample collection for dendrochronological series from Bo Krai Cave shown in figure 4-1.

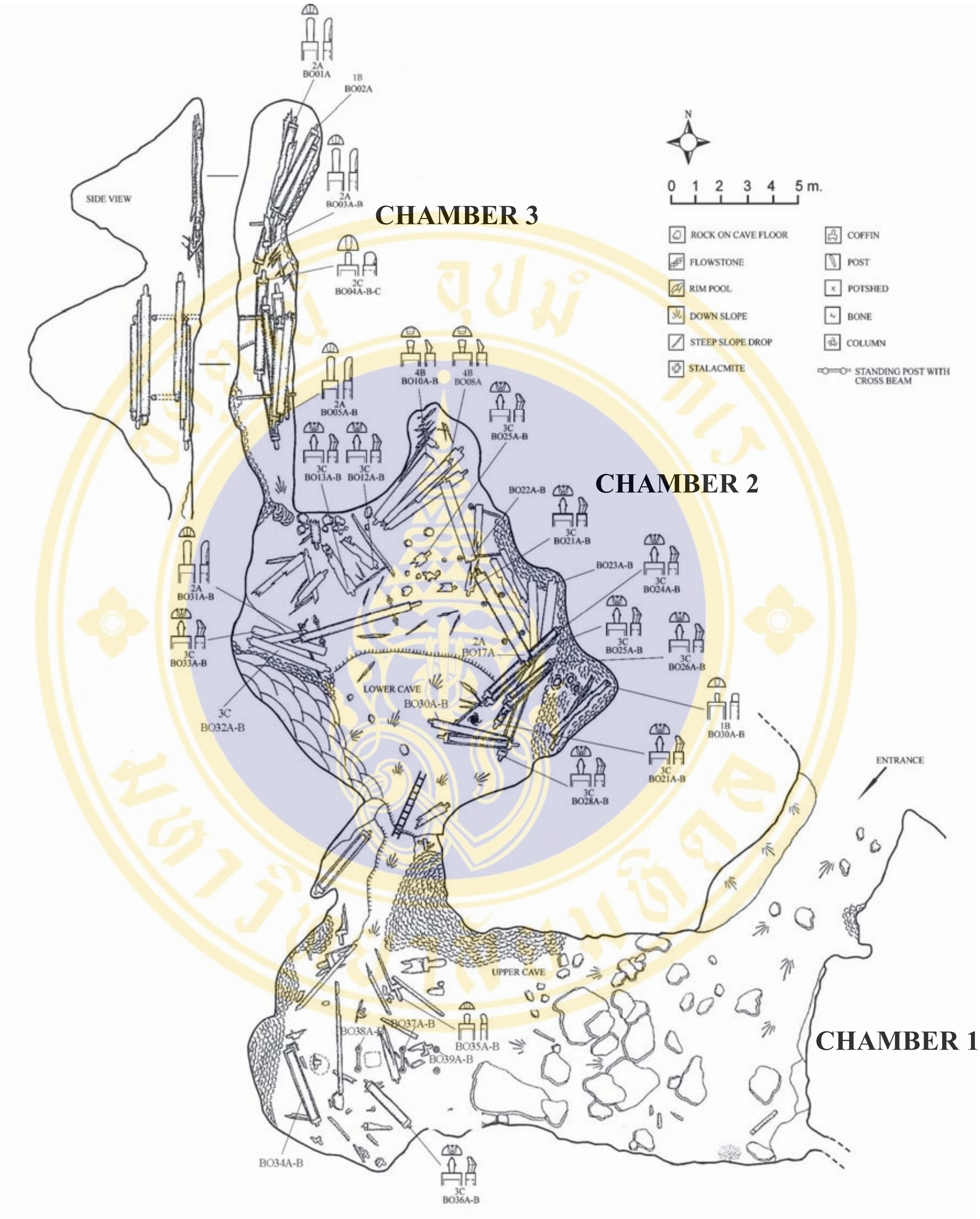



**Figure 4-1** The sample collection for dendrochronological series from Bo Krai Cave (3)

#### 4.1.1.1 Bo Krai chronological series 1 (BKS1)

The Bo Krai chronological series 1 were built from 3 log coffin lids (4 cores). BO17 and BO31 are place on a pair of posts and beams which raise them above cave's floor in chamber 2 that is dark chamber and located approximately 3 meters lower than the entrance. A lot of log coffins were found in this area. Both lids are large size, the both ends carved in 2A style. Each of samples supported on six large posts with cross beams which remain largely intact and in a good state of preservation. In chamber 3, the sample code BO02 has log coffins' head 1B style were found on the floor.

Tree-ring widths were measured, core BO02A has 145 rings, BO17A has 148 rings, BO31A has 210 rings, and BO31B has 207 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined. The time span of BKS1 is 270 years (Figure 4-2). The number of year in chronology started from inner ring (pith) to outer ring (bark). The total ring was number of rings that can be crossdated between each core in the same piece of wood.


**Figure 4-2** Spans of Bo Krai chronological series 1; • indicates the inner close to the pith

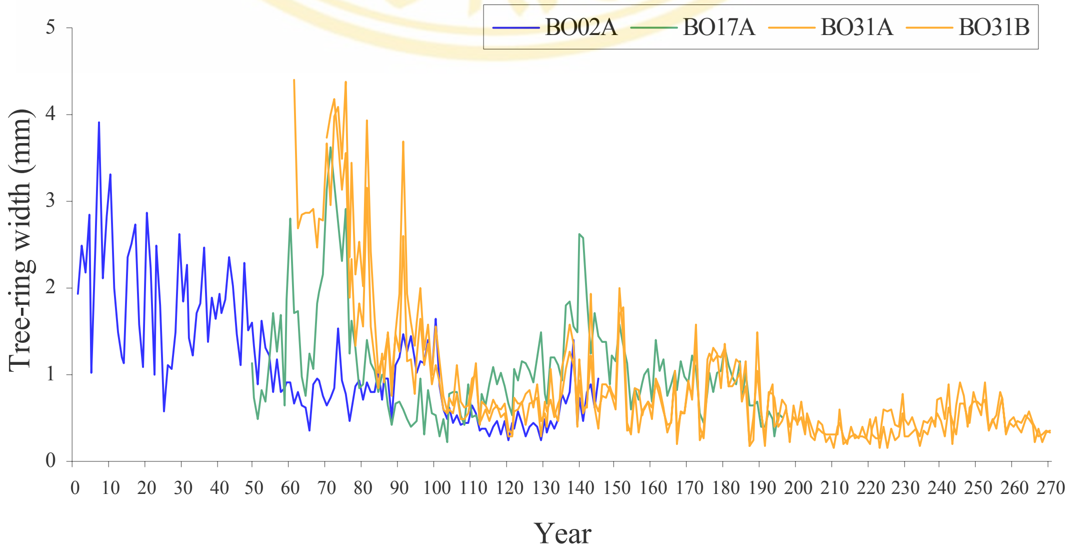



**Figure 4-3** The chronologies of specimens from Bo Krai chronological series 1

The tree-ring width on a linear scale representing the years of growth for the x-axis and y-axis for the width of each ring. Graphs of tree-ring width were then created with a floating date scale. The individual chronologies were crossdated in BKS1, specimens BO02, BO17 and BO31 were well correlation (Table 4-3).

**Table 4-3** Description statistics for the Bo Krai chronological series 1

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 40<br>79 | 60<br>99 | 80<br>119 | 100<br>139 | 120<br>159 | 140<br>179 | 160<br>199 | 180<br>219 | 200<br>239 | 220<br>259 | 240<br>279 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BO02A |  | 1 | 145 | .33A | .45 | .66 | .49 | .40 | | | | | | |
| BO17A | | 49 | 196 | .44 | .50 | .28A | .23A | .31A | .49 | .59 | | | | |
| BO31A | | 61 | 270 | | .70 | .72 | .84 | .79 | .77 | .75 | .56 | .41 | .48 | .45 |
| BO31B | | 70 | 270 | | .61 | .82 | .78 | .68 | .76 | .87 | .65 | .41 | .48 | .45 |

**Note** BO02 has log coffins' head 1B style.
BO17 and BO31 have log coffins' head 2A style.

From this series, these wood samples can match of pattern growth. The result of dendrochronological dating, the log coffin that carved the end in 1B style is earlier than 2A style. However, the sample undated in the cutting date because bark and outer were carved out. From this series, the samples from chamber 2 and 3 can overlapping growth pattern in the same range. It means the both chamber possibly were used as burial site in the same time.

#### 4.1.1.2 Bo Krai chronological series 2 (BKS 2)

The Bo Krai chronological series 2 were built from 5 log coffins lids (10 cores). Code BO07 has log coffins' head 10 and 4B styles, BO10 has log coffins' head 4B style but another end damaged, BO12, BO13 have log coffins' head 3C and 4B styles, BO36 has log coffins' head 3C and 5B styles. All of them found in chamber 2 exempt BO36 found in chamber 1.

The time span of BKS2 is 222 years (Figure 4-4). Core BO07A has 154 rings, BO07B has 142 rings, BO10A has 174 rings, BO10B has 149 rings, BO12A has 58 rings, BO12B has 44 rings, BO13A has 102 rings, BO13B has 86 rings, BO36A has 68 rings and B036B has 97 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

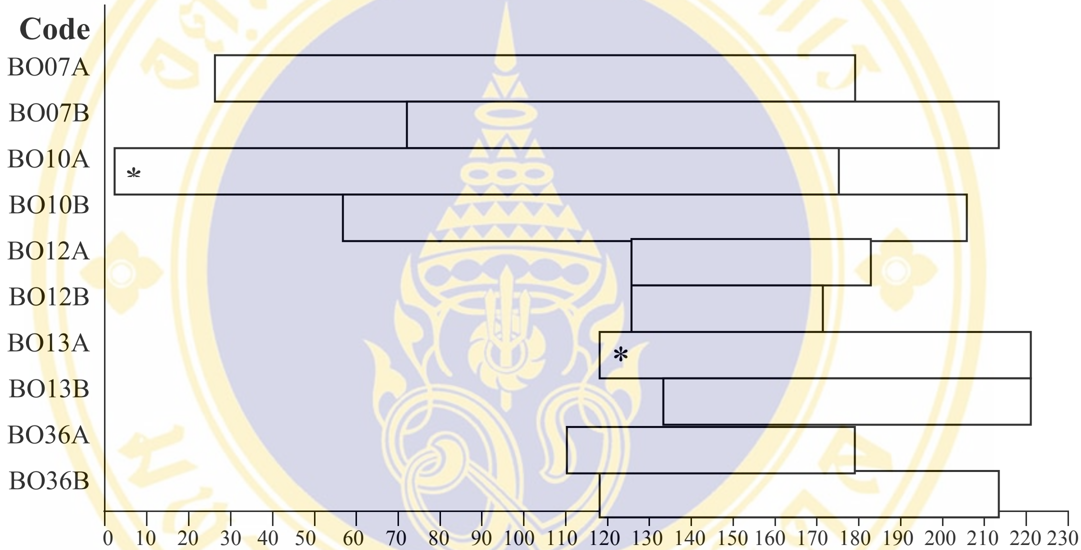



**Figure 4-4** Spans of Bo Krai chronological series 2; * indicates the inner rings contain the pith

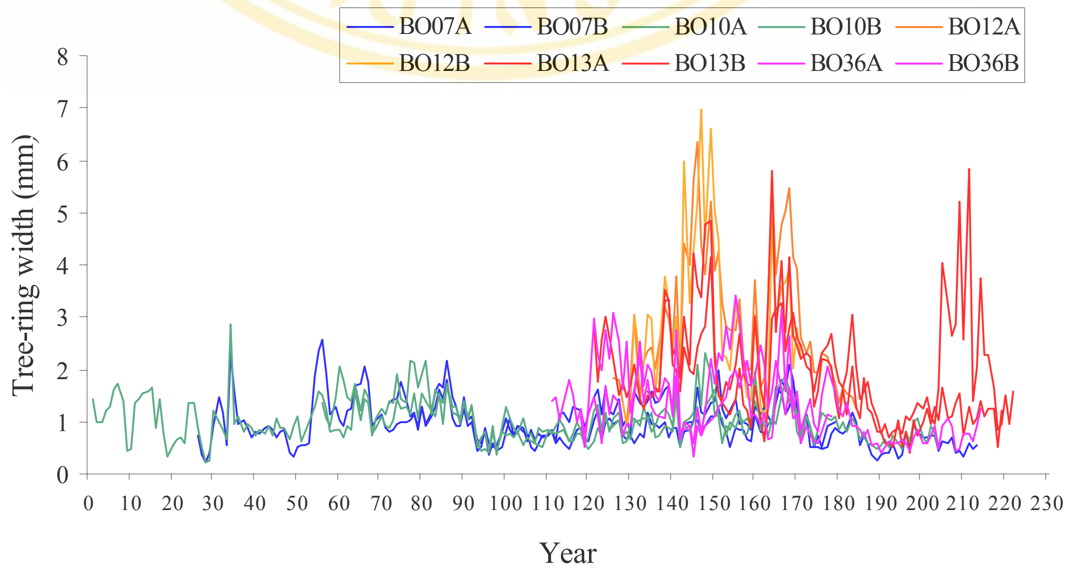



**Figure 4-5** The chronologies of specimens from Bo Krai chronological series 2

The individual chronologies were crossdated. Series 2, specimens BO07, BO10, BO12, BO13 and BO36 were well correlation (Table 4-4).

**Table 4-4** Description statistics for the Bo Krai chronological series 2

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 20<br>59 | 40<br>79 | 60<br>99 | 80<br>119 | 100<br>139 | 120<br>159 | 140<br>179 | 160<br>199 | 180<br>219 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BO07A |  | 26 | 179 | .65 | .63 | .76 | .69 | .65 | .76 | .69 | | |
| BO07B | | 72 | 213 | | | .60 | .61 | .39 | .62 | .73 | .68 | .62 |
| BO10A |  | 1 | 174 | .65 | .65 | .77 | .76 | .72 | .79 | .75 | | |
| BO10B | | 56 | 204 | | .48 | .58 | .56 | .37 | .66 | .77 | .70 | .70 |
| BO12A |  | 126 | 184 | | | | | .66 | .77 | .66 | | |
| BO12B | | 128 | 171 | | | | | | .67 | .69 | | |
| BO13A | | 121 | 222 | | | | | | .30A | .43 | .52 | .49 |
| BO13B | | 134 | 219 | | | | | | .57 | .63 | .57 | .51 |
| BO36A |  | 111 | 178 | | | | | .36A | .40 | .32A | | |
| BO36B | | 118 | 214 | | | | | .56 | .54 | .60 | .40 | .35A |

**Note** BO07 has log coffins' head 10 and 4B styles.

BO10 has log coffins' head 4B style but another end damaged.

BO12, 13 have log coffins' head 3C and 4B styles.

BO36 has have log coffins' head 3C and 5B styles.

Generally, the log coffin in Pang Mapha often carving of the simple style that no facial feature, merely a head like shape. By contrast, the styles characteristic of the log coffin heads discovered in Bo Krai Cave is often an animal head (3C style) carved on one end and one end a carved animal tail (4B style) except the log coffin BO07 that have one end 4B style but one end without any sculpture (10 style).

From the growth ring pattern the log coffin code BO07 (188 years) and BO10 (204 years) have very high correction between age and diameter growth assuming both of them were together and probably were made from same tree because the tree that growth in the same area and time should have the same growth ring pattern. Both samples have age more than 200 years and narrow ring width that may be caused by external factors such as geographic setting, altitude and amount of rain fall. The both lid probably intact by one coffin served as the lid another in history but now it consists of only half on floor in chamber 2. The result from BKS2 indicates that the samples from chamber 1 and 2 can be overlapped growth pattern in the same range. It means the both chamber maybe used as burial site in the same time if position unchanged by human. All of coffin styles in this series show the variety characteristic of the complex type (animal-like features) but all of them probably build in the same time because growth pattern have high correlation and the last end of each sample fix in the same point.

**4.1.1.3 Bo Krai chronological series 3 (BKS3)**

The Bo Krai chronological series 3 were built from 3 log coffin lids (6 cores) that found on floor in chamber 2. BO09 and BO15 found on the floor but BO16 place on two small posts and beam that are put together in the "H" shape. Code BO09 has log coffins' head 5B style, and BO15 and BO16 have log coffins' head 3C and 4B styles. The span of Bo Krai chronological series 3 is 116 year. Core BO09A has 97 rings, BO09B has 92 rings, BO15A has 61 rings, BO15B has 44 rings, BO16A has 89 rings, and BO16B has 99 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

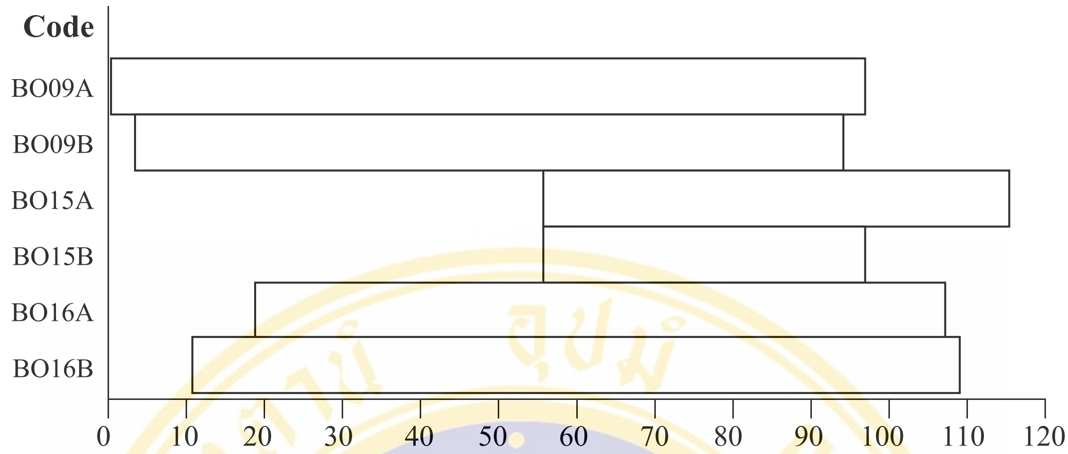



**Figure 4-6** Spans of Bo Krai chronological series 3.

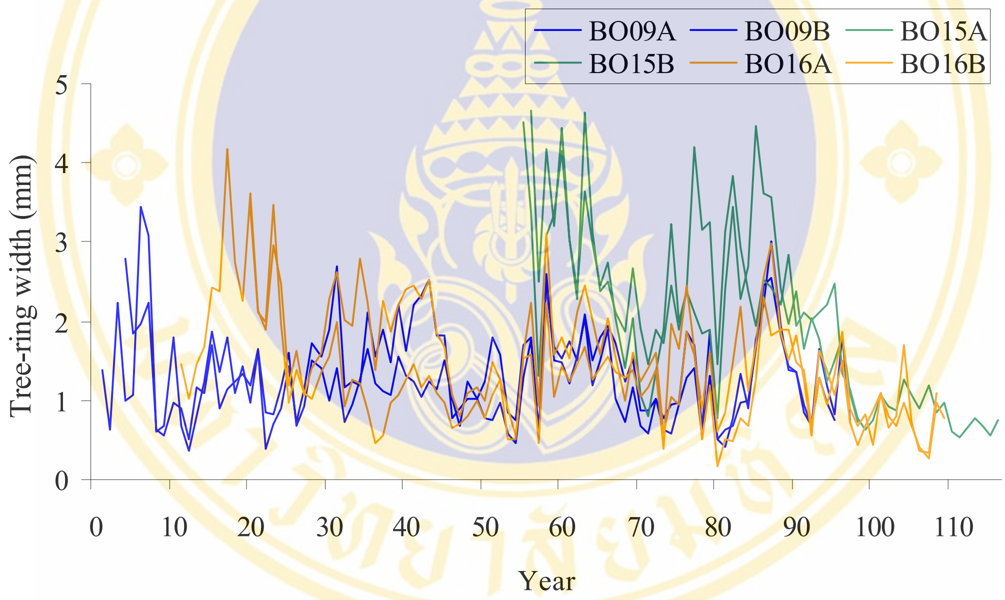



**Figure 4-7** The chronologies of specimens in Bo Krai chronological series 3.

The individual chronologies were crossdated. Series 3, specimens BO09, BO15 and BO16 were well correlation (Table 4-5).

**Table 4-5** Description statistics for the Bo Krai chronological series 3

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 0<br>39 | 20<br>59 | 40<br>79 | 60<br>99 | 80<br>119 |
|---|---|---|---|---|---|---|---|---|
| BO09A |  | 1 | 97 | .56 | .71 | .87 | .83 | |
| BO09B | | 4 | 95 | .50 | .62 | .82 | .85 | |
| BO15A | | 56 | 116 | | | .57 | .42 | .34A |
| BO15B | | 55 | 98 | | | .69 | .66 | |
| BO16A | | 20 | 108 | | .65 | .80 | .79 | .76 |
| BO16B | | 11 | 109 | .58 | .73 | .87 | .72 | .68 |

**Note** BO09 has log coffins' head 5B style.

BO15 and BO16 have log coffins' head 3C and 4B styles.

These styles of log coffin are used in the same period. The high correlation in this series indicate that log coffin in series were made from tree that growth in the same area and time.

### 4.1.1.4 Bo Krai chronological series 4

The tree-ring chronological series 4 were built from 2 log coffin lids (4 cores). Code BO32 and BO33 has log coffins' head that one end carved 3C style and one end carved 4B style. Core BO32A has 60 rings, BO32B has 36 rings, BO33A has 40 rings, and BO33B has 41 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

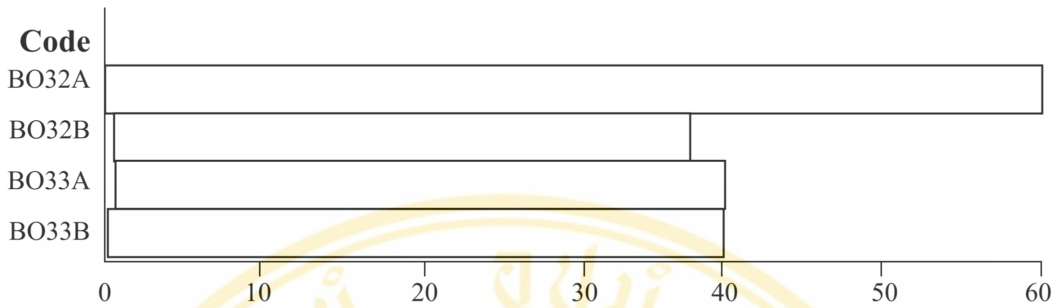



**Figure 4-8** Spans of Bo Krai chronological series 4.

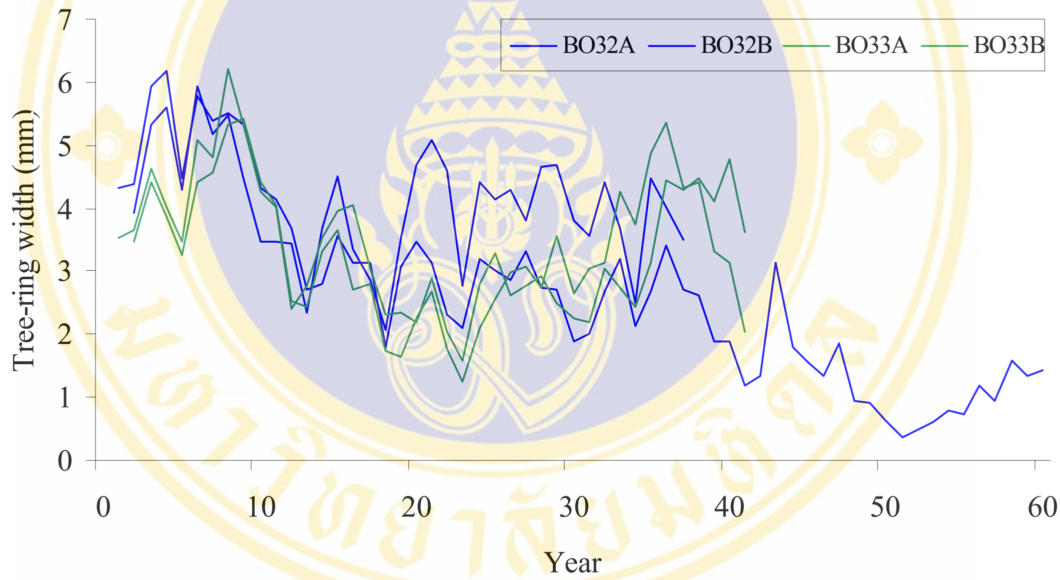



**Figure 4-9** The chronologies of specimens in Bo Krai chronological series 4.

The individual chronologies were crossdated. Series 4, specimens BO32 and BO33 were very high correlation (Table 4-6).

**Table 4-6** Description statistics for the Bo Krai chronological series 4

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 0 | 20 |
|---|---|---|---|---|---|
| | | | | 39 | 59 |
| BO32A | | 1 | 60 | .74 | .74 |
| BO32B |  | 2 | 37 | .59 | |
| BO33A | | 2 | 41 | .76 | |
| BO33B | | 1 | 41 | .58 | .60 |

**Note** BO32 and BO33 have log coffins' head 3C and 4B styles.

The both log coffin lids were collected in the same position in chamber 2. The time span of Bo Krai chronological series 4 is 60 years. From tree-ring pattern in this series explain BO32 and BO33 made from tree that growth in the same area in the same time because they have similar growth pattern and high correlation between them The both lids is probably couple (upper and lower lids). Unfortunately, the log coffins in this study are not intact in present but this result confirm the hypothesis that believe the set of coffin consist of two lids.

### 4.1.1.5 Bo Krai chronological series 5

A total sample in Bo Krai chronological series 5 is a total of 27 cores from teak log coffins and posts. In this series, 24 cores were taken from 12 log coffin lids in chamber 2 and 3 cores were taken from 3 posts in chamber 1. The most of log coffins in this series were decorated the ends in an animal head (3C style) carved on one end and the other end carved animal tail (4B style) except BO01 and BO03 have log coffins' head 2A style, BO02 has log coffins' head 2B style and BO18 has log coffins' head 1A style. The time span of BKS5 is 222 years (Figure 4-10).

By matching up similar spaced rings in core samples, the floating ages of ancient wood can be determined.

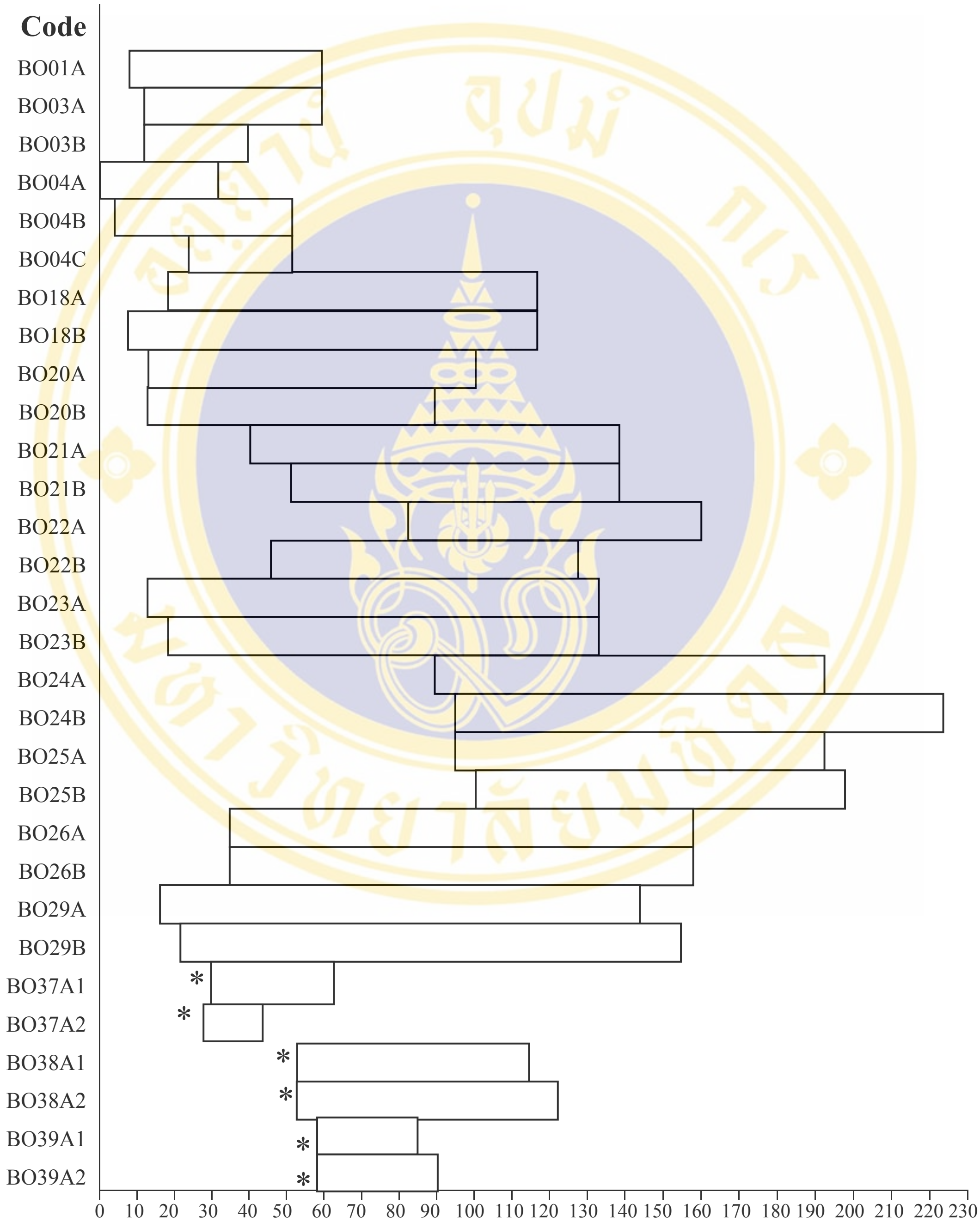



**Figure 4-10** Spans of Bo Krai chronological series 5; * indicates the inner rings contain the pith

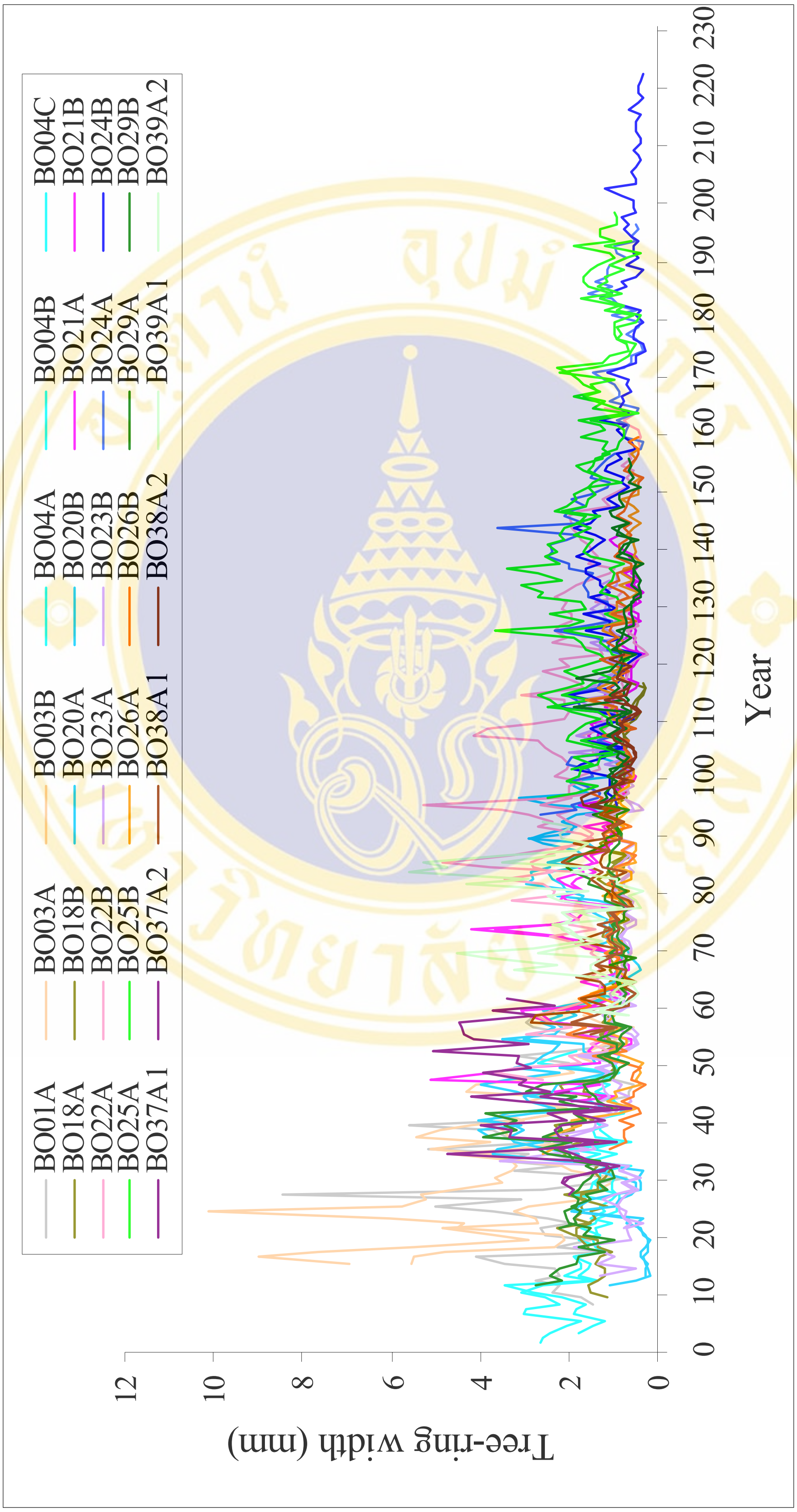



**Figure 4-11** The chronologies of specimens in Bo Krai chronological series 5

**Table 4-7** Description statistics for the Bo Krai chronological series 5

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position.

| Seg Series | Style | Time_span | | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 39 | 59 | 79 | 99 | 119 | 139 | 159 | 179 | 199 |
| BO01A |  | 8 | 58 | .50 | .49 | | | | | | | |
| BO03A | | 15 | 58 | .58 | .66 | | | | | | | |
| BO03B | | 15 | 42 | .53 | | | | | | | | |
| BO04A |  | 1 | 31 | .45 | | | | | | | | |
| BO04B | | 3 | 51 | .59 | .36A | | | | | | | |
| BO04C | | 26 | 52 | | .50 | | | | | | | |
| BO18A |  | 18 | 116 | .60 | .67 | .51 | .45B | .42B | | | | |
| BO18B | | 9 | 116 | .68 | .70 | .58 | .38B | .39 | | | | |
| BO20A | | 12 | 104 | .58 | .55 | .48 | .43 | .44 | | | | |
| BO20B | | 11 | 91 | .47 | .43 | .37 | .31A | | | | | |
| BO21A | | 43 | 142 | | | .59 | .61 | .56 | .46 | .45 | | |
| BO21B | | 51 | 138 | | | .63 | .47 | .42 | .70 | | | |
| BO22A | | 83 | 164 | | | | | .52 | .37 | .41 | .26A | |
| BO22B |  | 47 | 132 | | | .51 | .57 | .44 | .55 | | | |
| BO23A | | 13 | 135 | .27B | .37A | .24A | .37 | .36A | .37 | | | |
| BO23B | | 21 | 134 | | .48 | .37 | .28B | .21B | .38 | | | |
| BO24A |  | 93 | 196 | | | | | .33A | .29B | .49 | .56 | .49 |
| BO24B | | 95 | 222 | | | | | .35A | .48 | .71 | .79 | .62 |
| BO25A | | 96 | 193 | | | | | .37 | .41 | .44 | .66 | .70 |
| BO25B | | 101 | 198 | | | | | | .37 | .32B | .47 | .64 |
| BO26A | | 34 | 157 | | .48 | .47 | .25A | .14B | .48 | .53 | | |
| BO26B | | 35 | 159 | .33A | .37 | .37 | .26A | .41 | .50 | | | |
| BO29A | | 11 | 114 | .56 | .58 | .46 | .47B | .33A | .43 | .50 | | |
| BO29B | | 21 | 155 | | .78 | .65 | .55 | .38B | .27A | .40 | | |
| BO37A1 | | 29 | 61 | | .41 | | | | | | | |
| BO37A2 | | 27 | 45 | | .62 | | | | | | | |
| BO38A1 | | 55 | 115 | | | .57 | .56 | .55 | | | | |
| BO38A2 | | 55 | 121 | | | .56 | .54 | .38 | .31A | | | |
| BO39A1 | | 58 | 86 | | | .59 | | | | | | |
| BO39A2 | | 58 | 92 | | | .45 | | | | | | |

**Note** BO01 and BO03 have log coffins' head 2A style.
BO02 has log coffins' head 2C style.
BO18 has log coffins' head 1A style.
BO20, 21, 22, 23, 24, 25, 26 and 29 have log coffins' one end 3C style and one end 4B style.
BO37, 38, 39 are posts.

From the result, the chamber 3 probably was used as burial area before chamber 1 and 2. Moreover the log coffin head 2A and 2C styles from chamber 3 predated 1A style and complex styles from dendrochronological dating in BKS5. However, it is not convincing because the number of rings lost and all of samples are not finding bark or bark cell on the outside of the samples which show cutting time and the result is not comprehensive because the experience in many laboratories suggests that reliable crossdating should not be expected for sequences of less than 40 years (117). However, this series show the complex style was made in wide period. It means this style was continuously used for burial ceremony in Bo Krai Cave.

The five dendrochronological series from Bo Krai Cave have high correlation between the samples in each series. The BKS5 is important series that represent the correlation between the complex style used continuous and different period in this study area. Although, all of the complex style cannot be crossdated in one series, it might be used in different period or some portion of wood was damaged. Moreover, the log coffin carved in the same style can be crossdated such as BKS1 that is matching of log coffins' head simple style. Nowadays, it can describe about the log coffin probably made from one trunk and split in half, one piece use to lower lid and another use to upper lid. Similarly in chamber 2, two cases it appears the coffin served as the lid of another.

**4.1.2 Ban Rai Rockshelter**

Ban Rai Rockshelter was used as burial, habitation, ceremonial and rock painting site in different periods. This site found the skeleton remain dating to 9720±50 yrs BP (Beta-168217) (2). This is very important information because it indicates that the site was used before the Log Coffin culture (ca. 2200 years ago to $9^{th}$ century A.D.) The results of fauna, tree-ring and palynological analyses from Ban Rai Rockshelter indicate that the climate was slightly colder and moister than present in Late Pleistocene and Early Holocene. Around the site was possibly surrounded by evergreen forests, deciduous dipterocarp forest and pine forest in upland (1). The area in the Late Holocene was grassland and mixed deciduous forests (2).

The log coffin is a diagnostic find of the Log Coffin culture. This site has no absolute dates of log coffin so it dates by using relative dating technique with another dated. The other ancient remains such as pebble artifacts, rock paintings, earthenwares, shells, human bones and animal bones were also found in this area.

Log coffins and posts have been protected from sunshine and rain by the overhang of the rockshelter. Because Ban Rai Rockshelter is open site, the log coffin wood is easily decayed than Bo Krai Cave. Some coffins and posts in Ban Rai Rockshelter were burnt or covered with weed flora. The size of log coffin in Ban Rai Rockshelter is lager than Bo Krai Cave. Probably, surrounding of the site having pretty large teak forest area.

Ban Rai Rockshelter, most of log coffins were made from teak wood but sometimes it made from another wood such as jambolan (Syzygium *cumini*). Unfortunately, this tree specie is not good material to study by dendrochronological technique. The style of log coffin heads in this area is a simple type that has no facial features, including 1A, 1B, 2A, 2B and 2C styles (Table 4-8). The head form of coffins from Ban Rai Rockshelter and Bo Krai Cave resembles each other in 5 styles as 1A, 1B, 2A, 2B and 2C.

**Table 4-8** The style of log coffin heads from Ban Rai Rockshelter (4)

| Style | Image | Description |
|---|---|---|
| 1A |  | A long solid wood with curved at the end stick out. |
| 1B |  | A short solid wood with curved at the end stick out. |
| 2A |  | A long square solid wood with curved at the end stick out and pierced flat back at the bottom. |
| 2B |  | A short square solid wood with curved at the end stick out and flat back at the bottom. |
| 2C |  | A short square solid wood with curved at the end stick out and pierced flat back at the bottom. |

The tree-ring width measured from Ban Rai Rockshelter was conducted on 27 log coffin lids (64 cores) and 26 posts (52 cores). All of the tree-ring chronologies from anciant wood in this area have a floating age. The longest span of each pieces of log coffin lid was 265 years and the shortest one was 51 years. And the longest span of each piece of posts was 218 years and the shortest one was 49 years. The tree-ring numbers of specimens from Ban Rai Rockshelter are given in table 4-9.

The number of year by counting ring started from inner ring (pith) to outer ring (bark). The result of the tree-ring width crossdated of specimens from Ban Rai Rockshelter, seven dendrochronological series were built. The location of sample collection illustrated in figure 4-11.

**Table 4-9** The tree-ring numbers of specimens from Ban Rai Rockshelter

| Code | Head styles | Pith | Tree-ring numbers | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Core A | Core B | Core C | Core D | Core E | Total |
| BR01A-B | Post | NP/**P** | 100 | 114 | - | - | - | 114 |
| BR02A-B-C | Post | NP/NP/NP | 40 | 49 | 51 | - | - | 51 |
| BR03A-B | Post | NP/NP | 104 | 15 | - | - | - | 106 |
| BR04A-B | Post | NP/NP | 111 | 124 | - | - | - | 124 |
| BR05A-B | 2B | NP/NP | 217 | 227 | - | - | - | 231 |
| BR06A-B | 2B | NP/NP | 191 | 189 | - | - | - | 186 |

**Table 4-9** The tree-ring numbers of specimens from Ban Rai Rockshelter (cont.)

| Code | Head styles | Pith | Tree-ring numbers | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Core A | Core B | Core C | Core D | Core E | Total |
| BR07A-B-C-D | 1B&2C | NP/NP/NP/NP | 97 | 75 | 98 | 76 | - | 98 |
| BR08A-B-C-D | 1B | NP/NP/NP/NP | 90 | 85 | 100 | 114 | - | 114 |
| BR09A-B-C-D- E | 1B | NP/NP/NP/NP/NP | 265 | 211 | 182 | 211 | 194 | 265 |
| BR10A-B | 1B | NP/NP | 166 | 219 | - | - | - | 229 |
| BR11A-B | Post | **P/P** | 115 | 112 | - | - | - | 115 |
| BR12A-B | Post | **P**/NP | 153 | 218 | - | - | - | 218 |
| BR13A-B | Post | **P/P** | 128 | 89 | - | - | - | 128 |
| BR14A-B-C1,2-D-E | Post | NP/NP/NP/NP | 134 | 97 | 49/133 | 128 | 122 | 155 |
| BR15A-B | Post | NP/NP | 129 | 124 | - | - | - | 129 |
| BR16A-B-C-D | 1A | NP/NP/NP/NP | 128 | 103 | 124 | 130 | - | 133 |
| BR17A-B | - | NP/NP | 168 | 124 | - | - | - | 168 |
| BR20A1,2-B | Post | NP/NP | 60/149 | 157 | - | - | - | 159 |
| BR22A-B | 2A | NP/NP | 160 | 148 | - | - | - | 169 |
| BR23A-B-C-D | Post | **P/P/P/P** | 71 | 57 | 81 | 73 | - | 85 |
| BR24A-B | Post | **P**/NP | 64 | 43 | - | - | - | 64 |
| BR26A-B | Post | **P/P** | 74 | 102 | - | - | - | 102 |
| BR27A-B1,2 | Post | NP/NP | 61 | 45/72 | - | - | - | 72 |
| BR28A-B | 2A | NP/NP | 131 | 108 | - | - | - | 131 |
| BR29A-B | 2A | NP/NP | 115 | 110 | - | - | - | 120 |
| BR30A-B | 2A | NP/NP | 103 | 148 | - | - | - | 148 |
| BR32A-B | - | NP/NP | 116 | 132 | - | - | - | 143 |
| BR34A-B-C | 1A | NP/NP/NP | 88 | 70 | 118 | - | - | 118 |
| BR35A-B-C1,2 | 2B | NP/NP/NP/NP | 99 | 102 | 72/41 | - | - | 113 |
| BR36A-B | Post | NP/NP | 45 | 148 | - | - | - | 148 |
| BR37A-B | Post | NP/NP | 25 | 85 | - | - | - | 85 |
| BR39A-B | - | NP/NP | 124 | 21 | - | - | - | 128 |
| BR43A | - | NP | 51 | - | - | - | - | 51 |
| BR44A-B | - | NP/NP | 80 | 38 | - | - | - | 80 |

**Note** P = The inner rings either contained the pith or were close to the pith.

NP = No-pith.

Total tree-ring numbers = Tree-ring numbers after crossdated core A, B and other.

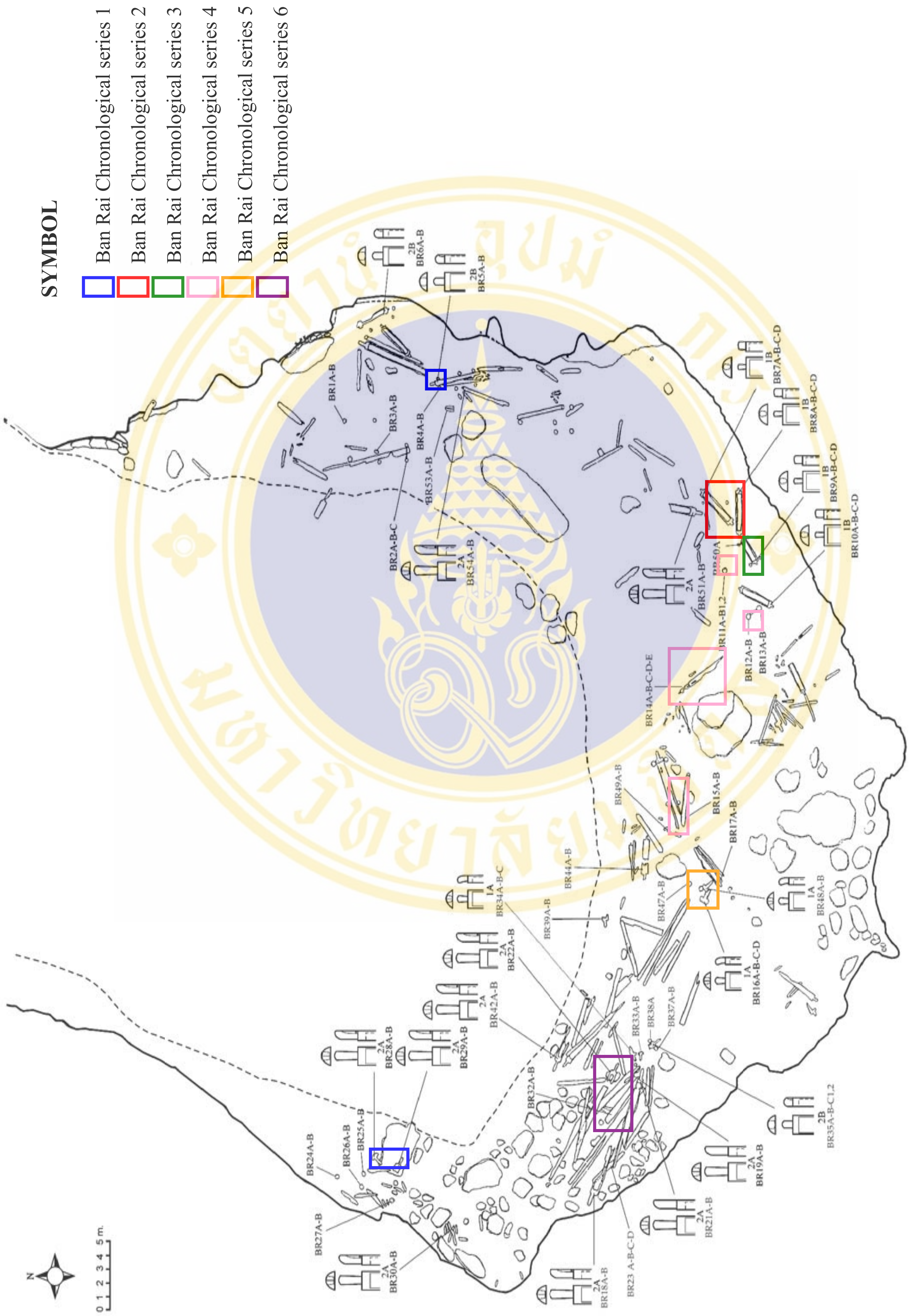



**Figure 4-11** The sample collection for dendrochronological series from Ban Rai Rockshelter (3)

#### 4.1.2.1 Ban Rai chronological series 1 (BRS1)

The Ban Rai chronological series 1 were built from 10 cores. Code BR05 has log coffins' head 2B style and support by post code BR04, BR28 and BR29 have log coffins' head 2A style and BR52 is log coffin but unidentified head style. Core BR04A has 111 rings, BR04B has 124 rings, BR05A has 217 rings, BR05B has 227 rings, BR28A has 131 rings, BR28B has 108 rings, BR29A has 115 rings, BR29B has 110 rings, BR52A has 210 rings and BR52B has 112 rings.

In the series, the sample from different coffins' head including 2A and 2B styles and the sample from the same log coffin set can be crossdated. The time span of BRS1 is 278 years. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

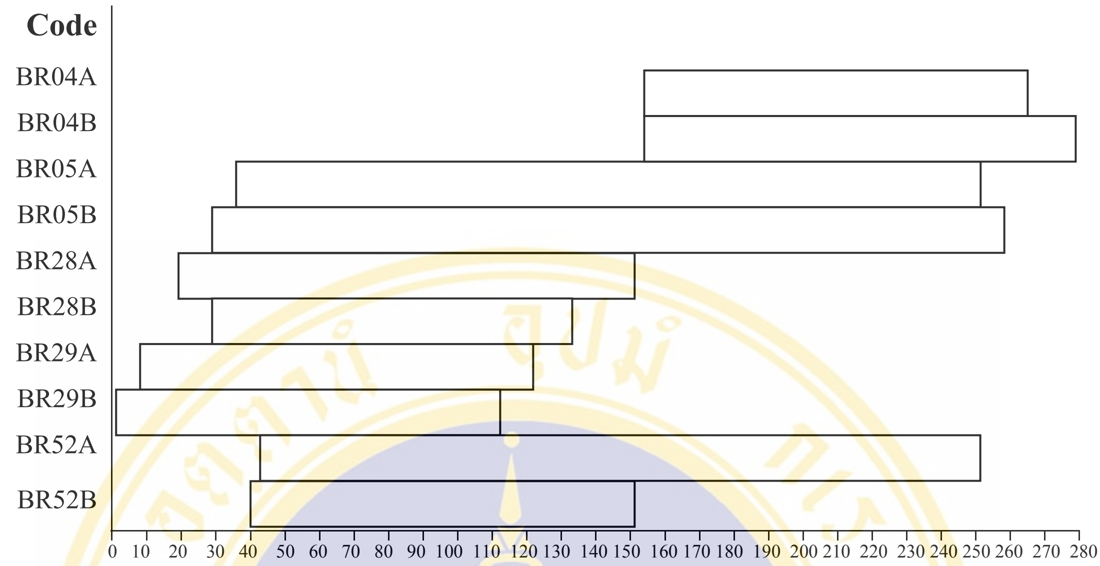



**Figure 4-13** Spans of Ban Rai chronological series 1

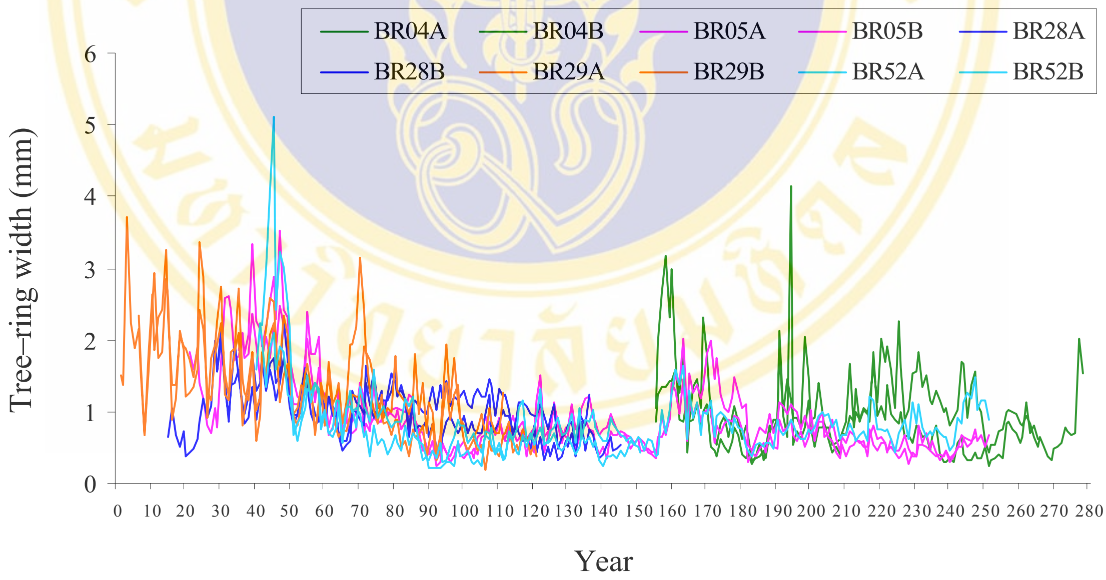



**Figure 4-14** The chronologies of specimens from Ban Rai chronological series1

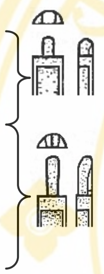
The individual chronologies were crossdated. BRS1 were well correlation. These specimens might have been taken from the same area and time because there is high correlation between them (Table 4-10).

**Table 4-10** Description statistics for the Ban Rai chronological series 1

Correlations of 40−year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position



| Seq Series | Style | Time_span | | 0 39 | 20 59 | 40 79 | 60 99 | 80 119 | 100 139 | 120 159 | 140 179 | 160 199 | 180 219 | 200 239 | 220 259 | 240 279 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BR04A | | 155 | 265 | | | | | | | | .37 | .32A | .45 | .32A | .35B | .42 |
| BR04B | | 155 | 278 | | | | | | | | .71 | .63 | .54 | .55 | .63 | .65 |
| BR05A | | 35 | 251 | | .56 | .57 | .56 | .51 | .59 | .68 | .76 | .74 | .55 | .44 | .41 | |
| BR05B | | 21 | 247 | | .24A | .53 | .49 | .32A | .60 | .67 | .61 | .70 | .62 | .48 | .59 | |
| BR28A | | 15 | 145 | .43 | .61 | .48 | .43 | .42 | .52 | .51 | | | | | | |
| BR28B | | 29 | 136 | | .66 | .55 | .33A | .25B | .39B | | | | | | | |
| BR29A | | 6 | 120 | .67 | .57 | .53 | .52 | .32B | .30B | | | | | | | |
| BR29B | | 1 | 110 | .66 | .67 | .47 | .39 | .42 | | | | | | | | |
| BR52A | | 42 | 251 | | | .61 | .50 | .34A | .46 | .58 | .71 | .65 | .54 | .49 | .60 | |
| BR52B | | 40 | 151 | | | .49 | .41 | .33A | .56 | .48 | | | | | | |

**Note** BR05 has log coffins' head 2B style and support by post code BR04.

BR28 and BR29 have log coffins' head 2A style.

BR52 is log coffin but unidentified head style.

The log coffin in BRS1 is 2B and 2A styles. Code BR28 and BR29 that were a head of log coffin piece without the body found on the floor in the eastern part of rockshelter but BR05 place on beam and post code BO04 in the western part of rockshelter. The result of the series show the log coffin has 2A style probably used before 2B style. From the result, the area that found sample in the eastern part of rockshelter is possibly used as a burial site before the western part of rockshelter. The post (BR04) that supported the log coffin (BR05) gives high correlation between them. It means the both sample were made from tree that growth in the same area and time. Possible, these samples were cutting in the same period because the last ring stop in the similar point in this series. In the same case, the coffin BR28 and BR29 might be the same coffin lid because they are very high correlation and found it in the same area.

#### 4.1.2.2 Ban Rai chronological series 2 (BRS2)

The Ban Rai chronological series 2 were built from 2 log coffin lids (8 cores). Code BR07 has log coffins' head 1B and 2C styles because the both ends of log coffin are different head style. And BR08 has log coffins' head 1B style but one end has a quardrilateral hole. Core BR07A has 97 rings, BR07B has 75 rings, BR07C has 98 rings, BR07D has 86 rings, BR08A has 90 rings, BR08B has 85 rings, BR08C has 100 rings and BR08D has 114 rings.

Nowadays, the log coffin code BR07 and BR08 lay on floor near cliff in the western part of rockshelter. The both log coffin lids are the same size, BR07 is total length 3.57 m, width 0.54 m and thick 0.29 m. and BR08 is total length 3.58 m, width 0.54 m and thick 0.24 m. The ends of log coffins decorated in similar style. The time span of Ban Rai chronological series 2 is 116 years. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

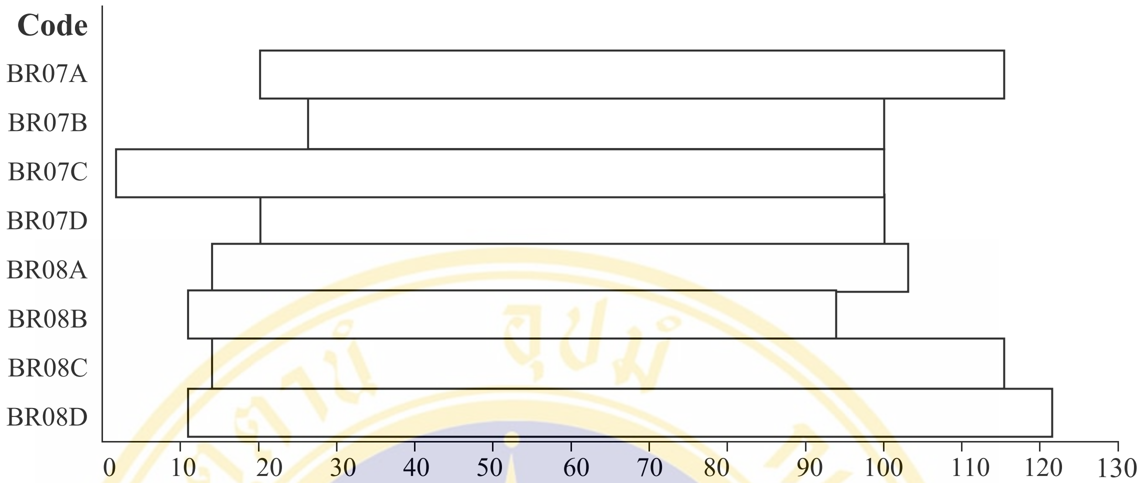



**Figure 4-15** Spans of Ban Rai chronological series 2

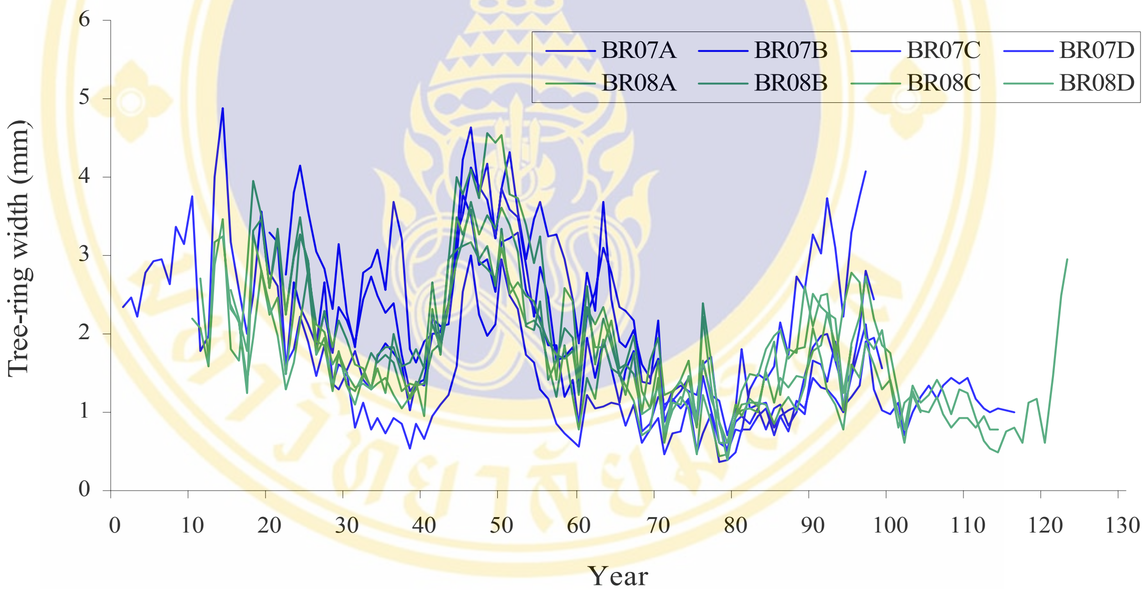



**Figure 4-16** The chronologies of specimens from Ban Rai chronological series 2

The individual chronologies were crossdated. BRS2, specimens BR07A, BR07B, BR07C, BR07D, BR08A, BR08B, BR08C and BR08D were very high correlation. These specimens might have been taken from the same tree and time because there is high correlation between them (Table 4-11) and were cutting in the similar period because the last ring from BR07 and BR08 finish in the same position of floating chronology.

**Table 4-11** Description statistics for the Ban Rai chronological series 2

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 0<br>39 | 20<br>59 | 40<br>79 | 60<br>99 | 80<br>119 |
|---|---|---|---|---|---|---|---|---|
| BR07A |  | 20 | 116 | | .72 | .81 | .75 | .60 |
| BR07B |  | 25 | 99 | | .81 | .81 | .70 | |
| BR07C |  | 1 | 98 | .66 | .67 | .77 | .73 | |
| BR07D |  | 22 | 97 | | .72 | .77 | .78 | |
| BR08A |  | 15 | 104 | .73 | .70 | .84 | .59 | .46 |
| BR08B |  | 11 | 95 | .81 | .85 | .83 | .79 | |
| BR08C | | 15 | 114 | .79 | .76 | .89 | .86 | .69 |
| BR08D | | 10 | 123 | .63 | .72 | .86 | .89 | .83 |

**Note** BR07 has log coffins' head 1B and 2C styles.
BR08 has log coffins' head 1B style.

The 1B and 2C styles used in the same lid (BR07) and the result in BRS2 from BR07 and BR08 probably explained these styles were used in the same period of the Log Coffin culture. Sometimes, one coffin lid in this series was served as the lid of another (the upper and lower part). And BR07 and BR08 probably placed on 6 posts in the same group near them. Unfortunately, in this study cannot be collected the sample from these posts because they are very damage. This result can be confirmed the log coffin set including two log coffin lids that showing tongue-and-groove joint.

**4.1.2.3 Ban Rai chronological series 3 (BRS3)**

The Ban Rai chronological series 3 was built from 2 log coffin lids (7 cores) and post (1 core). Code BR09 and BR10 have log coffins' head 1B style. The both of log coffin lids were supported by post code BR50. Core BR09A has 265 rings, BR09B has 211 rings, BR09C has 182 rings, BR09D has 211 rings, BR09E has 194 rings, BR10A has 166 rings, BR10B has 219 rings and BR50A has 49 rings. In 2001, the sample collection by tree-ring and environment team in Highland Archaeology Project in Pang Mapha, Mae Hong Son Province: Phase 1 found another end of log coffin lid BR10 supported on beam and 4 posts. But BR09 lay on floor near this set of log coffin. After the excavation in Ban Rai Rockshelter by Highland Archaeology Project in Pang Mapha, Mae Hong Son Province: Phase 1, the log coffin BR09 was moved to cover BR10. The both log coffin lids put on the cross beam but the beam that supported the opposite end of these log coffins was damaged in present. The log coffins are same size (length 3.10 m, width 0.52 m, thick 0.22 m). In this series, one of the 4 posts in this group was taken for tree-ring dating (BR50). By matching up similar spaced rings in sample, the floating ages of ancient wood in this series can be determined.

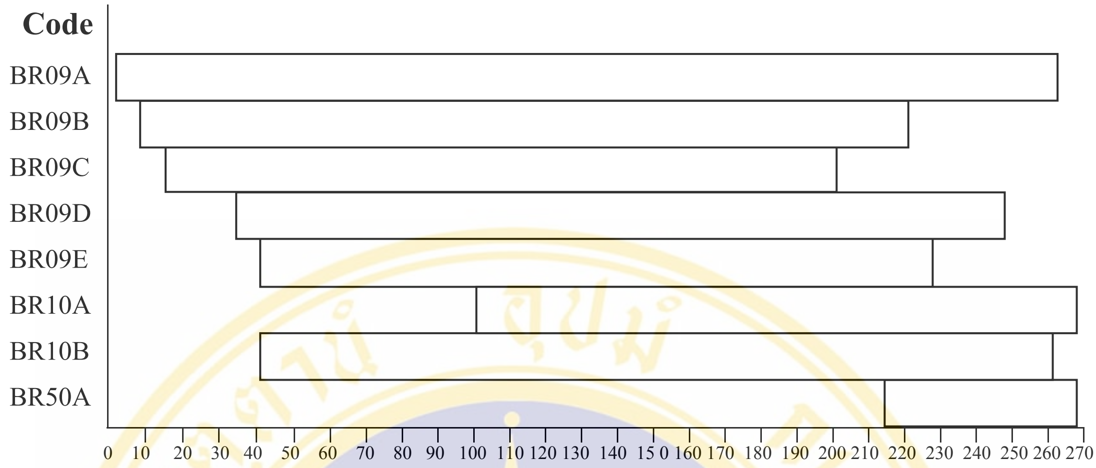



**Figure 4-17** Spans of Ban Rai chronological series 3

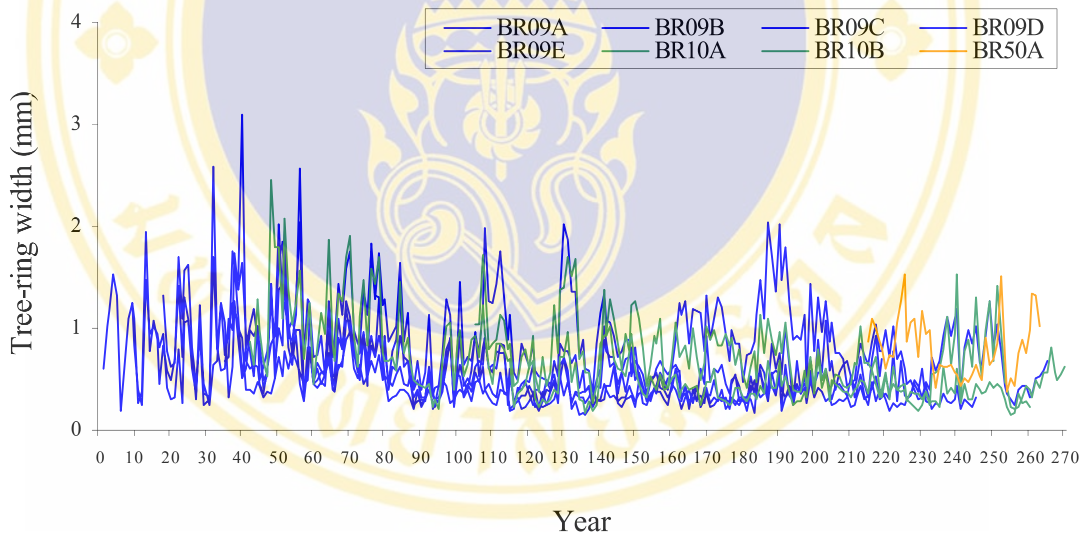



**Figure 4-18** The chronologies of specimens from Ban Rai chronological series 3

The individual chronologies were crossdated. The BRS3, specimens BR09A, BR09B, BR09C, BR09D, BR09E, BR10A, BR10B and BR50A were well correlation. The specimens BR09 and BR10 might have been taken from the same tree and time because there is high correlation between them (Table 4-12).

**Table 4-12** Description statistics for the Ban Rai chronological series 3

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 0<br>39 | 20<br>59 | 40<br>79 | 60<br>99 | 80<br>119 | 100<br>139 | 120<br>159 | 140<br>179 | 160<br>199 | 180<br>219 | 200<br>239 | 220<br>259 | 240<br>279 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BR09A |  | 1 | 265 | .76 | .74 | .72 | .89 | .86 | .77 | .68 | .45 | .58 | .72 | .57 | .74 | .75 |
| BR09B | | 9 | 219 | .72 | .74 | .78 | .82 | .70 | .56 | .59 | .49 | .56 | .64 | | | |
| BR09C | | 18 | 199 | .59 | .58 | .71 | .82 | .59 | .39 | .33A | .37 | .29A | | | | |
| BR09D | | 35 | 245 | | .78 | .79 | .87 | .84 | .81 | .78 | .61 | .52 | .47 | .35A | .52 | |
| BR09E |  | 39 | 232 | | .66 | .65 | .60 | .49 | .44 | .40 | .33A | .43B | .37B | .25B | | |
| BR10A | | 105 | 270 | | | | | | .75 | .65 | .51 | .60 | .61 | .47 | .72 | .71 |
| BR10B | | 42 | 260 | | | .79 | .79 | .74 | .82 | .77 | .47 | .50 | .68 | .59 | .66 | .67 |
| BR50A | | 215 | 263 | | | | | | | | | | | .28B | .29A | .35A |

**Note** BR09 and BR10 that have log coffins' head 1B style were supported by post code BR50.

All of log coffins in this series have the last ring in the similar point. The log coffins and post made from tree which cutting in the same time. The younger tree made to post and older tree made to coffin. It means the environment around Ban Rai Rockshelter in this time was a mixed deciduous forest. If the both lids were building from the same tree, it shows the high skill of human in the Log Coffin culture period. However, the both lids are possibly made from tree that growing in the same area because the environmental factors affected the patterns of tree growth over time.

#### 4.1.2.4 Ban Rai chronological series 4 (BRS4)

The Ban Rai chronological series 4 was built from 4 large posts (11 cores). Core BR11A has 115 rings, BR11B has110 rings, BR12A has 152 rings, BR12B has 146 rings, BR14A has 135 rings, BR14B has 97 rings, BR14C1 has 49 rings, BR14C2 has 133 rings, BR14D has 128 rings, BR14E has 122 rings, BR15A has 132 rings and BR15B has 126 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

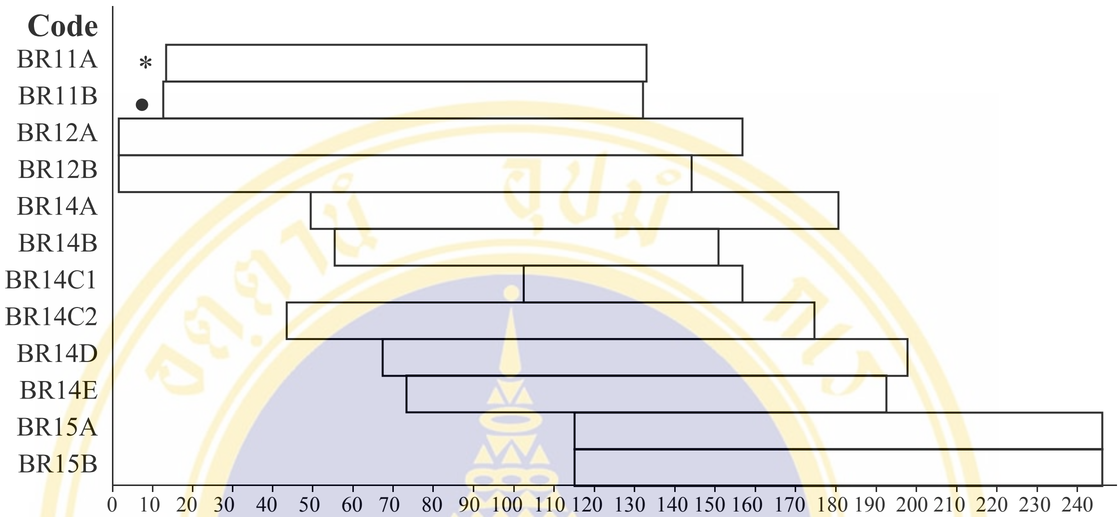



**Figure 4-19** Spans of Ban Rai chronological series 4. ∗ indicates the inner rings contain the pith, and • indicates the inner close to the pith

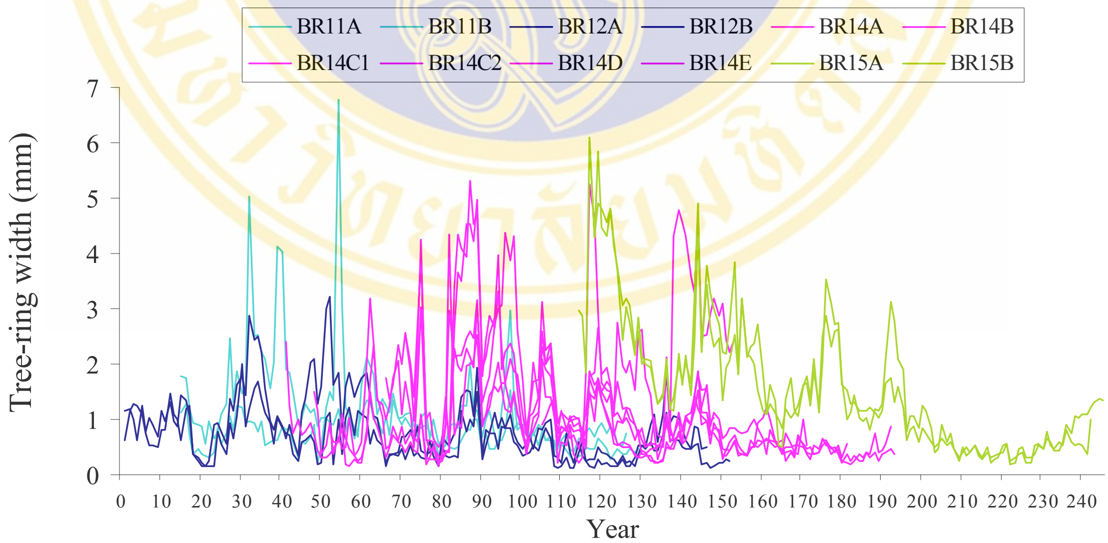



**Figure 4-20** The chronologies of specimens from Ban Rai chronological series 4

The individual chronologies were crossdated. The Ban Rai chronological series 4 was well correlation (Table 4-13).

**Table 4-13** Description statistics for the Ban Rai chronological series 4

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Time span | | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 39 | 59 | 79 | 99 | 119 | 139 | 159 | 179 | 199 | 219 | 239 | 259 |
| BR11A | 15 | 129 | .47 | .46 | .33A | .40 | .56 | .48 | | | | | | |
| BR11B | 15 | 126 | .59 | .56 | .56 | .46 | .42 | .37B | | | | | | |
| BR12A | 1 | 152 | .35A | .60 | .40 | .55 | .62 | .31A | .17B | | | | | |
| BR12B | 1 | 146 | .44 | .59 | .45 | .70 | .67 | .43 | .42 | | | | | |
| BR14A | 48 | 181 | | | .45 | .54 | .66 | .74 | .64 | .26A | .29A | | | |
| BR14B | 52 | 148 | | | .71 | .74 | .79 | .76 | .70 | | | | | |
| BR14C1 | 105 | 153 | | | | | | .57 | .35A | | | | | |
| BR14C2 | 41 | 171 | | | .37 | .45 | .49 | .59 | .59 | .47 | | | | |
| BR14D | 66 | 193 | | | | .62 | .70 | .71 | .57 | .52 | .60 | | | |
| BR14E | 71 | 192 | | | | .75 | .75 | .81 | .75 | .49 | .49 | | | |
| BR15A | 114 | 245 | | | | | | .72 | .73 | .58 | .47 | .63 | .63 | .61 |
| BR15B | 117 | 242 | | | | | | .61 | .59 | .60 | .64 | .64 | .63 | .61 |

**Note** The sample code BR11, BR12, BR14 and BR15 are posts.

The specimens of BRS4 are large posts. These posts have near position. BR14 and BR15 lay on the floor. The top of BR14 carved look like human and some section were burnt. From the result represent in this series, the BR14 probably stood in the same group with BR11 and BR12 by similar tree-ring pattern, size and position.

#### 4.1.2.5 Ban Rai chronological series 5 (BRS5)

The Ban Rai chronological series 5 was built from 2 log coffin lids (6 cores). Code BR16 and BR49 have log coffins' head 1A style. Core BR16A has 128 rings, BR16B has 103 rings, BR16C has 124 rings, BR16D has 130 rings, BR48A has 73 rings and BR48B has 80 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

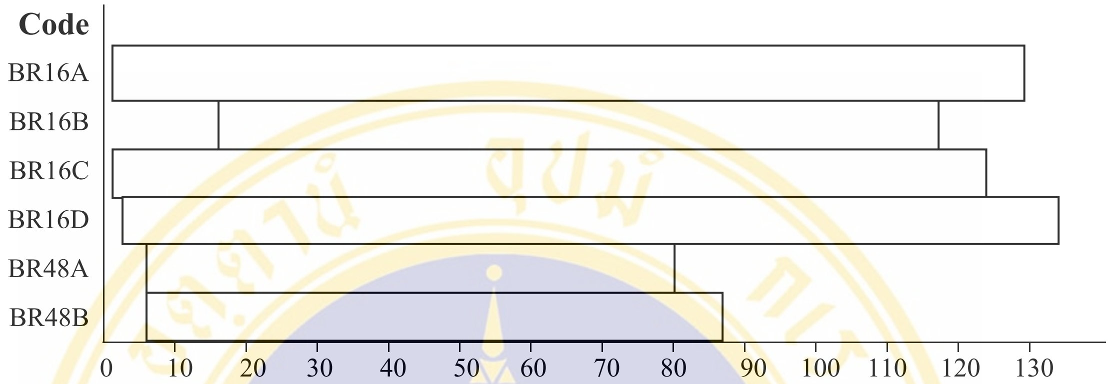



**Figure 4-21** Spans of Ban Rai chronological series 5

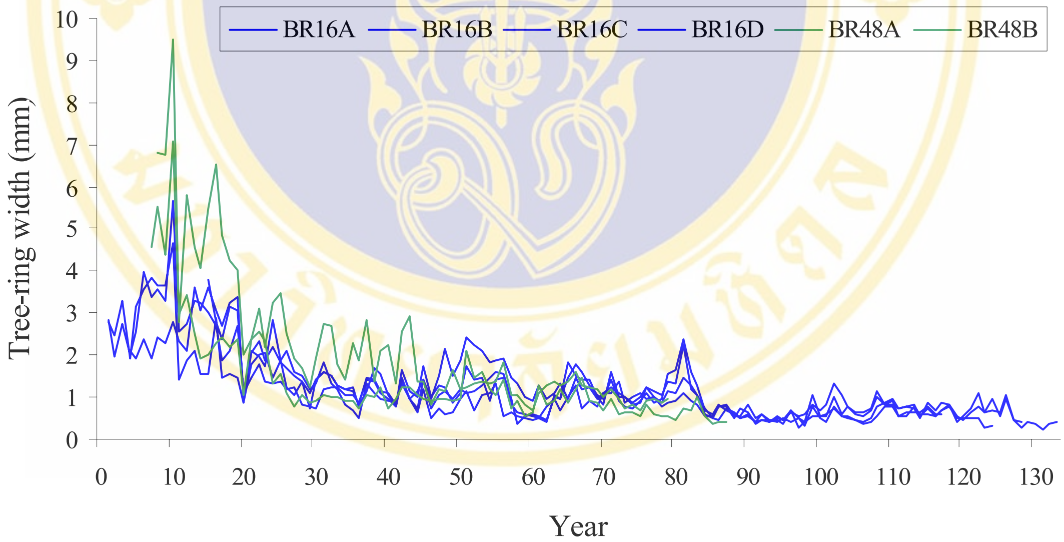



**Figure 4-22** The chronologies of specimens from Ban Rai chronological series 5

The individual chronologies were crossdated. The BRS5, specimens BR16A, BR16B, BR16C, BR16D, BR48A and BR48B were well correlation. These specimens might have been taken from the same tree and time because there is high correlation between them (Table 4-14).

**Table 4-14** Description statistics for the Ban Rai chronological series 5

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 0<br>39 | 20<br>59 | 40<br>79 | 60<br>99 | 80<br>119 | 100<br>139 |
|---|---|---|---|---|---|---|---|---|---|
| BR16A |  | 1 | 128 | .77 | .79 | .77 | .70 | .74 | .66 |
| BR16B | | 15 | 117 | .75 | .70 | .44 | .53 | .69 | |
| BR16C | | 1 | 124 | .67 | .68 | .59 | .59 | .74 | .58 |
| BR16D | | 4 | 133 | .69 | .85 | .77 | .74 | .71 | .66 |
| BR48A | | 7 | 79 | .67 | .63 | .57 | | | |
| BR48B | | 8 | 87 | .54 | .53 | .46 | .55 | | |

**Note** BR16 and BR48 have log coffins' head 1A style.

Because of the last ring from log coffin BR16 and BR48 finished in the different range in BR48. Probably, the log coffins' head 1A style was used in the different time. However the date of terminate of growth cannot be determined because this series are not finding bark cell on outside of the specimen.

#### 4.1.2.6 Ban Rai chronological series 6 (BRS6)

The Ban Rai chronological series 6 were built from 4 log coffin lids (9 cores). Code BR22 has log coffins' head 2A style, BR35 has log coffins' head 2B style. The head of log coffin code BR32 and BR39 were damaged so the style of log coffins' head unidentified. Core BR22A has 160 rings, BR22B has 148 rings, BR32A has 116 rings, BR32B has 131 rings, BR35A has 99 rings, BR35B has 102 rings, BR35C1 has 77 rings, BR35C2 has 42 rings, BR39A has 124 rings and BR39B has 21 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

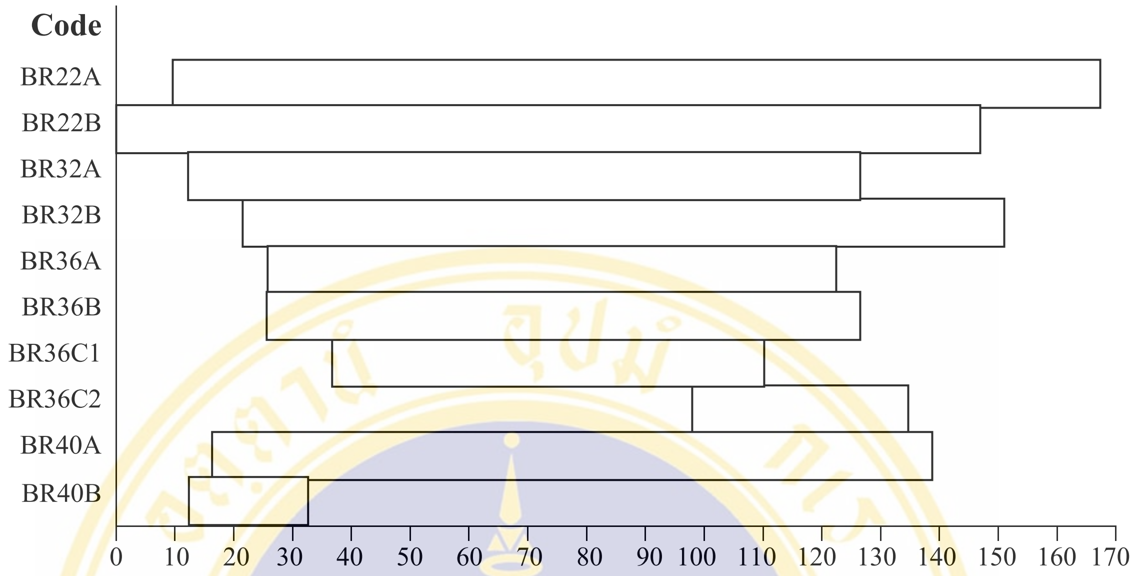



**Figure 4-23** Spans of Ban Rai chronological series 6

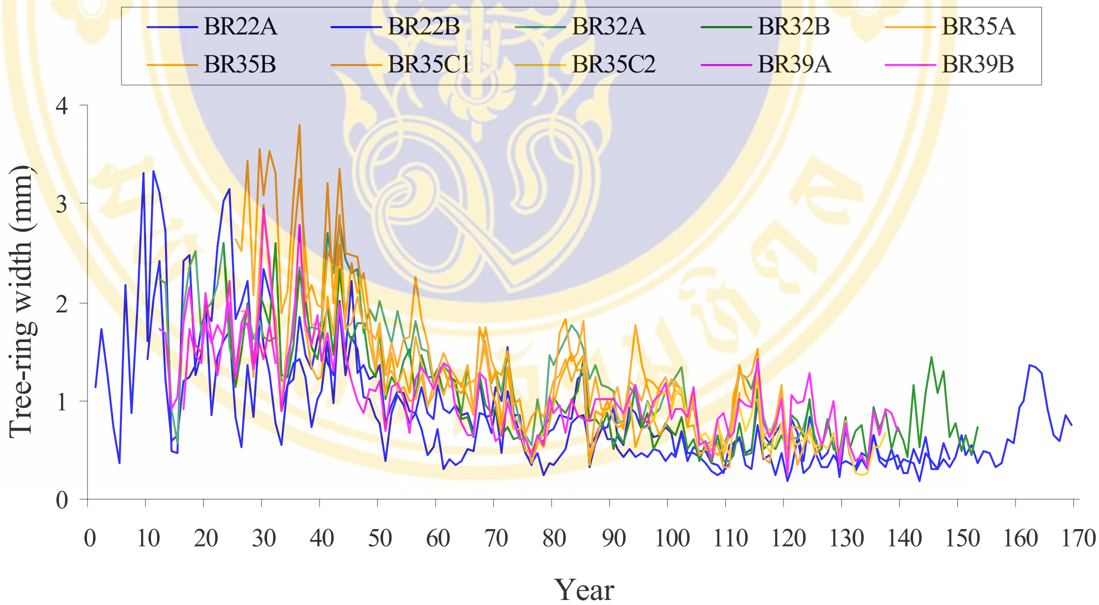



**Figure 4-24** The chronologies of specimens from Ban Rai chronological series 6

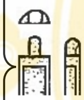
The individual chronologies were crossdated. In BRS6, specimens BR22A, BR22B, BR32A, BR32B, BR35A, BR35B, BR35C1-2, BR39A and BR39B were well correlation. These specimens might have been taken from the same area and time because there is high correlation between them (Table 4-15).

**Table 4-15** Description statistics for the Ban Rai chronological series 6

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Style | Time_span | | 0<br>39 | 20<br>59 | 40<br>79 | 60<br>99 | 80<br>119 | 100<br>139 | 120<br>159 |
|---|---|---|---|---|---|---|---|---|---|---|
| BR22A |  | 10 | 169 | .63 | .64 | .58 | .38 | .42 | .50 | .32A |
| BR22B | | 1 | 148 | .66 | .65 | .74 | .79 | .73 | .69 | .62 |
| BR32A | | 12 | 127 | .66 | .51 | .60 | .69 | .71 | .80 | |
| BR32B | | 23 | 153 | | .61 | .62 | .58 | .58 | .60 | .37B |
| BR35A |  | 26 | 124 | | .71 | .64 | .66 | .74 | .71 | |
| BR35B | | 25 | 126 | | .70 | .72 | .68 | .67 | .56 | |
| BR35C1 | | 36 | 112 | | .66 | .67 | .67 | .71 | | |
| BR35C2 | | 96 | 137 | | | | | .79 | .81 | |
| BR39A | | 16 | 139 | .64 | .66 | .64 | .51 | .50 | .80 | |
| BR39B | | 12 | 32 | .77 | | | | | | |

**Note** BR22 has log coffins' head 2A style.

BR35 has log coffins' head 2B style.

The head of log coffin code BR32 and BR39 unidentified head style.

The result of this series shows the overlapping in the same period of log coffin that was decorated at the ends in simple style. The 2A and 2B styles of log coffin can be overlapped in the same range in BRS7. The log coffin BR35 was damage but it look like 1A style. From this series can be estimated the style of log coffin in the area probably doesn't show the evolution of log coffins' head style in the Log Coffin culture. Because the different style of coffin can be overlapped in the same range.

### 4.1.2.7 Ban Rai chronological series 7 (BRS7)

The Ban Rai chronological series 7 were built from 2 posts (6 cores). Core BR23A has 71 rings, BR23B has 52 rings, BR23C has 81 rings, BR23D has 73 rings, BR31A has 173 rings and BR31B has 124 rings. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

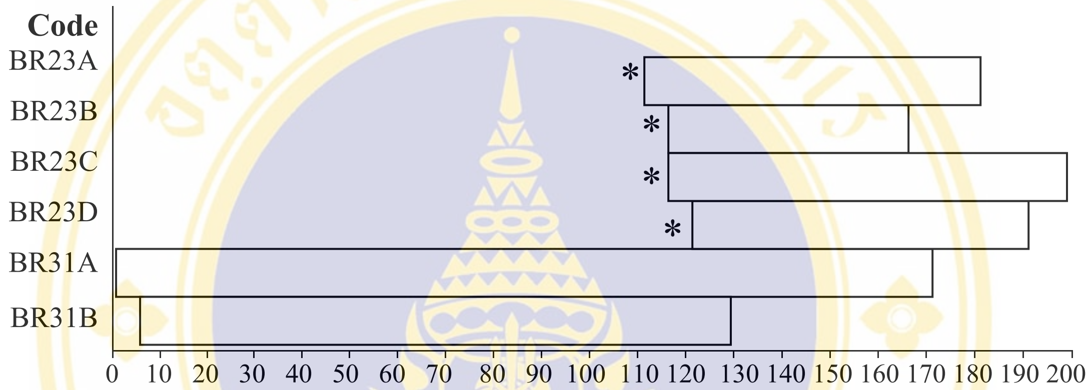



**Figure 4-25** Spans of Ban Rai chronological series 7; * indicates the inner rings contain the pith

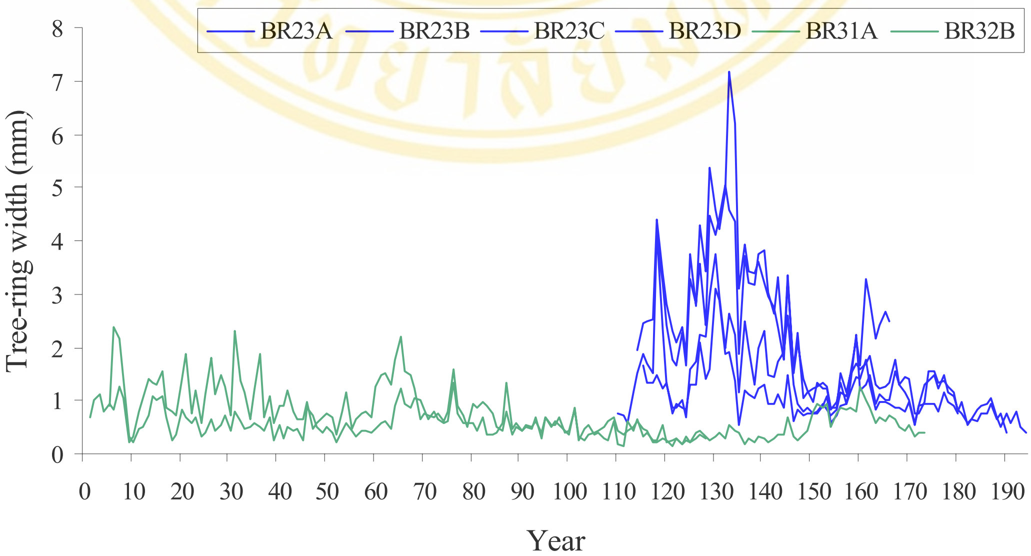



**Figure 4-26** The chronologies of specimens from Ban Rai chronological series 7

The individual chronologies were crossdated. The BRS7, specimens BR23A, BR23B, BR23C, BR23D, BR31A and BR31B were well correlation. These specimens might have been taken from the same tree and time because there is high correlation between them (Table 4-16).

**Table 4-16** Description statistics for the Ban Rai chronological series 7

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seq Series | Time_span | | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 39 | 59 | 79 | 99 | 119 | 139 | 159 | 179 | 199 |
| BR23A | 110 | 180 | | | | | | .68 | .78 | .80 | .80 |
| BR23B | 115 | 166 | | | | | | .80 | .82 | .79 | |
| BR23C | 114 | 194 | | | | | | .66 | .74 | .74 | .64 |
| BR23D | 118 | 190 | | | | | | .76 | .76 | .77 | .61 |
| BR31A | 1 | 173 | .64 | .56 | .47 | .48 | .44 | .32A | .36A | .54 | |
| BR31B | 5 | 128 | .64 | .56 | .47B | .48 | .44 | .51 | | | |

**Note** BR23 and BR31 are posts.

In this series, the age of wood that selected for making the post were different age. But they were probably growth in the same area and time before cutting.

Ban Rai Rockshelter was continuously used in variety purpose. This area found a numerous of archaeological evidence. In the result, the ring has very narrow ring and half ring porous structure. The 7 chronological series from Ban Rai Rockshelter come from the simple head style. The log coffins or posts in the same group often can be crossdated such as BRS2 and BRS3 or crossdated with the near group such as BRS4. And the result from BRS3 and BRS5 shown the same of log coffins' head can be crossdated in the same range. From the result, the same style of log coffins was used in the same time.

Moreover the result of BRS1 shown 2A style probably used before 2B style but these styles of log coffin can be crossdated in the same range and the last ring at the outside of specimen finished in the same point in BRS6. And BRS 2 shown the 2C and 1B styles were used in the same lid. From the result, the different styles of log coffin head were used in the same time of the Log Coffin culture. After the samples in each site were crossdated then the samples between Bo Krai Cave and Ban Rai Rockshelter were crossdated by tree-ring method.

**4.1.3 The correlation between Bo Krai Cave and Ban Rai Rockshelter**

Although the log coffin from Bo Krai Cave and Ban Rai Rockshelter area cannot be crossdated but the posts (BRS7) from Ban Rai Rockshelter can be crossdated with log coffins and posts (BKS5) from Bo Krai Cave.

**4.1.3.1 Bo Krai and Ban Rai chronological series 1 (BKBR1)**

The Bo Krai and Ban Rai chronological series 1 were built from 12 log coffin lids (27 cores) and 3 posts (3 cores) at Bo Krai Cave and 2 posts (6 cores) at Ban Rai Rockshelter. Code BO01 and BO03 have log coffins' head 2A style and BO02 has log coffins' head 2A style found in chamber 3. Code BO18 has a log coffins' head 1A style and code BO20, 21, 22, 23, 24, 25, 26, 29 have log coffins' head complex style (3C and 4B styles) found in chamber 2. And code BO37, 38, 39 are posts in chamber 1. By matching up similar spaced rings in samples, the floating ages of ancient wood can be determined.

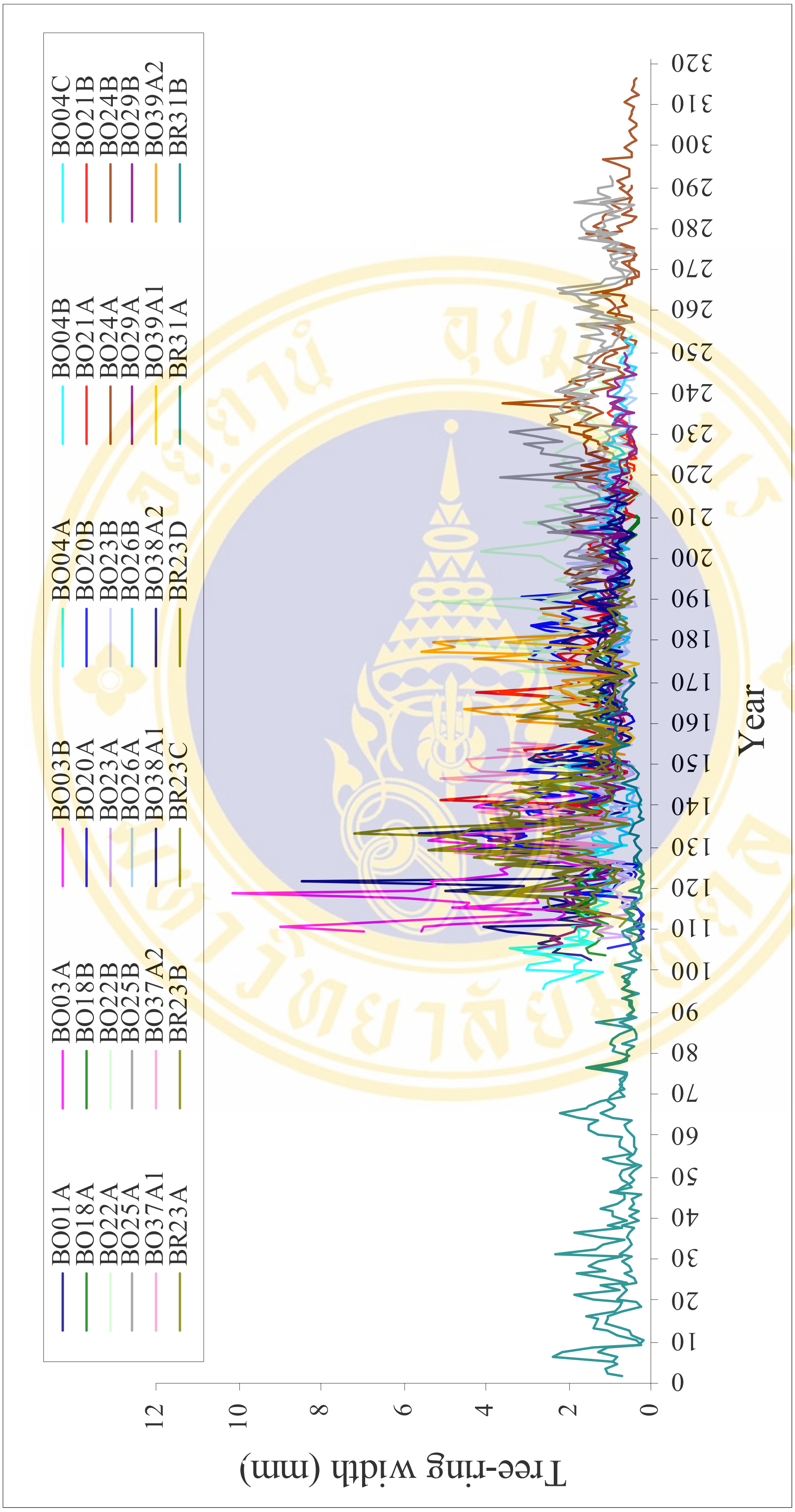



**Figure 4-27** The chronologies of Bo Krai and Ban Rai chronological series 1

The individual chronologies were crossdated. BKBR 1 were well correlation (Table 4-17).

**Table 4-17** Description statistics for the Bo Krai and Ban Rai chronological series 1

Correlations of 40-year dated segments, lagged 20 years

Flags: A = correlation under .3665 but highest as dated;

B = correlation higher at other than dated position

| Seg Series | Time_span | | 0<br>39 | 20<br>59 | 40<br>79 | 60<br>99 | 80<br>119 | 100<br>139 | 120<br>159 | 140<br>179 | 160<br>199 | 180<br>219 | 200<br>239 | 220<br>259 | 240<br>279 | 260<br>299 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BO01A | 102 | 152 | | | | | | .52 | .49 | | | | | | | |
| BO03A | 109 | 152 | | | | | | .52 | .62 | | | | | | | |
| BO03B | 109 | 136 | | | | | | .49 | | | | | | | | |
| BO04A | 95 | 125 | | | | | .33A | | | | | | | | | |
| BO04B | 97 | 145 | | | | | .52 | .49 | .39 | | | | | | | |
| BO04C | 120 | 146 | | | | | | | .44 | | | | | | | |
| BO18A | 112 | 210 | | | | | | .51 | .51 | .52 | .51B | .43B | | | | |
| BO18B | 103 | 210 | | | | | | .69 | .66 | .49 | .42B | .38 | | | | |
| BO20A | 107 | 198 | | | | | | .59 | .55 | .42 | .39 | | | | | |
| BO20B | 105 | 185 | | | | | | .52 | .42 | .29B | .25A | | | | | |
| BO21A | 137 | 236 | | | | | | | .60 | .58 | .62 | .49 | .45 | | | |
| BO21B | 145 | 232 | | | | | | | | .58 | .48 | .60 | .70 | | | |
| BO22A | 177 | 258 | | | | | | | | | .52 | .54 | .37 | .26A | | |
| BO22B | 141 | 226 | | | | | | | | .48 | .49 | .58 | .55 | | | |
| BO23A | 107 | 229 | | | | | | .37B | .45 | .44 | .47 | .52 | .37 | | | |
| BO23B | 115 | 228 | | | | | | .61 | .57 | .42 | .29B | .44 | .39 | | | |
| BO24A | 187 | 290 | | | | | | | | | | .34B | .43 | .51 | .49 | .49 |
| BO24B | 189 | 316 | | | | | | | | | | .36A | .58 | .66 | .79 | .62 |
| BO25A | 190 | 287 | | | | | | | | | | .36A | .40 | .49 | .69 | .70 |
| BO25B | 195 | 292 | | | | | | | | | | .37 | .36A | .41 | .52 | .64 |
| BO26A | 128 | 251 | | | | | | | .42 | .25A | .39 | .41 | .49 | .53 | | |
| BO26B | 129 | 253 | | | | | | | .28A | .34A | .45 | .33A | .40 | .50 | | |
| BO29A | 105 | 238 | | | | | | .49 | .55 | .44B | .36B | .40 | .50 | | | |
| BO29B | 115 | 249 | | | | | | .76 | .66 | .59 | .54 | .28A | .31A | .40 | | |
| BO37A1 | 123 | 155 | | | | | | | .29B | | | | | | | |
| BO37A2 | 121 | 139 | | | | | | | .47 | | | | | | | |
| BO38A1 | 149 | 209 | | | | | | | | .56 | .54 | .53 | | | | |
| BO38A2 | 149 | 215 | | | | | | | | .58 | .57 | .27A | | | | |
| BO39A1 | 152 | 180 | | | | | | | | .59 | | | | | | |
| BO39A2 | 152 | 186 | | | | | | | | .50 | | | | | | |
| BR23A | 110 | 180 | | | | | | .40 | .38 | .67 | .68 | | | | | |
| BR23B | 115 | 166 | | | | | | .39B | .36B | .34B | | | | | | |
| BR23C | 114 | 194 | | | | | | .45 | .45 | .50 | .53 | | | | | |
| BR23D | 118 | 190 | | | | | | .45 | .42 | .58 | .59 | | | | | |
| BR31A | 1 | 173 | .64 | .56 | .47 | .47 | .32A | .27A | .48 | .73 | | | | | | |
| BR31B | 5 | 128 | .64 | .56 | .47B | .45 | .33A | .40 | | | | | | | | |

**Note** Bo Krai Cave: BO01 and BO03 have log coffins' head 2A style.
BO02 has log coffins' head 2C style.
BO18 has log coffins' head 1A style.
BO20, 21, 22, 23, 24, 25, 26 and 29 have log coffins' one end 3C style and one end 4B style.
BO37, 38, 39 are posts.

Ban Rai Rockshelter: BR23 and BR31 are posts.

This series is very important because the samples from Bo Krai Cave can be crossdated with the posts from Ban Rai Rockshelter. In the series, the log coffin has complex style in chamber 2 from Bo Krai Cave can be crossdated in different range. It means the human continuous used this site and the style was not specifically used in certain time. The range of age and last ring in outside the specimen showed the simple style (1A and 1B styles) were probably older than the complex style by dendrochronological dating in this series. However the samples from Ban Rai Rockshelter are posts, so this BKBR1 was not representing the chronology of log coffins' head style between from the both sites. After the samples between Bo Krai Cave and Ban Rai Rockshelter were crossdated, these samples were scanned with the Win$^{TM}$DENDRO program to store the tree-ring width pattern. Then the date of log coffins from Bo Krai Cave and Ban Rai Rockshelter explain by radiocarbon dating ($^{14}C$ method).

### 4.2 Radiocarbon dating

Nowadays, the chronological series of teak log coffins and posts from Bo Krai Cave and Ban Rai Rockshelter by dendrochronological dating cannot date in calendar year with the longest Teak Chronology Indices from Thailand. However, the date from another site dates the Late Holocene period between ca 2200 yrs BP to 9$^{th}$ century A.D. The study calibrated the data of absolute age again. From table 2-2, the result from new calibrated dates (2 sigma) by Oxcal program (2 sigma), the oldest of radiocarbon age from a piece of log coffins' head 1A style (AMS385) at Lahu Pot Cave dating to 2080±60 yrs BP calibrated to B.E. 183- B.E. 603 (B.C.360-A.D.60). Tham Sri Sophon from 2B style (AMS386) which has radiocarbon age 1120±80 yrs BP when calibrated by Oxcal program this ranging to B.E. 1223-1583 (A.D.680-1040) (4). However, the other samples of calibrated dates in the same range of time.

In Bo Krai Cave and Ban Rai Rockshelter. The radiocarbon dating method was used to study the date of teak wood samples. For each tree ring chronological series, two samples were selected to dating age by radiocarbon dating at the Office of Atomic for Peace (OAP), Bangkok (Table 4-18).

**Table 4-18** The radiocarbon determination of log coffins from Bo Krai Cave and Ban Rai Rockshelter

| Site | Code | Series | Style | Code laboratory | % modern | $^{14}C$ age (yrs BP) | Age Calibrated (2 sigma) |
|---|---|---|---|---|---|---|---|
| Ban Rai Rockshelter | BR07 | BRS2 | 1B and 2C | OAP2195 | 80.98±2.05 | 1700±210 | B.C. 200 – A.D. 800 |
| | BR08 | BRS2 | 1B | OAP2196 | 80.81±2.25 | 1710±230 | B.C. 400 – A.D. 800 |
| | BR48 | BRS5 | 1A | OAP2197 | 75.47±2.19 | 2260±240 | B.C. 900 – A.D. 300 |
| | BR28 | BRS1 | 2A | OAP2198 | 77.70±2.12 | 2030±220 | B.C. 800 – A.D. 600 |
| | BR29 | BRS1 | 2A | OAP2199 | 80.89±2.19 | 1700±220 | B.C. 200 – A.D. 800 |
| | BR09 | BRS3 | 1B | OAP2200 | 77.30±1.98 | 2070±210 | B.C. 800 – A.D. 500 |
| | BR10 | BRS3 | 1B | OAP2201 | 82.76±2.12 | 1520±210 | A.D. 50 – A.D. 1000 |
| Bo Krai Cave | BO07 | BKS2 | 4B and 10 | OAP2202 | 76.00±2.00 | 2210±210 | B.C. 800– A.D.300 |
| | BO10 | BKS2 | 4B | OAP2204 | 81.58±2.09 | 1640±210 | B.C. 100 – A.D. 900 |
| | BO13 | BKS2 | 3C and 4B | OAP2205 | 80.23±2.17 | 1770±220 | B.C. 400 – A.D. 700 |
| | BO16 | BKS3 | 3C and 4B | OAP2206 | 80.37±2.13 | 1760±220 | B.C. 400– A.D. 700 |
| | BO11 | - | 3C and 4B | OAP2207 | 74.87±2.07 | 2330±230 | B.C. 1000 – A.D. 200 |
| | BO32 | BKS4 | 3C and 4B | OAP2208 | 81.52±2.08 | 1640±210 | B.C. 100 – A.D. 900 |
| | BO25 | BKS5 | 3C and 4B | OAP2209 | 84.81±2.20 | 1320±210 | A.D. 250 – A.D. 1200 |
| | BO40 | - | 5D | OAP2162 | 87.32±2.22 | 1090±210 | A.D. 550– A.D. 1300 |

**Note** OAP = the radiocarbon laboratory, the Office of Atomic for Peace (OAP), Bangkok, Thailand.
The age calibration by Oxcal v 3.9 program (116).

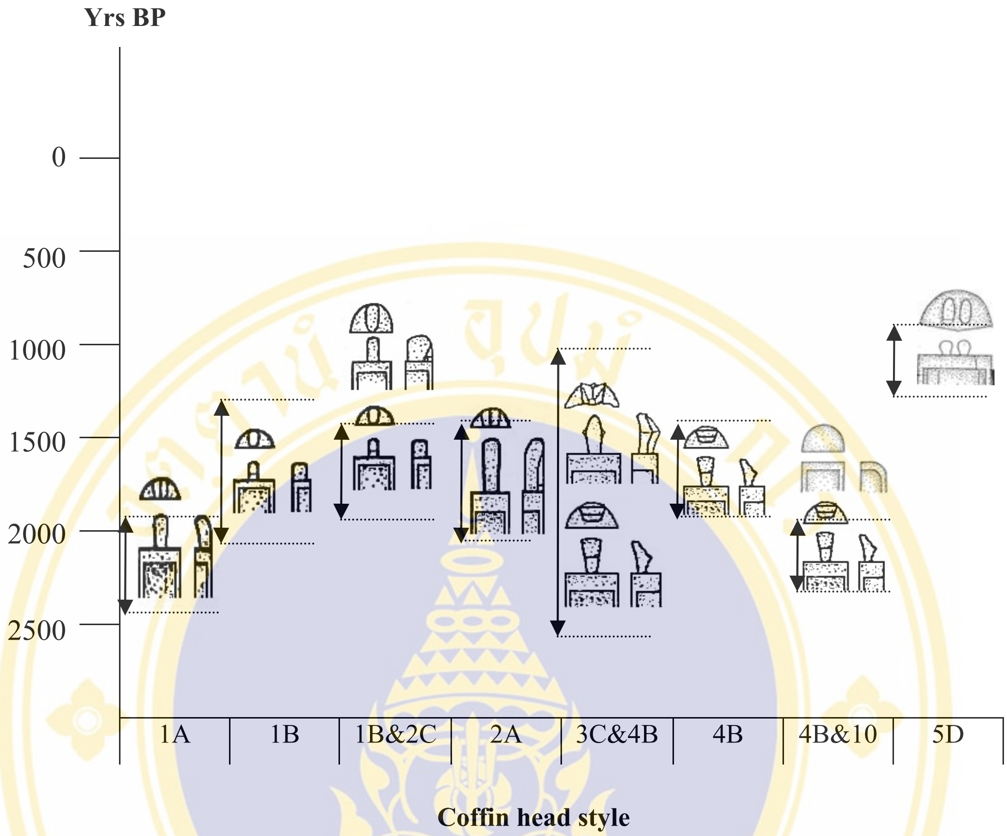



**Figure 4-28** The chronological distribution of individual coffin head styles from Bo Krai Cave and Ban Rai Rockshelter according to $^{14}C$ data

From 15 data of radiocarbon dating; the dates of log coffins in Ban Rai Rockshelter have 7 samples. The oldest age is 2260±240 yrs BP from the log coffins' head 1A style and the youngest is 1520±210 yrs BP from the log coffins' head 1B style. The log coffins' head 1B, 2C and 2A styles have date in the same time (1700 yrs BP).

In Bo Krai Cave, 8 samples were dated. This study was a first date of the log coffins' head complex style. The oldest age from Bo Krai Cave is 2330±230 yrs BP from the log coffins' head 3C style and another end decorate in 4B style. In contrast, the youngest age is 1090±210 yrs BP from the log coffins' head 5D style. The date of this style was overlapped with the date of simple style (1A, 1B, 2A and 2C styles). Moreover, the result of radiocarbon dating from Bo Krai Cave showed the different dates of log coffins' head complex style. This style was probably used continuously in Bo Krai Cave.

# CHAPTER V
# DISCUSSION

This chapter discusses the chronological patterns of the dendrochronological and radiocarbon dates to show how the different styles of coffins were used at Bo Krai Cave and Ban Rai Rockshelter. The chapter begins with a discussion of the palaeoenvirmental implications of the use of teak for log coffins in the Log Coffin culture and then examines the temporal changes described in the previous chapter. The relationship of the dated coffin styles to other coffin sites in the region is also discussed.

## 5.1 The Log Coffin culture: the relationship between humans and their environment

Caves and rockshelters accessible to humans have been used from Paleolithic to the present. Log coffins are common in caves and rockshelters of Mae Hong Son area of Thailand. Most of the log coffins and posts in study area (Bo Krai Cave and Ban Rai Rockshelter) were made from teak trees (*Tectona grandis* L.) that are very hard and resistant to decay for hundreds of years. The properties of teak are strength, stability, durability, resistance to termites, fungi, weather and corrosion (24). People of the Log Coffin culture period used teak because of these properties. However, the type of wood that log coffins were made probably depended on available forest resources, for example, coffins at Ongbah Cave and Ap-ya Cave were often made of rosewood (*Dalbergia sp.*), a high quality hardwood (79).

The presence of teak log coffins and posts suggests that the forest around the study area was probably the mixed deciduous forest because teak one formed major component of this forest type (23). This is related to the present environment around Bo Krai Cave and Ban Rai Rockshelter. Moreover, all of the samples in the study area have the narrow ring and half ring porous structures that indicated the vegetation around Bo Krai Cave and Ban Rai Rockshelter in the Log Coffin culture period may have been much denser than present (1). The present forest surrounding the study area is predominantly mixed deciduous forest which has been changed by logging and human activities. These activities may have been responsible for reducing the vegetation density.

## 5.2 Dendrochronological dating

This study used dendrochronological dating to examine the chronological relationships of the log coffin styles in study area (Bo Krai Cave and Ban Rai Rockshelter). The tree ages from wood samples are usually determined from ring counts on cores and crossdating the growth pattern between cores in the same pieces of wood. Unfortunately, the wood materials from the study area had their surface hidden so that indeterminate amount of sapwood is missing. So when the date of termination of growth cannot be determined, it means that the tree was cut after the date of outermost ring.

At Bo Krai Cave the longest tree age span is 270 years (sample BO31) and the shortest span is 41 years (sample BO33). At Ban Rai Rockshelter the longest tree age span is 265 years (sample BR09) and the shortest is 51 years (sample BR51). The dendrochronological data can be arranged into two groups described below.

### 5.2.1 The tree growth patterns from log coffins and posts that could not be crossdated with other wood samples.

Although these data were not useful for constructing a sequence for the sites. The tree-ring width from Bo Krai and Ban Rai Rockshelter were the database of Teak chronology for archaeological site in northern Thailand and very important information for the dendrochronological study in the future. The causes the prevent these samples from being crossdated include:

5.2.1.1 The loss of tree rings because the bark and sapwood were cut out during the process of making the coffins and posts. Outer surfaces were also destroyed by decay, environmental erosion and human activities.

5.2.1.2 The wood that the log coffins and posts were made from may have grown in the different times or environmental conditions. The tree rings may have response to microclimatic condition in each area more than macroclimatic conditions.

5.2.1.3 The use of core samples in this study can make it difficult to measuring tree rings in some cores because of abnormal rings such as false and absent rings.

**5.2.2 The tree growth patterns that can be crossdated with other samples to build dendrochronological series.**

5.2.2.1 Dendrochronological series at Bo Krai Cave

At Bo Krai Cave, the tree-ring width was measured on 71 samples. The five dendrochronological series at Bo Krai Cave were built from 51 samples (71.83 % of total samples from Bo Krai Cave). A dendrochronological series is a set of wood samples with overlapping ring growth patterns. These five series from Bo Krai Cave can be grouped into three categories depending on style of log coffin that the samples were taken from:

1. Bo Krai chronological series 1 (BKS1) is the chronological series of samples taken from the log coffins of the simple style only.
2. Bo Krai chronological series 2, 3 and 5 (BKS2, BKS3 and BKS5) are the chronological series of samples taken from the log coffins of the simple style and complex style.
3. Bo Krai chronological series 4 and 5 (BKS4) is the chronological series of samples taken from the log coffins of the complex style only.

BKS1 was derived from log coffins made in the simple style. In chamber 2 of Bo Krai samples BO17 and BO31 in this series have log coffin head 2A style but in chamber 3 sample BO02 has log coffins' head 1B style. The log coffins with code BO17 and BO31 were placed on beams and posts in chamber 2 and these coffins look newer than BO02 which lays on the floor in chamber 3.

Dendrochronological dating confirms this impression, indicating that log coffin BO02 probably predated BO17 and BO31. This means that log coffins' head 1B style probably predated the log coffins' head 2A style although this conclusion would be more certain with an increased number of samples from each style. Moreover, BKS1 was possibly correlated with the log coffins' head simple style in chamber 3. Unfortunately, samples from these coffins were not collected in this study because of limited time. However, this result explains that these coffins in this series were made from teak trees that grew in the same area and at the same time.

BKS2 and BKS3 are two series of samples that include coffins with shows the relationship between the log coffins that had one end in 4B style but one end without any carving (10 style) and the log coffins that had an animal head (3C style) carved on one end and on the other end a carved animal tail (4B style). These styles of log coffins can be crossdated in the same range of dendrochronological series. It means the both characteristic may have been used at similar times. Similarly with BKS3 the log coffin that had 5B style can be crossdated with the complex styles of log coffins heads. These samples of different styles that date to similar times suggest that the different styles do not show change over time and evolution of design.

BKS4 is the series of samples that include only the complex style of coffin heads. At Bo Krai Cave there were two sets of coffins (BO17 and BO31 group) that included the upper lid cover and the lower lid and another log coffin lid was scattered in the floor. The result of BKS4 suggests that log coffin upper and lower lids may be made from one trunk and split in half. Both lids from this series were not intact at the time of recording but it is likely that these lids are from the same coffin because they have the same size and give very high statistical correlation for their growth patterns.

The last series is BKS5. In this series are log coffins that were decorated with the complex style and placed on floor in chamber 2. These log coffins can be dated with the posts in the chamber 1. The floor of chamber 1 was approximately 3 m higher than chamber 2. This suggests that people of the Log Coffin period used all of spaces in this cave in the same time. The result shows that the complex style was used in a different time and might be used continuously in this area.

This study has found that all of the chambers in Bo Krai Cave (Chamber 1, 2 and 3) probably were used at the same time because the samples between these chambers can be crossdated in the same range of floating chronological series. Currently, the results are unclear about the evolution of log coffins in this area because of the limited number of samples and the possible loss of wood by the processes of removing the sapwood and bark out.

One problem in this study is some data recorded from samples is incomplete and the positions of log coffins have probably moved by interference by visitors to the caves and nature. All of these problems impact the interpretation of data between chambers.

5.2.2.2 Dendrochronological series at Ban Rai Rockshelter

At Ban Rai Rockshelter, tree-ring width was measured on 121 samples. The seven chronological series at Ban Rai Rockshelter were built from 58 samples (47.93% of total samples from Ban Rai Rockshelter). The series from Ban Rai Rockshelter were made from log coffins that had simple style. The series can be arranged into three groups according to the coffin styles they represent:

1. Ban Rai chronological series 1, 2, and 6 (BRS1, BRS2, and BRS6) are the chronological series from the different style of log coffins.
2. Ban Rai chronological series 3 and 5 (BRS3 and BRS5) are the chronological series from the same style of log coffins.
3. Ban Rai chronological series 4 and 7 (BRS4, and BRS7) are the chronological series from the posts.

The BRS1 can be crossdated with wood samples from the west and east of Ban Rai Rockshelter. This series suggests that people used different areas in Ban Rai Rockshelter as burial site at the same time. The 2A style (sample BR28, BR29) probably used before 2B style (sample BR05). But in BRS6, the 2A and 2B styles can be crossdated and the last rings finished in the same age range of floating chronology. However these wood materials from BRS1 and BRS6 had their surface hidden so that indeterminate amount of sapwood is missing. So when the date of termination of growth cannot be determined. Although, the log coffin head style from BRS1 and BRS6 had similar style (2A and 2B styles) but the tree growth pattern cannot be crossdated. It means the style of log coffins is possible unchanged through time. The humans of the Log coffin culture at Ban Rai Rockshelter might have used the area continuously and used the 2A and 2B styles of log coffins at the different times. On the other hand, the wood material that made log coffins might be grew in the different environmental condition.

The BRS2 and BRS3 can be crossdated the log coffins 1B style. In BRS2, the sample BR07 (1B and 1C styles) can be crossdated with BR08 (1B style). This means that the 1B and 1C styles were used in the same time. The log coffins in BRS2 and BRS3 probably were couple lids (upper and lower lid) and made from the same tree because the both log coffin lids from each series are the same size and give high statistic correlation between them.

BRS5 is chronological series from the log coffins of 1A style. The sample BR16 is head coffin piece near BR48. The both samples probably were the same lids by size and location.

However, the seven chronological series from Ban Rai Rockshelter do not matching growth patterns between them. It might be the Ban Rai Rockshelter was used as a burial site in several times or the teak tree that made log coffin wood were not growing in the same area and time. It is also possible that the loss of wood resulting from cutting the sapwood and bark out has removed the crossdating rings.

In this study, the tree growth pattern from Bo Krai Cave and Ban Rai Rockshelter cannot be crossdated in the same series except the coffins and posts from BKS5 and the posts from BRS7 that crossdated with in BKBRS1. At present, the dendrochrnological dating cannot explain the chronology of coffin head style between Bo Krai Cave and Ban Rai Rockshelter because the limited samples which can be crossdated between these sites. The different of growth patterns of trees between the two sites might be caused by microclimate between these sites.

### 5.3 Radiocarbon dating

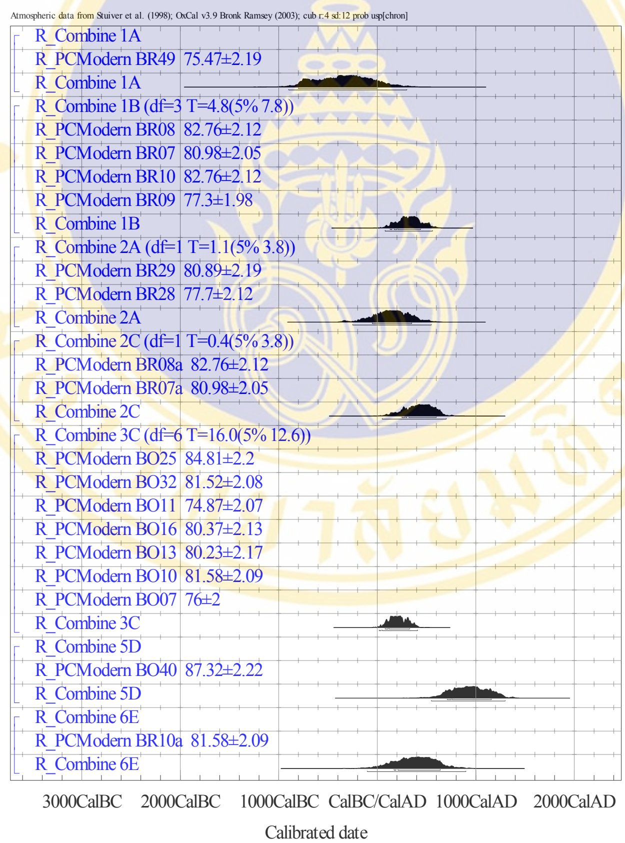



**Figure 5-1** The combination of probabilities for all the dates in each coffin style

Figure 5-1 shows the results of the combination of the radiocarbon dates obtained for this project. The dates are combined before calibration and a chi-square test is performed for internal consistency. The chi-square test is of limited relevance for sets with less than four members, but it is interesting that the complex style fails the test. This suggests that the distribution of complex style does not follow a normal curve, probably because the dates span a relatively long period. This figure shows that 1A style is earlier than all the other styles and 5D style is later than all the other styles and that 1B, 2A, 2C and 3C styles were all used at about the same time. The sample sizes are very small, so these results may be inaccurate.

The dates of log coffins in this study were obtained using radiocarbon dating by direct $CO_2$ absorption method. This method required a minimum of 30 g of dry wood, therefore the sample must be a mix of approximately 200 years of tree ring wood core together in one sample for dating. By applying this dating method, the age of the sample will have inevitably wider age range than the Accelerator Mass Spectrometry dating method previously used at 7 archaeological sites in Pang Mahpa including Umong Cave, Namlang Jum (Lang Chan), Lahu Pot Cave, Lahu Village Cave, Sri Soppong Cave (Tham Sri Sophon), Lod Cave and Chanrong Cave (4,77,78)

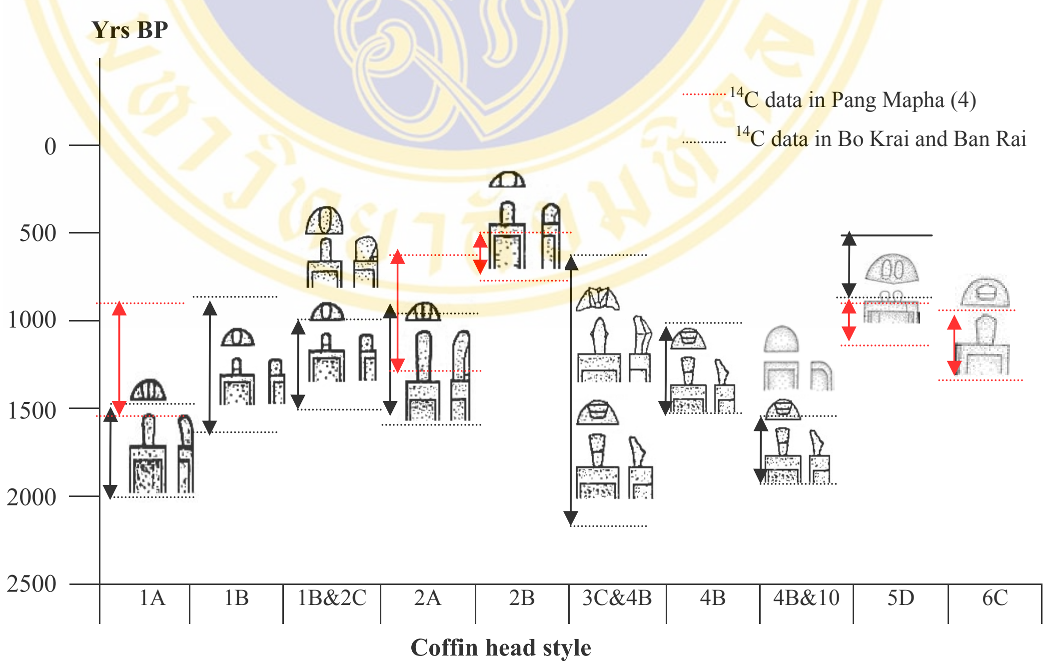



**Figure 5-2** The chronological distribution of individual coffin head styles from Bo Krai Cave and Ban Rai Rockshelter and other sites in Pang Mapha District according to $^{14}C$ data (4)

Figure 5-2 shows the overlapping radiocarbon chronology of log coffins in simple styles (1A, 1B, 2C, 2A, 5D, 6C styles) and log coffins with the complex styles (3C and 4B). The $^{14}C$ data in study area are currently limited and uncertain because of the wide range of dates. However these dates are an important contribution to the database for further study and can be used to construct the chronology of coffin head styles in the Log Coffin Culture. The $^{14}C$ data showed the period of log coffins at both sites ranging between 1090±210 to 2330±230 yrs BP. This period correspondes with dates from 7 archaeological sites in the Pang Mapha area including Tham Kao Chin, Umong Cave, Namlang Jan (Lang Chan), Luhu Pot Cave, Lahu Village Cave, Sri Soppong Cave (Tham Sri Sopon) and Lod cave. At these sites the log coffins have been dated to 2080±60 to 1240±90 yrs BP or the Iron Age period (4,77,78). Because most sites associated with the metal artifacts that was found with the carving marked on surface of log coffin lids (2,3,76).

The data of log coffins head simple style in figure 5-2 suggest that style 1A is probably the oldest style. The 1A style was used at 2260±240 yrs BP. Later, the log coffins appeared more than one style including 1B, 2A, and 2C styles. After that 6C style appears and 5C style, which may have developed from style 6C. Finally, 2B style appeared age of 1240±90 yrs BP.

On the other hand, the data from the complex style of log coffins head showed that this style was used in over a long time range and different periods. This complex style was made between 2330±230 yrs BP to 1320±210 yrs BP and is older than 1A style. However the $^{14}C$ data suggests that log coffins of different styles, including the simple and complex style from Bo Krai Cave and Ban Rai Rockshelter, were made in the same range of time. These data suggest that the log coffin styles in this study area were not developed from one style to another in sequence but that these styles were used continuously and simultaneously.

# CHAPTER VI
# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

Teak (*Tectona Grandis* L.) is a tropical tree species that has potential to be studied by tree-ring analysis. The durable wood has many properties that make it a durable building material and has been used since prehistory. This species was often used to build log coffins during the Log Coffin culture period in the Pang Mapha area. This study has examined the relationship of chronology and log coffin style using tree-ring analysis and radiocarbon dates. The materials were taken from two sites: Bo Krai Cave and Ban Rai Rockshelter. These two sites are important sources of data to study the chronology of log coffins' head because of numerous of log coffins in different styles discovered in this area.

In Bo Krai Cave, a total of 71 cores from 36 log coffin lids and 3 posts were taken. Analysis of correlations between these samples resulted in five chronological series. These series indicated that the cave has functioned as burial site with the same styles of log coffins used over a long period of time. It means the people of the Log Coffin culture probably used each log coffin style continuously and used all of chambers at the same time because the samples from three chambers have overlapping date ranges according to the tree-ring crossdating.

In Ban Rai Rockshelter, a total of 121 samples were taken from 30 log coffin lids and 27 posts. Correlating the tree-ring width crossdating resulted in seven tree-ring chronological series. These series show this area was used as burial site in several periods. The chronology of the log coffins head styles indicate that different styles of log coffins were used at the same time, similar to the pattern of coffin use at Bo Krai Cave.

The different styles including 1A, 1B, 2A, 2B and 2C style of log coffins in these areas were used in several periods. The different styles of log coffin do not show a pattern of evolution and the culture change in this area.

The radiocarbon age values shown that the log coffins in the study area date to between 1090±210 to 2330±230 yrs BP. This age is similar to other Log Coffin sites in Pang Mapha that date to Late Holocene. The result of radiocarbon dating from 15 samples confirms the dendrochronological data and shows overlapping between the simple styles and complex styles of coffin heads. This means that the styles of log coffins in this area do not represent the development from simple style to complex style. The simultaneous use of different coffin styles suggests that style may be related to the status of the buried individual or their ethnic affiliation rather than different culture-historical periods.

**6.2 Recommendations**

6.2.1 The date of log coffins in this study using radiocarbon dating by direct $CO_2$ absorption method. This method required minimum dry wood 30 g, therefore the sample must be mixed with 200 years of tree-ring wood core together in one sample of dating. By applying this dating method, the error of the sample will have inevitably wider range of error than using Accelerator Mass Spectrometry dating method (AMS method). It is recommended that future radiometric dating of log coffin samples use only the AMS method for high resolution dates.

6.2.2 Reliability of the collected dendrology samples depended on the number of samples collected. Therefore, the results of the current study may have had more validity and reliability if there additional samples were collected from the coffins in the identical archeological site in Pang Mapha District, Mae Hong Son Province, in which additional samples may helping in associate with the data of current study and improve the reliability and validity of the study. This study of coffins in two archeological sites collected only parts of wood core which may lead to errors in the sample collected (researcher will see some parts of the wood core which may be the part that has imprecise ring data). The next study it recommended that the researcher should collect the whole dish of wood by using hand saw in order to get data from the whole ring instead of collecting only a few parts by applying increment borer.

6.2.3 During data collection period there were many problems resulting from tourists visiting the coffins in the archeology site and moving the coffins around the cave. It is recommended that future researchers should carefully plan to collect the detailed data from coffins in archeological sites to avoid confusion with recent repositioning of the coffins.

6.2.4 Coffins in archeological sites are sightseeing places for many tourists. Inevitably there are some reckless tourists and tour guides putting candles on the coffins which may damage the coffins and damaging valuable resources for studying dendrology. It is recommended that the Tourism Authority of Thailand protect the coffins by restricting access to caves containing coffins and educating tourists and tour guides about the importance of preserving the coffins as a cultural and scientific resource. It is also recommended that future researchers train and educate people in community about log coffins and archeological sites to preserve the wood data in order for further study in dendrochronology.

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# APPENDIX

# APPENDIX I
# RADIOCARBON DATING

The routine work of radiocarbon laboratory, the Office of Atomic for Peace (OAP), Bangkok, Thailand by Manit Sonsuk (115).

## 1.1 Apparatus

1. Low-level Liquid Scintillation Counter (1220 Quantulus).
2. Vacuum line for carbondioxide preparation.
3. Vacuum line for carbondioxide absorption.

## 1.2 Procedure

### 1.2.1 Carbondioxide preparation

1. Approximate 5 g of sample is weighted and taken into crucible.
2. About 12 cm of Ni wire is connected to the electrodes.
3. Close the bomb.
4. Open the valve A (Figure 1) and released the oxygen from the tank into the bomb to remove the air inside.
5. Close valve A and observed the pressure in the bomb (the pressure should not above 15).
6. Connect the electrical wire to the control box and push the black bottom if the wire is proper connected, the red light will show (in case no red light repeat step 2).
7. Temperature of the bomb will increase if combustion occurs and ready for next step.

**1.2.2 Purification of carbondioxide**

1. Fill trap with liquid nitrogen and turn on the pump.
2. Close valve 13, T4 and open T5 as shown in Figure 1.
3. Connect the $CO_2$ tank at point A2 and vac the tank by open valve T4.
4. Weight the $CO_2$ tank.
5. Close valve T4 and disconnect the tank and weight.
6. Connect the bomb or flask at point Al.
7. EtOH/liq.$N_2$ to trap B1 and B2.
8. Open the valve T1, T2, T3.
9. Liq. $N_2$ to trap B3, 84, B5 and close valve T3.
10. Slowly open valve A at the oxygen bomb and watching $KI/I_2$ bubbler (do not allow over vigorous bubbling).
11. Watching the vacuum gauge do not let the pressure over 5. If the pressure over 15 open valve T3 slowly.
12. When all carbon dioxide in the bomb is released (the pressure drop to 0). then close valve T2 and open valve B on the bomb.
13. Remove EtOH/liq. $N_2$ from trap B1 and B2.
14. Open valve T3 and vac the line and then close valve T3.
15. Connect the $CO_2$ tank to vacuum line at point A2 open valve T4.
16. Remove liq. $N_2$ from trap, B3, B4, B5.
17. Liq. $N_2$ to $CO_2$ tank close valve T5 and open valve T3.
18. Wait until $CO_2$ has transferred from trap B3, 84, B5 to $CO_2$ tank.
19. Close valve T3 open valve T5 vac for 5 min and then close the valve on $CO_2$ tank and close valve T4.

20. Remove liq. $N_2$ from $CO_2$ tank and remove $CO_2$ tank from the line.
21. Weight the $CO_2$ tank and calculate the weight of $CO_2$.

**1.2.3 Absorption of carbondioxide**

1. Liq. $N_2$ to trap of absorption line as shown in figure 2.
2. Close valve 11, 12, El, E2, Fl, F2 and open valve 5 and 6.
3. Connect the $CO_2$ tank at the point to $CO_2$ tank as shown in Figure 2.
4. Open the valve on the tank to transfer $CO_2$ from the tank to the bladder
5. The amount of $CO_2$ produced is used as a guide to decide how much C/P mixture to use.
6. Flush sample bubbler with nitrogen for approx 1 min. and plug then weight.
7. Injected C/P mixture into sample bubbler and then weight again. The amount of C/P mixture can be calculated.
8. Connect the sample bubbler and C/P trap (0) to the line.
9. Open valve El, E2, Fl, F2.
10. EtOH liq. $N_2$ to trap A and D.
11. Slowly open valve 11 and 12 and close valve 13 firmly.
12. Turn on circulation pump.
13. Adjust flow of bubbler with valve 13 ensure over bubbling does not occur, monitor and adjust flow continuously.
14. Time bubbling 20 minutes.
15. Rinse the injector with EtOH and dry by flush with nitrogen.
16. Weigh counting vial and label.
17. After 20 minutes turn off circulation pump.

18. Close valve 11 and 12.

19. Remove sample bubbler and plug.

20. Remove EtOH/liq.$N_2$ from trap A and D.

21. Remove trap D and then remove plugs from trap D.

22. Pour sample from sample bubbler into trap D test tube. Thoroughly grain C/P mixture from sample bubbler.

23. Pour C/P mixture from trap D tube into preweighed counting vial and then weigh the counting vial again. (The vial is ready for counting with liquid scintillation counter.

24. Rinse the all bits with EtOH and then dry.

25. Ready to go back to start the new sample.

**1.2.4 Counting with Liquid Scintillation Counter.**

1. Place the standard, sample and background vials in to the counter.

2. Set counting with 20 cycles and period of 50 minutes for each sample.

3. The data are statistically analysed by computer and a plot of mean count, standard deviation (Gaussian and Poisson), standard error (Gaussian and Poisson) Gaussian/Poisson ratio, channel ratio, and histogram obtained. In addition, a histogram plotting the deviation of each successive count from the mean is drawn to detect machine malfunctions producing irregularities in the distribution.

4. Radiocarbon dates are calculated according to the equation.

$$T = 8033 \ln (A/A_0)$$

Where A = $^{14}$C activity in sample.

A = $^{14}$C activity in standard (ANU sucrose standard).

With the addition of the NBS oxalic acid/ANU sucrose conversion factor. Although ANU sucrose is the laboratory's principal contemporary dating standard, activities of the NBS oxalic acid have been determined. The conversion factor $D^{14}C = 508.1 \pm 2‰$ is utilized as it represents a mean derived from a large number of laboratories throughout the world.

5. All date and parameter calculations are performed by computer. Data released to submitters are generally restricted to: conventional radiocarbon age and standard error, $^{14}C$ depletion ($D\ ^{14}C$) and standard error, and $\delta\ ^{13}C$ values, unless submitters request additional parameters.

6. Chronological samples are reported as MODERN with the reservoir corrected, conventional radiocarbon age is less than 200 years; > MODERN.

7. The maximum dating age for the laboratory is taken as 30,000 years. Dates beyond this age have low reliability as they are subject to both high errors due to changing background levels, and errors arising from sample contamination.

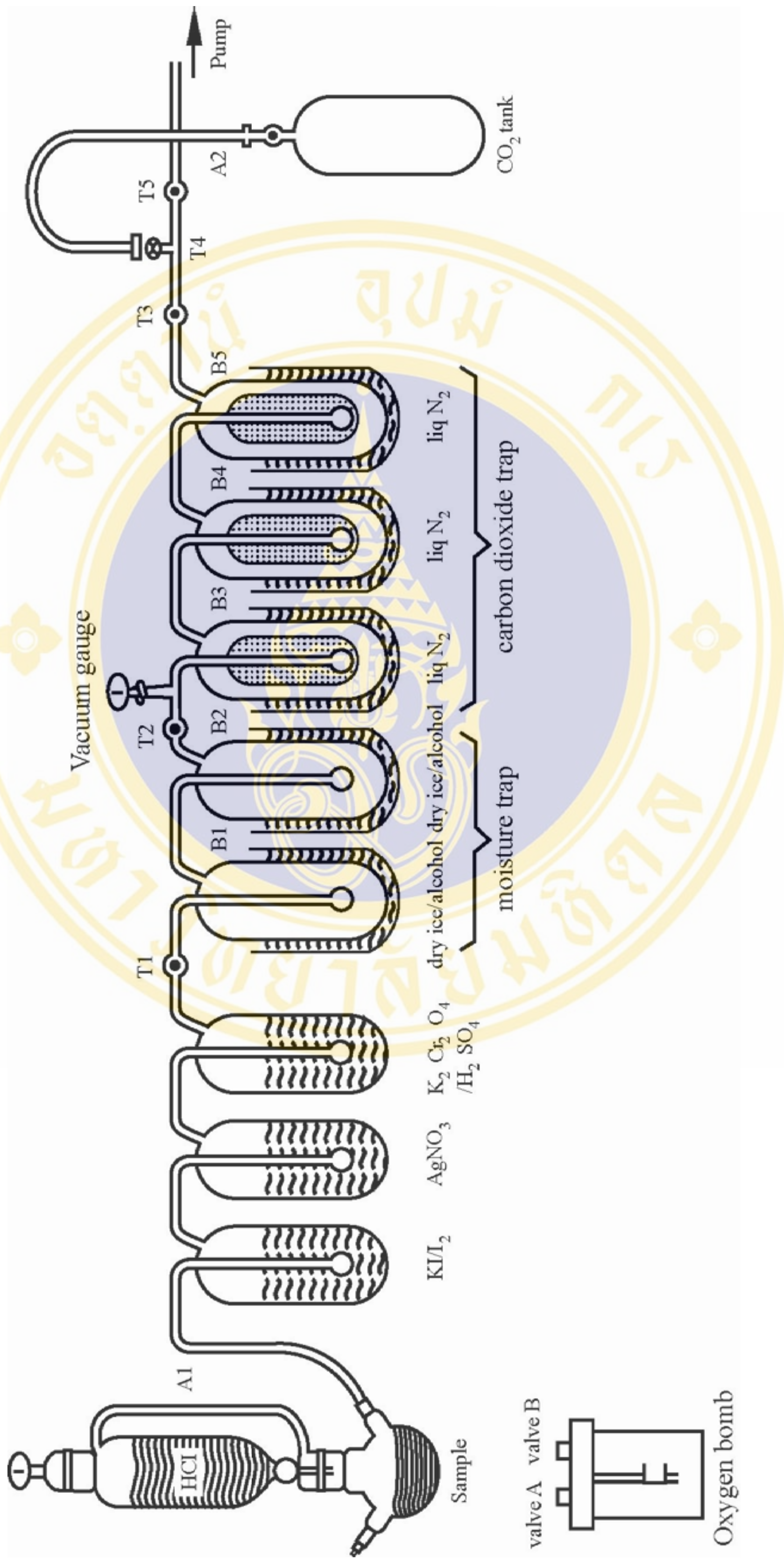



**Figure 1** Vacuum line for carbondioxide preparation.

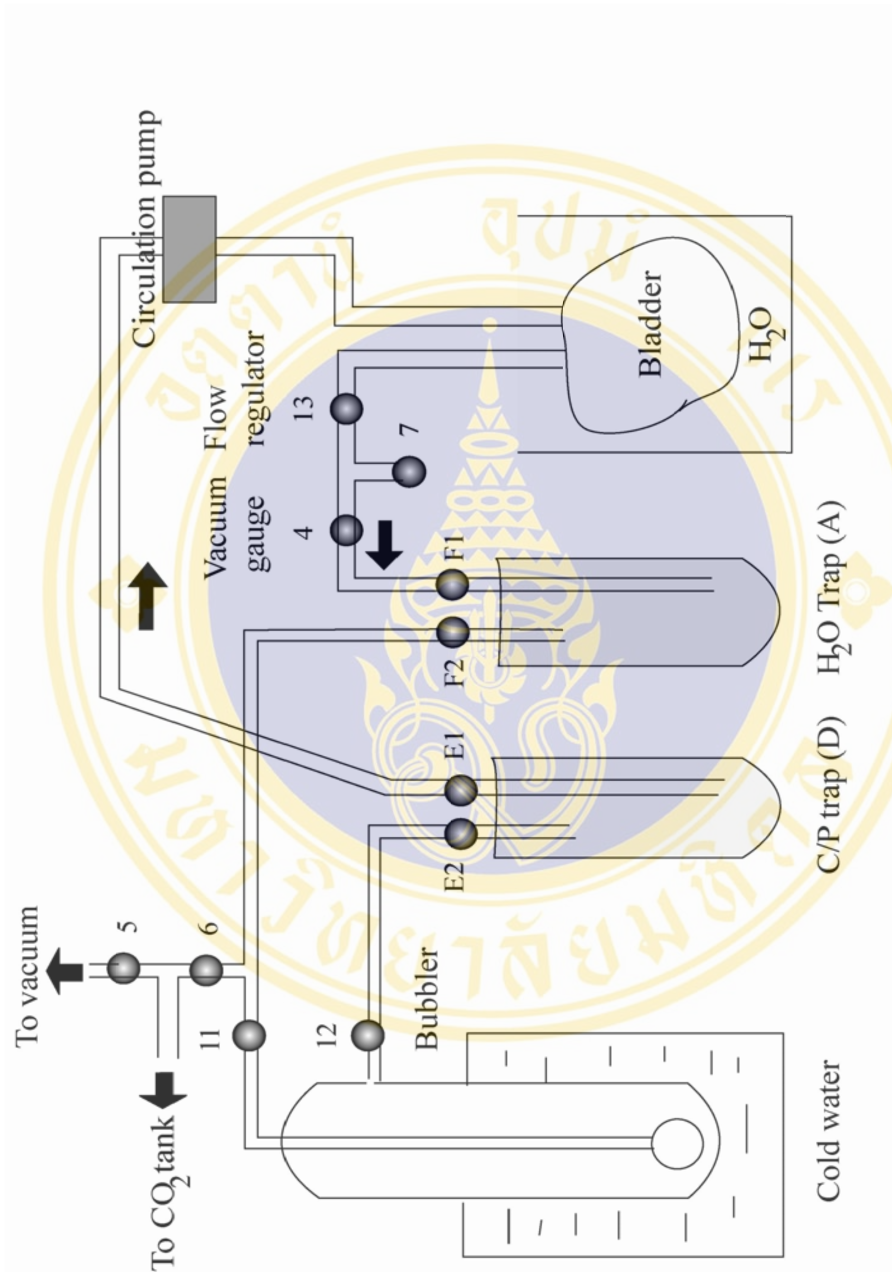
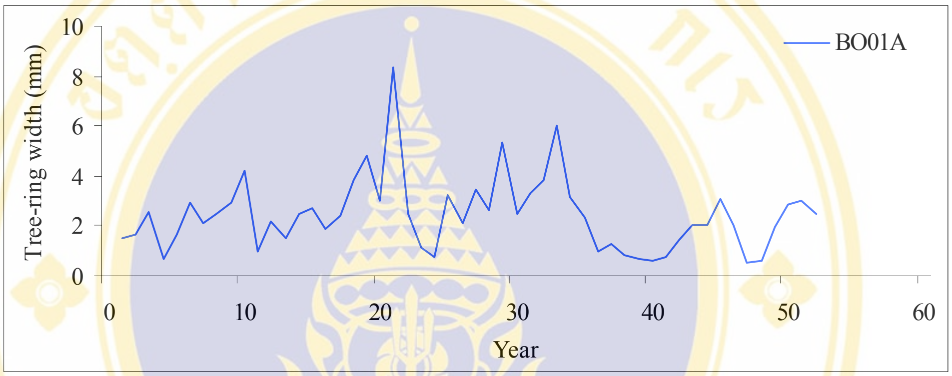
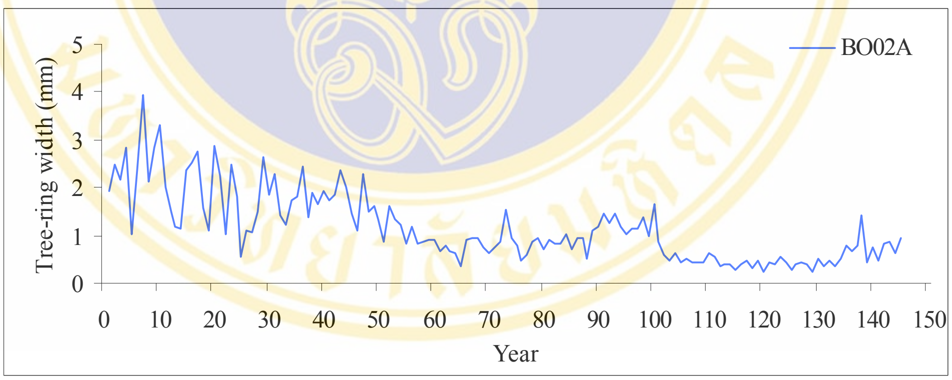


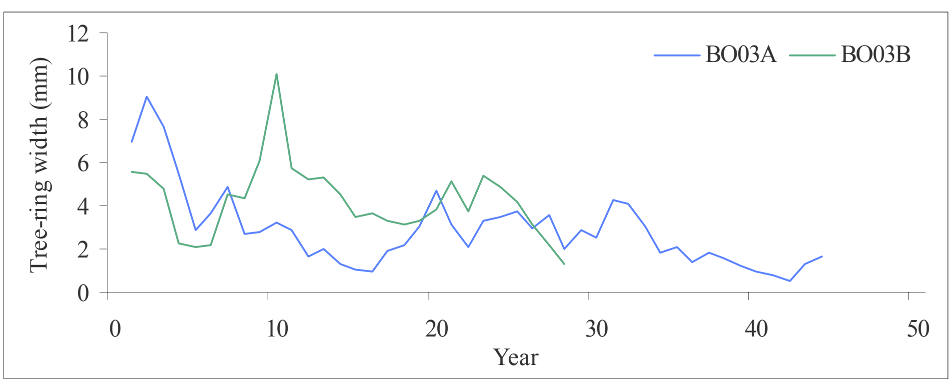

**Figure 2** Vacuum line for carbondioxide absorption.

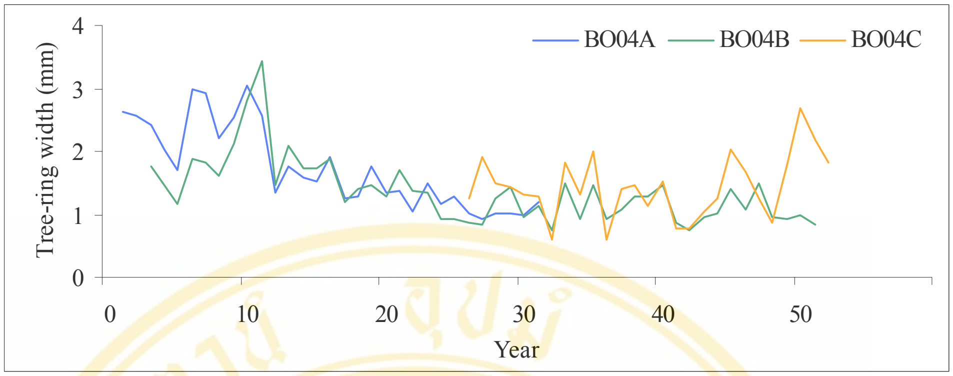
# APPENDIX II
# THE RAW DATA OF MEASURING RING WIDTH

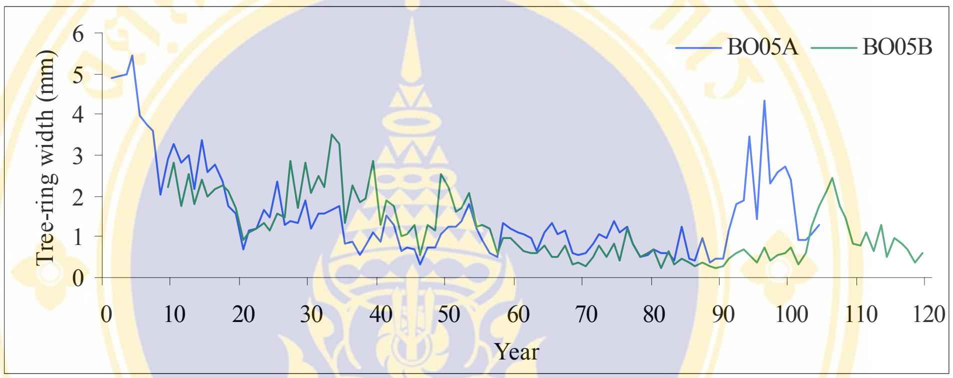
**PART I** The raw data of measured ring width for individual series from Bo Krai Cave, Pang Mapha District, Mae Hong Son Province.

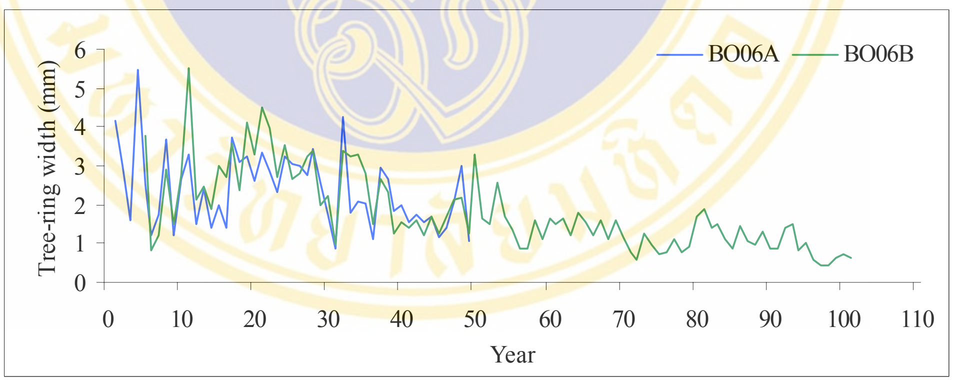


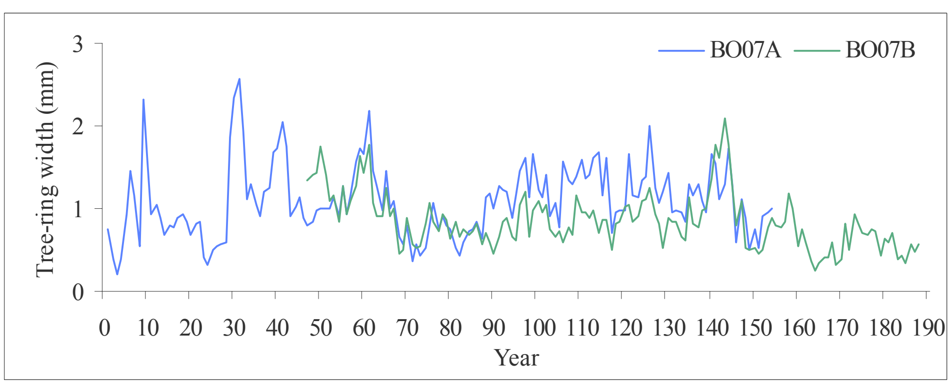



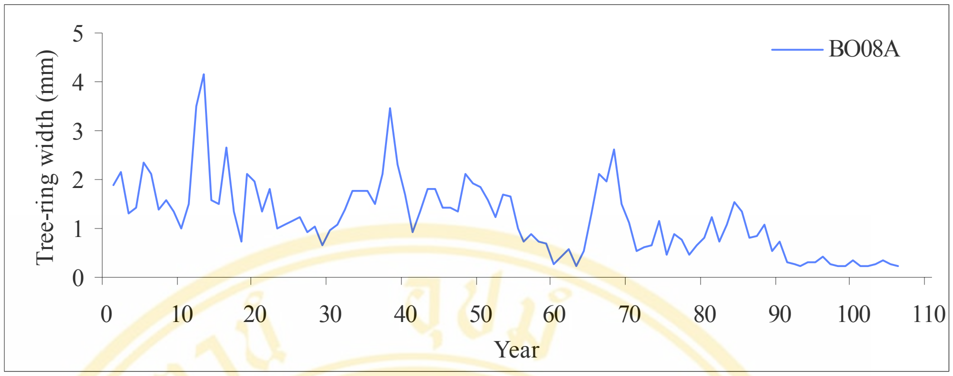



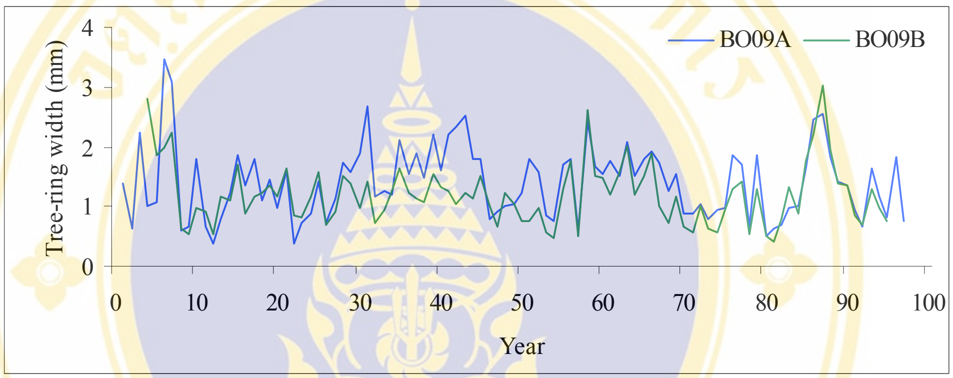

BO04A
BO04B
BO04C
Tree-ring width (mm)
Year
0
1
2
3
4
0
10
20
30
40
50

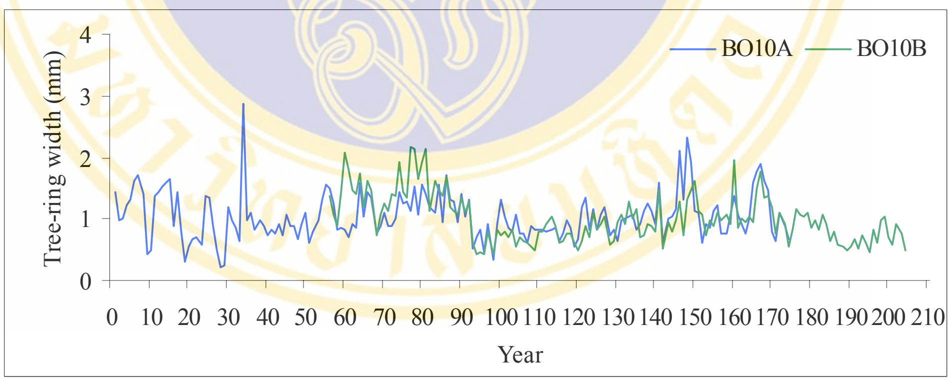

BO05A
BO05B
Tree-ring width (mm)
Year
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
100
110
120

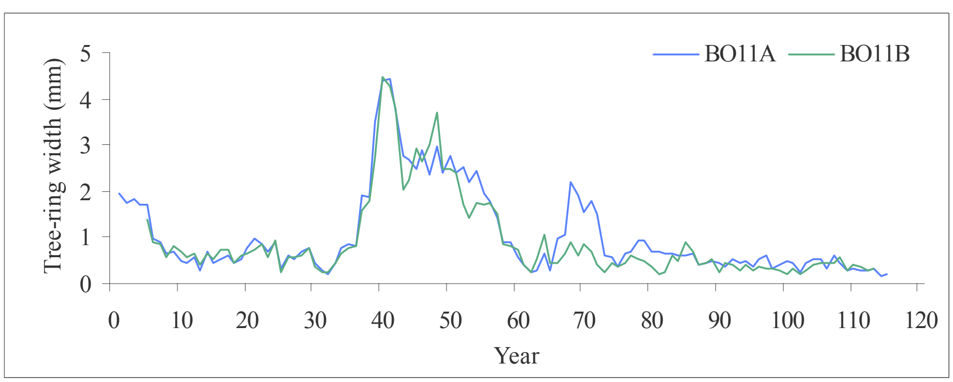

BO06A
BO06B
Tree-ring width (mm)
Year
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
100
110

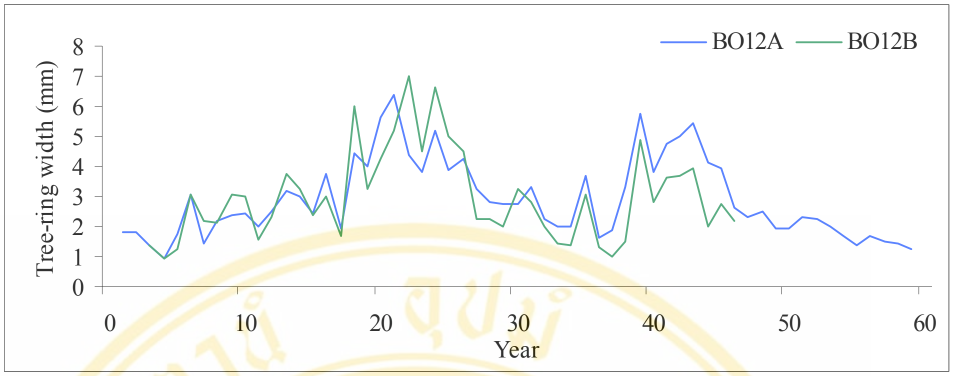

BO07A
BO07B
Tree-ring width (mm)
Year
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190

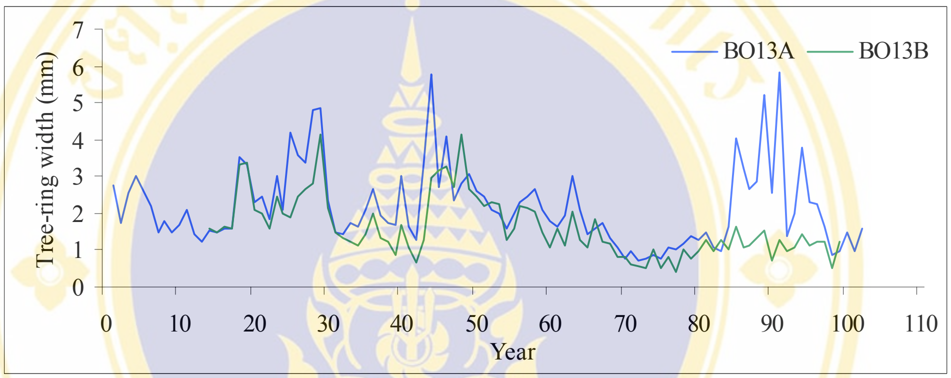

BO08A
Tree-ring width (mm)
Year

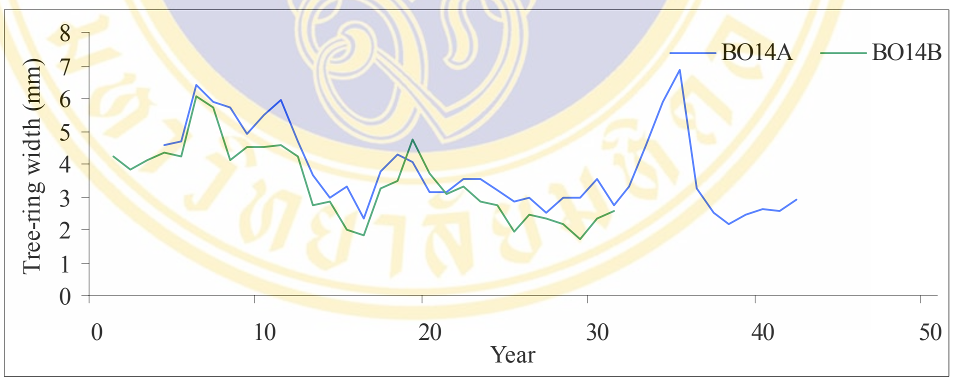

BO09A
BO09B
Tree-ring width (mm)
Year

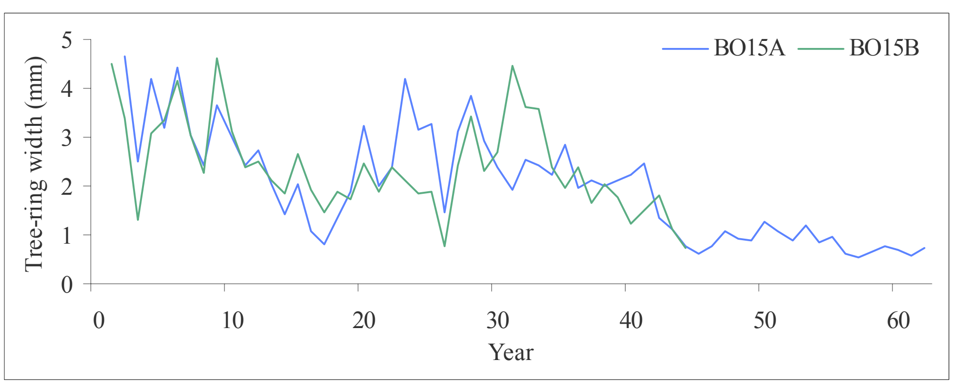

BO10A
BO10B
Tree-ring width (mm)
Year

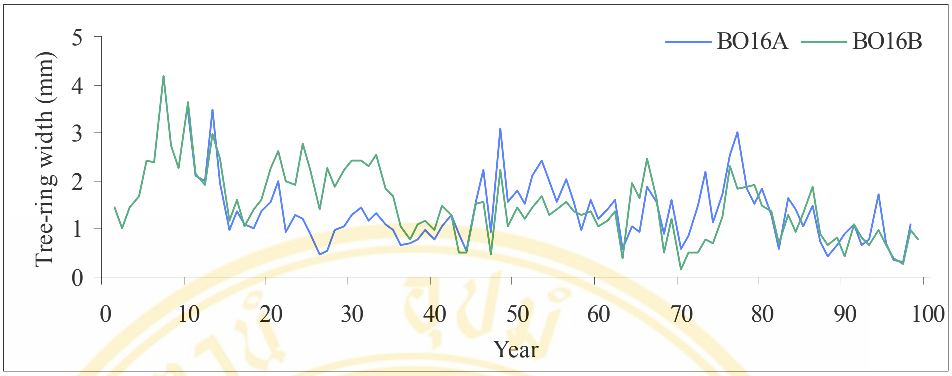

BO11A
BO11B
Tree-ring width (mm)
Year

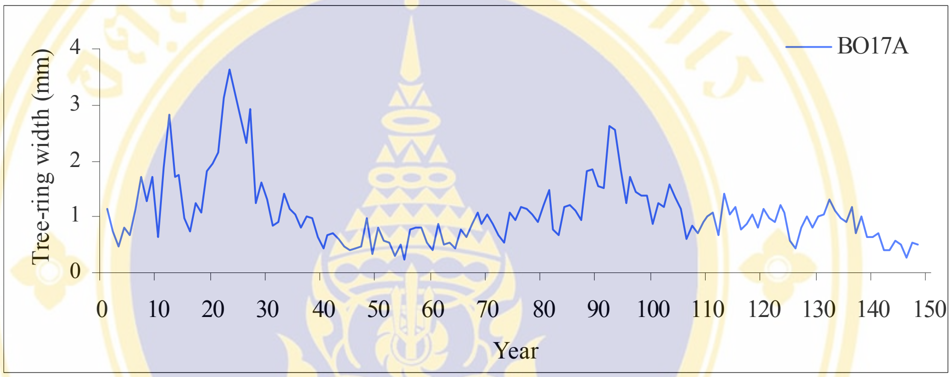

BO12A
BO12B
Tree-ring width (mm)
Year
0 1 2 3 4 5 6 7 8
0 10 20 30 40 50 60

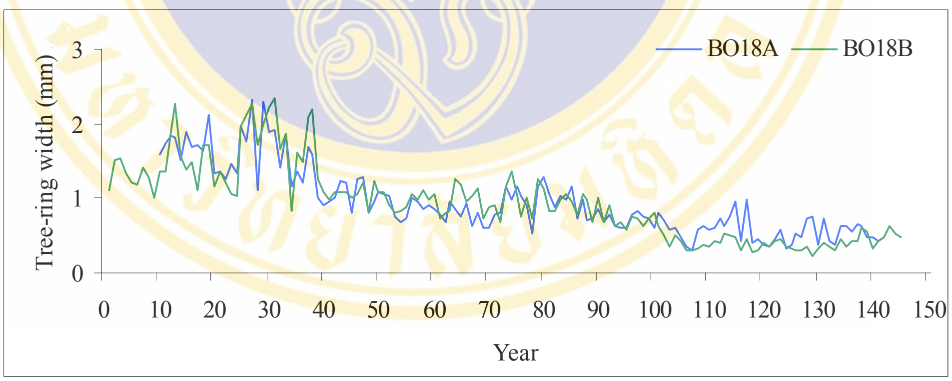

BO13A
BO13B
Tree-ring width (mm)
Year
0 1 2 3 4 5 6 7
0 10 20 30 40 50 60 70 80 90 100 110

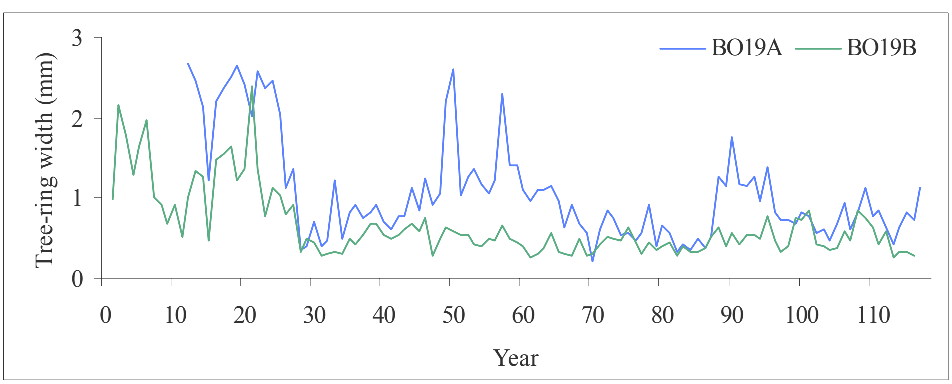

BO14A
BO14B
Tree-ring width (mm)
Year
0 1 2 3 4 5 6 7 8
0 10 20 30 40 50

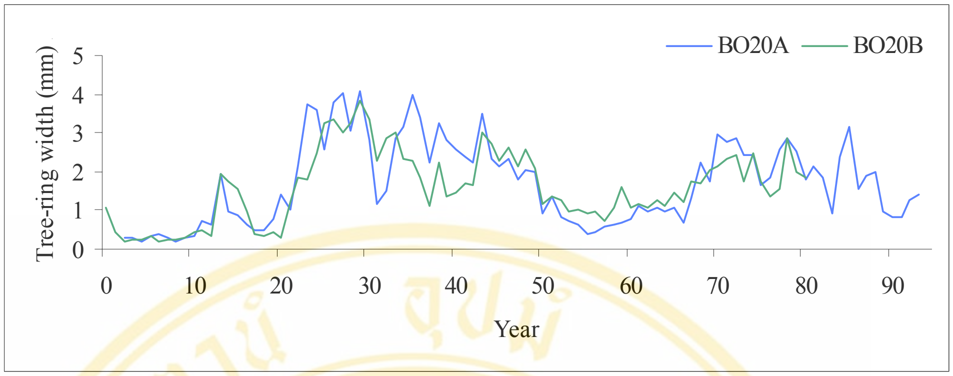

BO15A
BO15B
Tree-ring width (mm)
Year
0 1 2 3 4 5
0 10 20 30 40 50 60

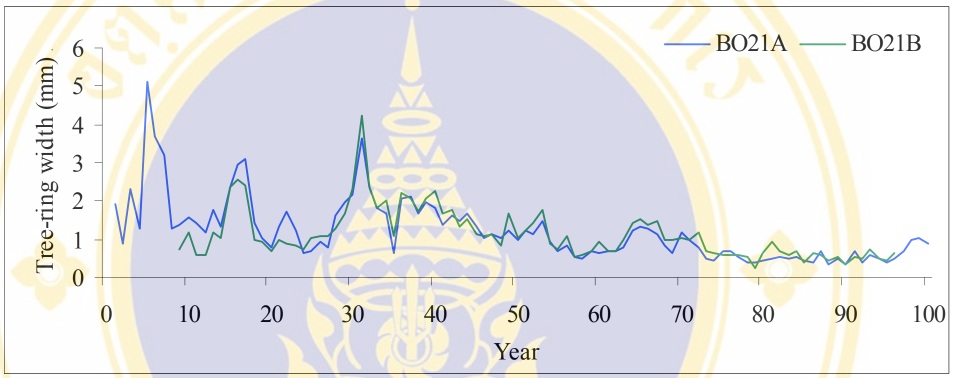

BO16A
BO16B
Tree-ring width (mm)
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90
100
Year

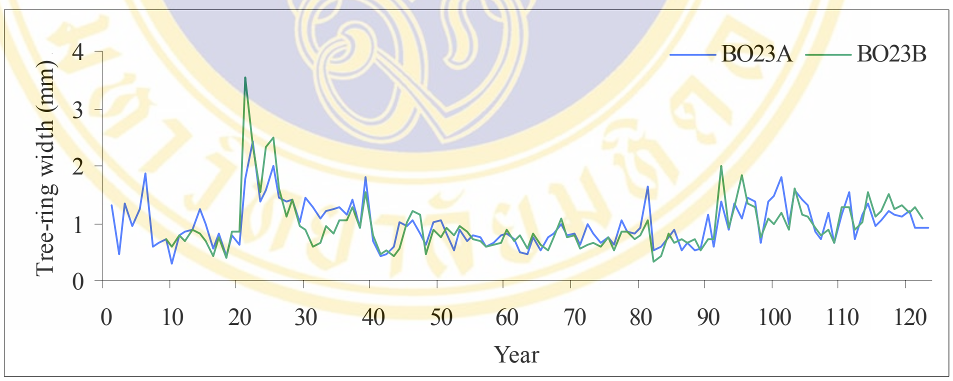

BO17A
Tree-ring width (mm)
0
1
2
3
4
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Year

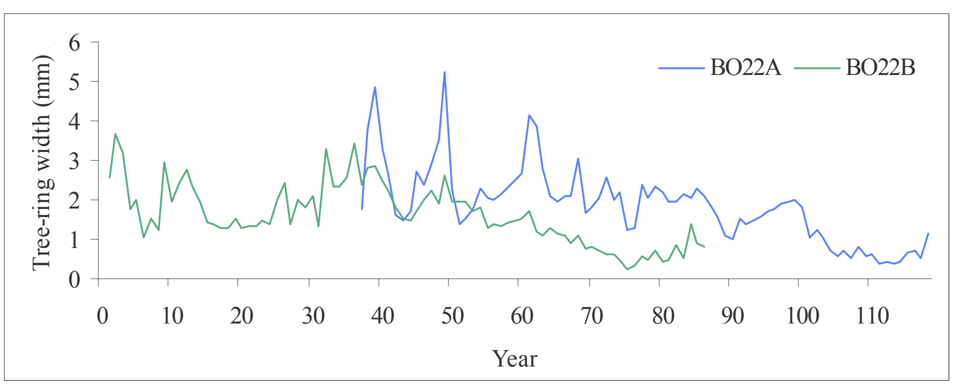

BO18A
BO18B
Tree-ring width (mm)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Year

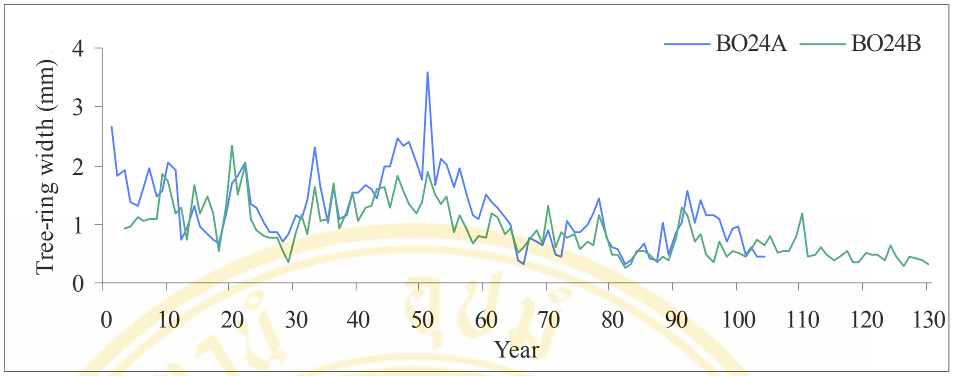

BO19A
BO19B
Tree-ring width (mm)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100
110
Year

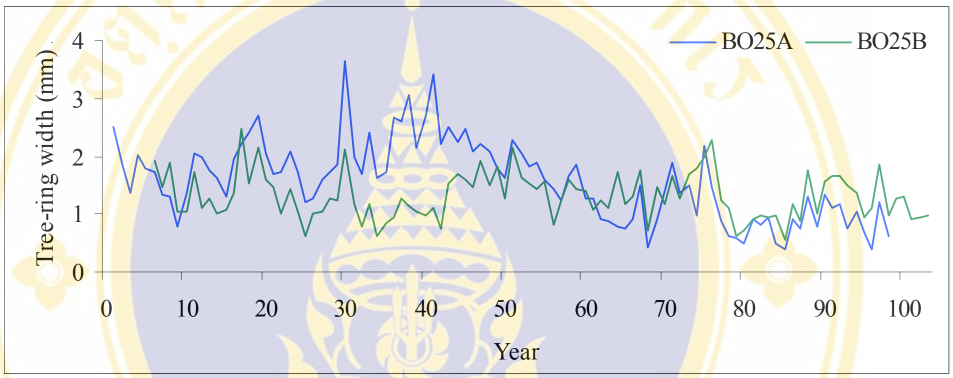

BO20A
BO20B
Tree-ring width (mm)
Year

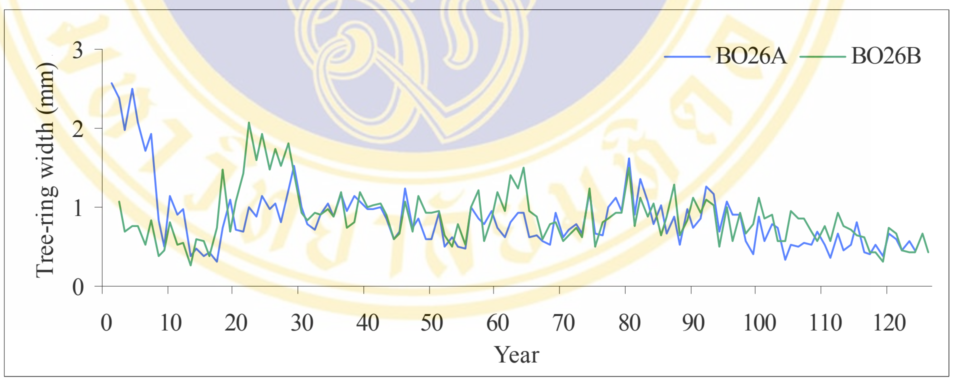

BO21A
BO21B
Tree-ring width (mm)
Year

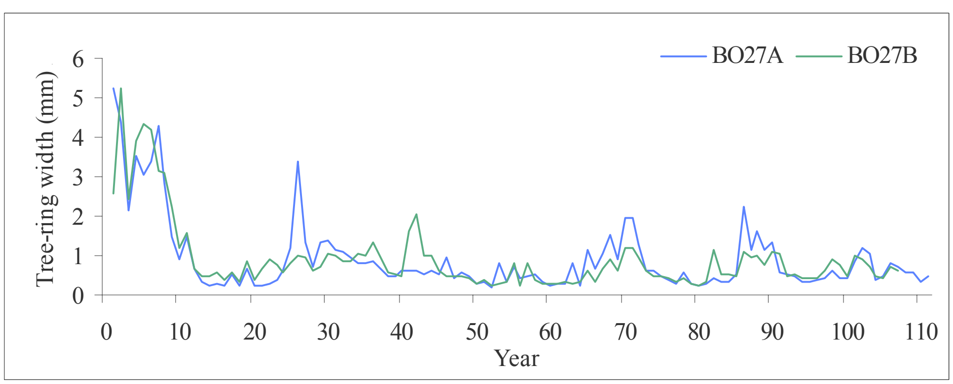

BO23A
BO23B
Tree-ring width (mm)
Year

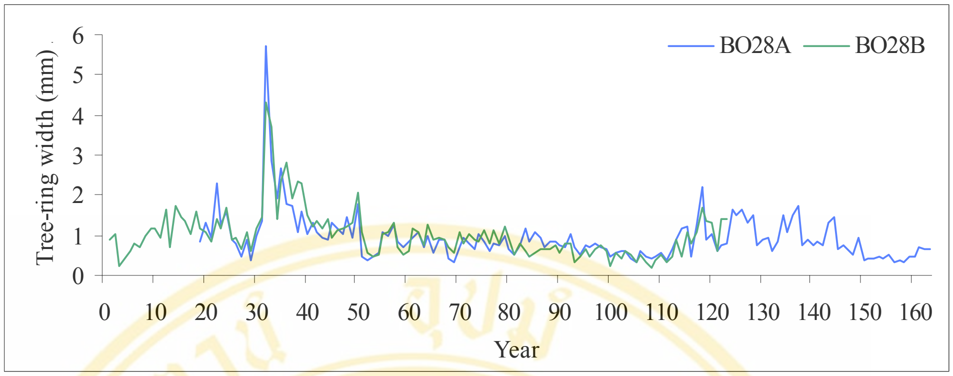

BO22A
BO22B
Tree-ring width (mm)
Year

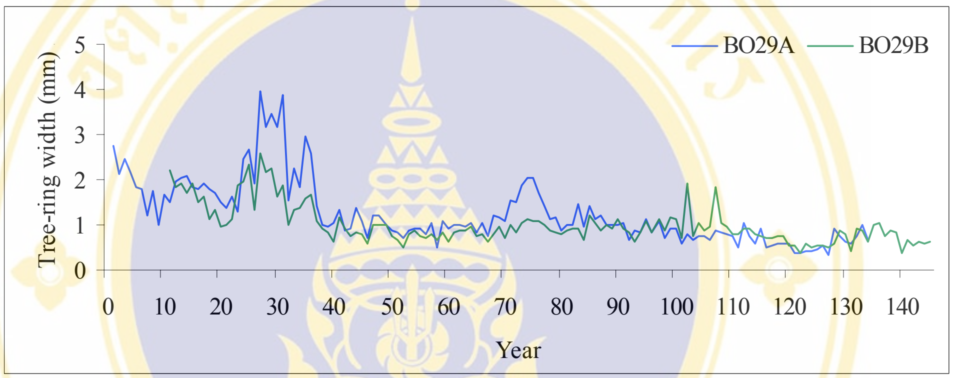

BO24A
BO24B
Tree-ring width (mm)
Year

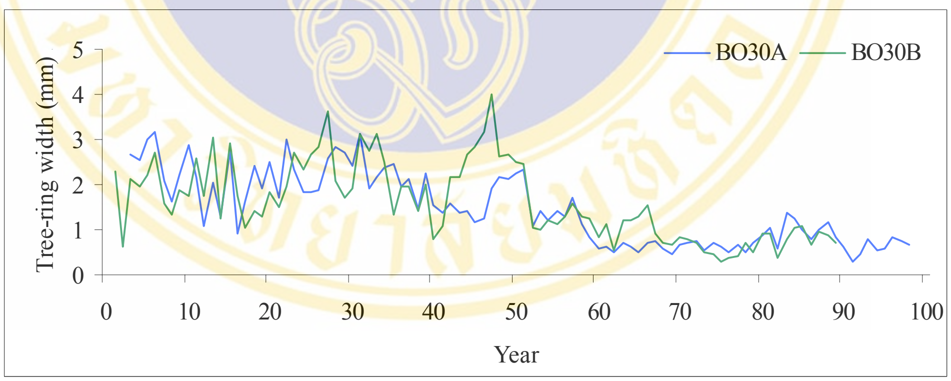

BO25A
BO25B
Tree-ring width (mm)
Year

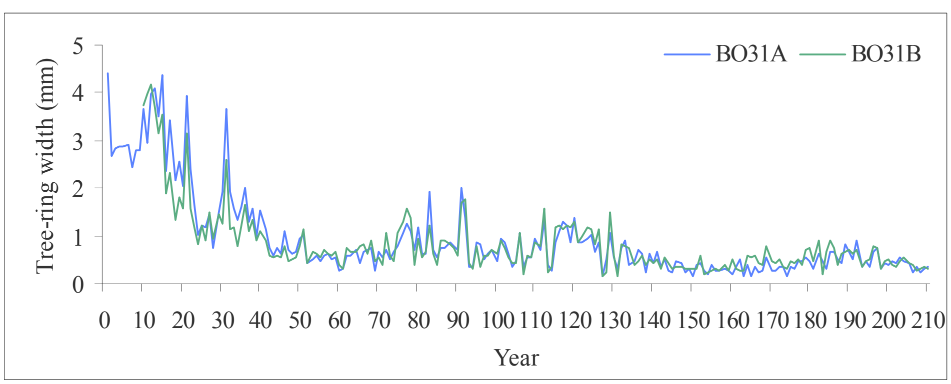

BO26A
BO26B
Tree-ring width (mm)
Year

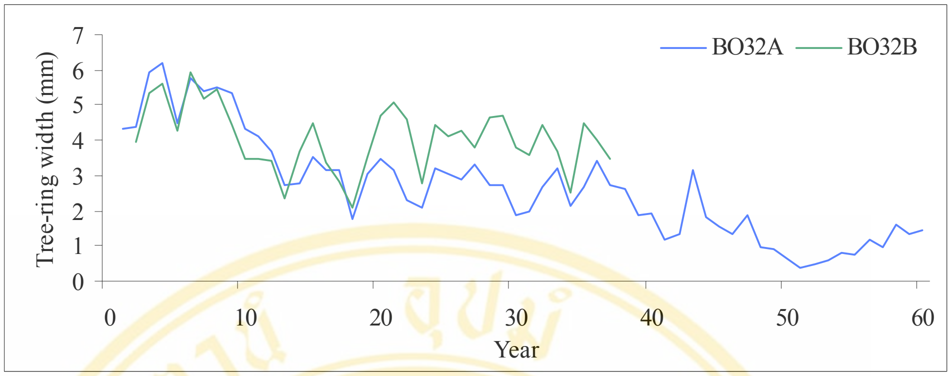

BO27A
BO27B
Tree-ring width (mm)
Year

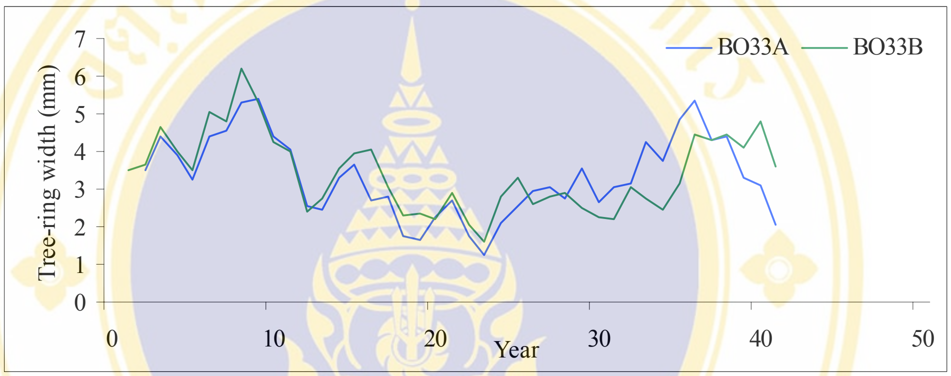

Tree-ring width (mm)
BO28A
BO28B
Year

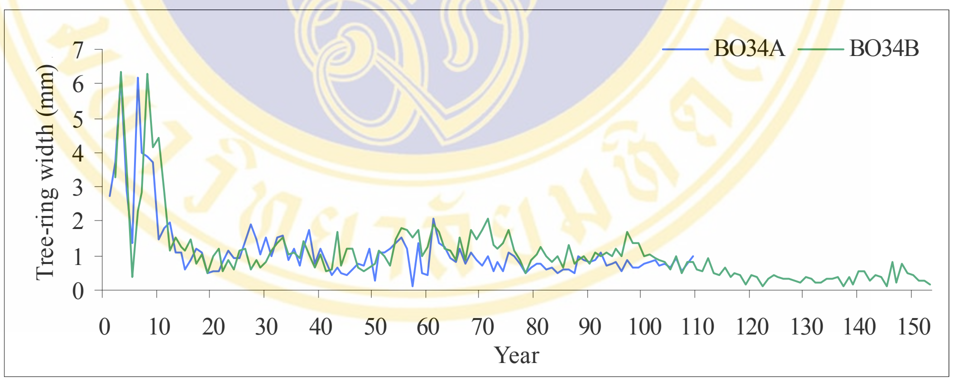

Tree-ring width (mm)
BO29A
BO29B
Year

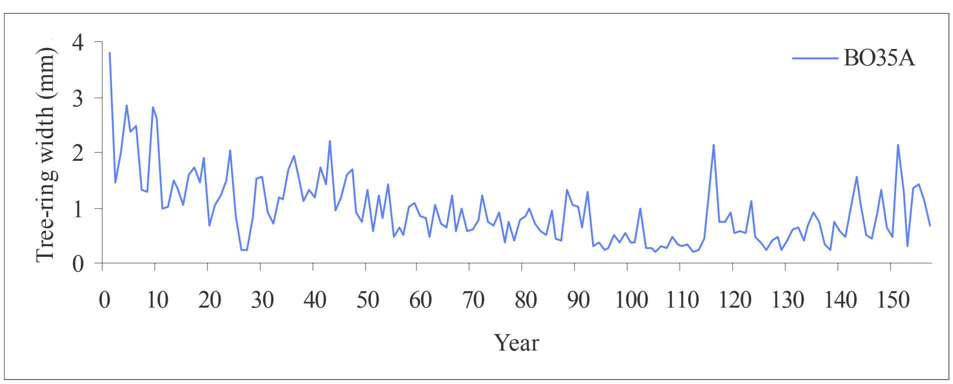

Tree-ring width (mm)
BO30A
BO30B
Year

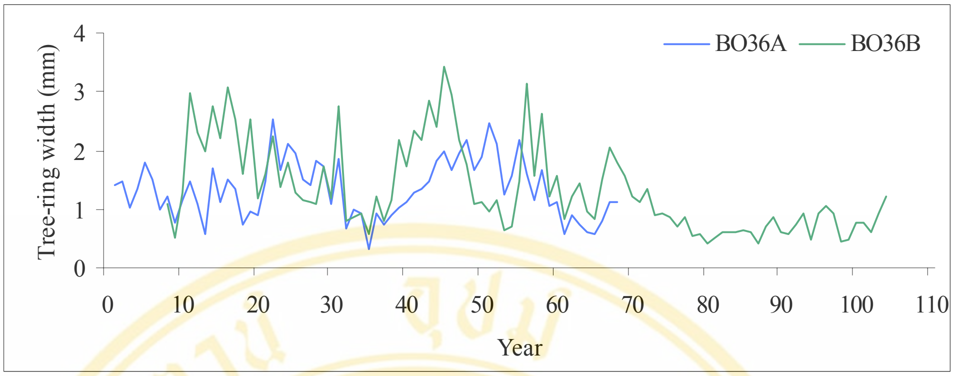

Tree-ring width (mm)
BO31A
BO31B
Year

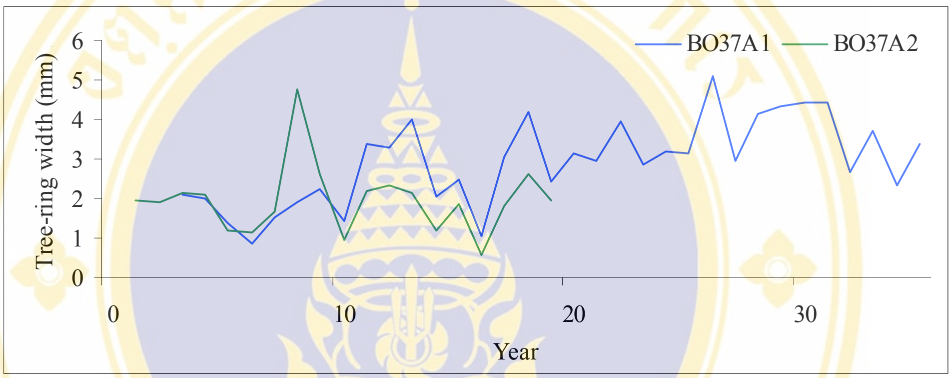

Tree-ring width (mm)
BO32A
BO32B
Year

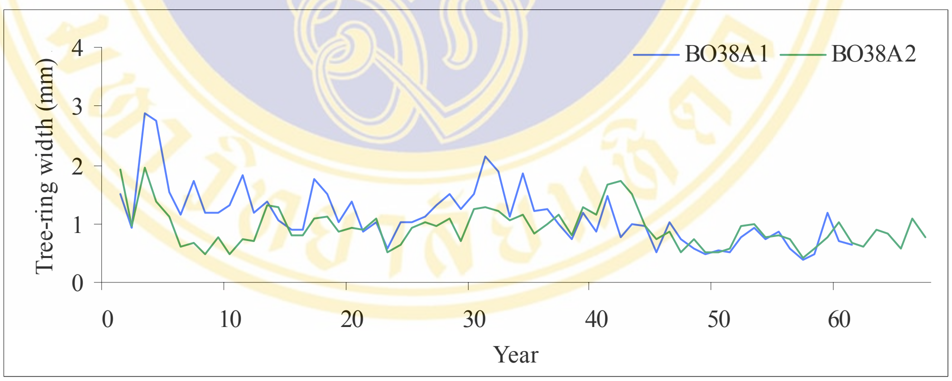

Tree-ring width (mm)
BO33A
BO33B
Year

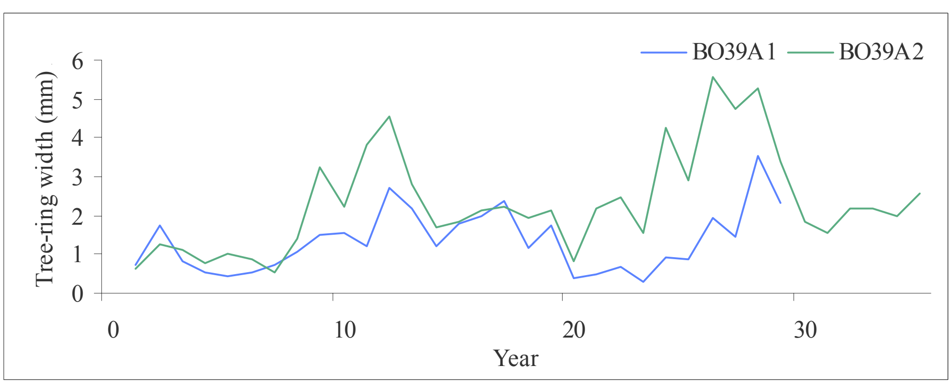

Tree-ring width (mm)
BO34A
BO34B
Year


Tree-ring width (mm)
BO35A
Year

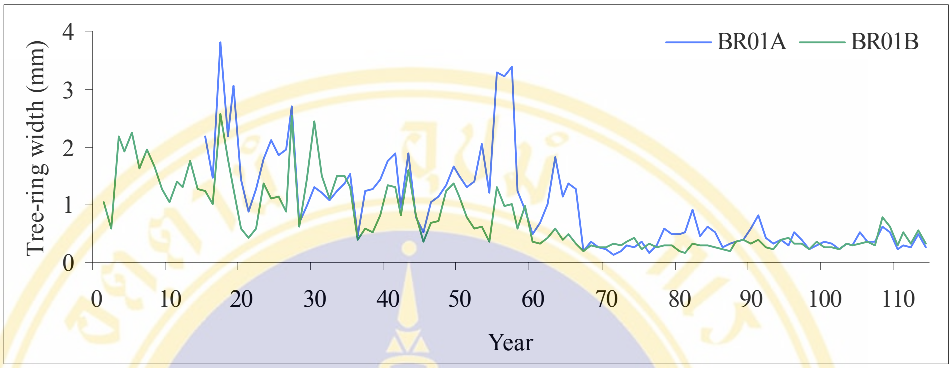

BO36A
BO36B
Tree-ring width (mm)
0
1
2
3
4
0
10
20
30
40
50
60
70
80
90
100
110
Year

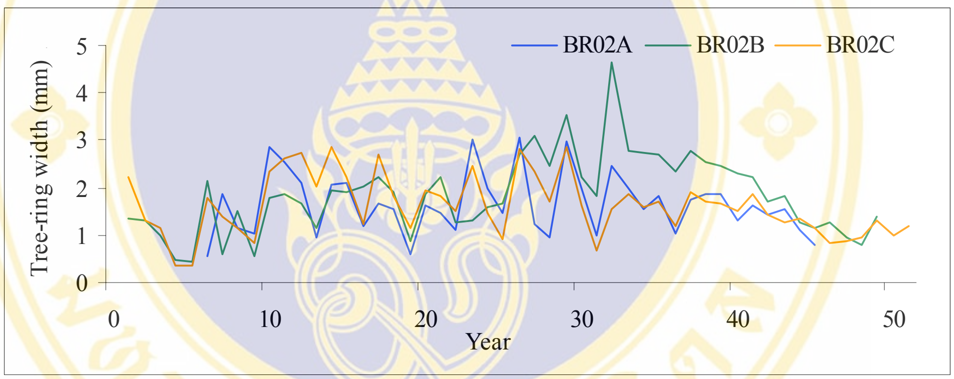

BO37A1
BO37A2
Tree-ring width (mm)
0
1
2
3
4
5
6
0
10
20
30
Year

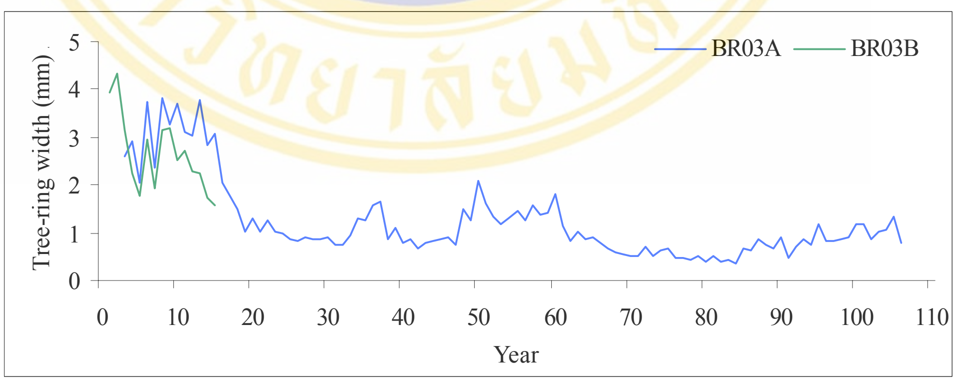

BO38A1
BO38A2
Tree-ring width (mm)
0
1
2
3
4
0
10
20
30
40
50
60
Year

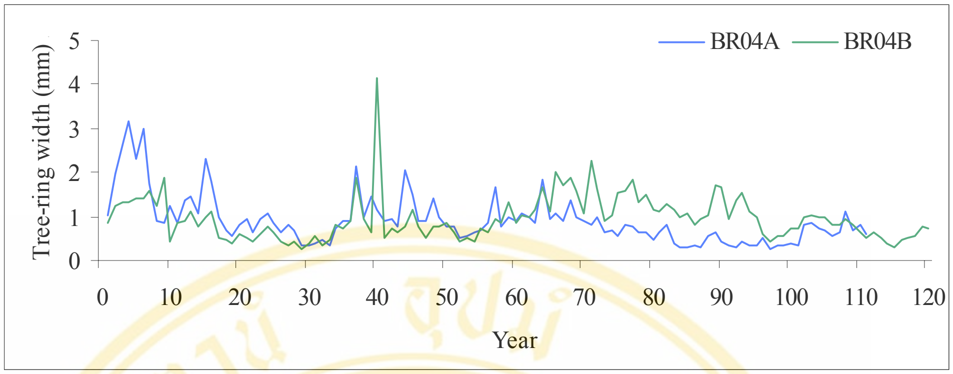

BO39A1
BO39A2
Tree-ring width (mm)
0
1
2
3
4
5
6
0
10
20
30
Year

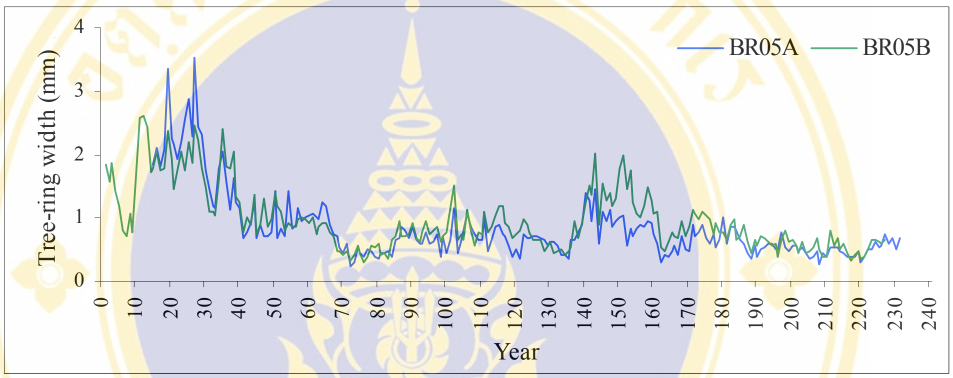
**PART II** The raw data of measured ring width for individual series from Ban Rai Rockshelter, Pang Mapha District, Mae Hong Son Province.

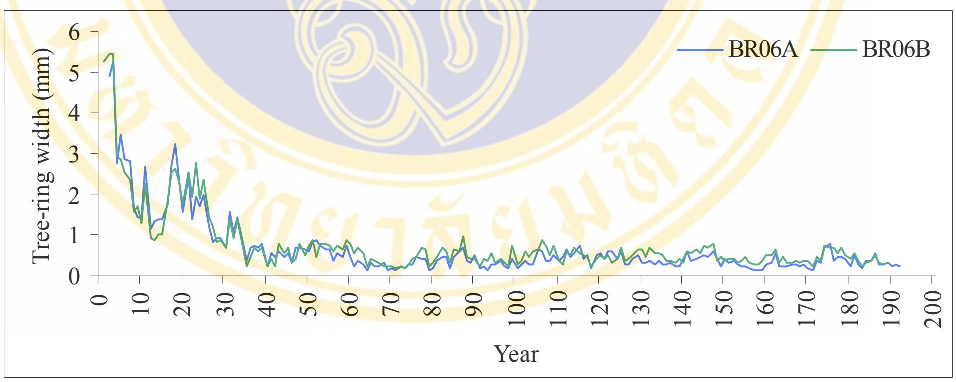


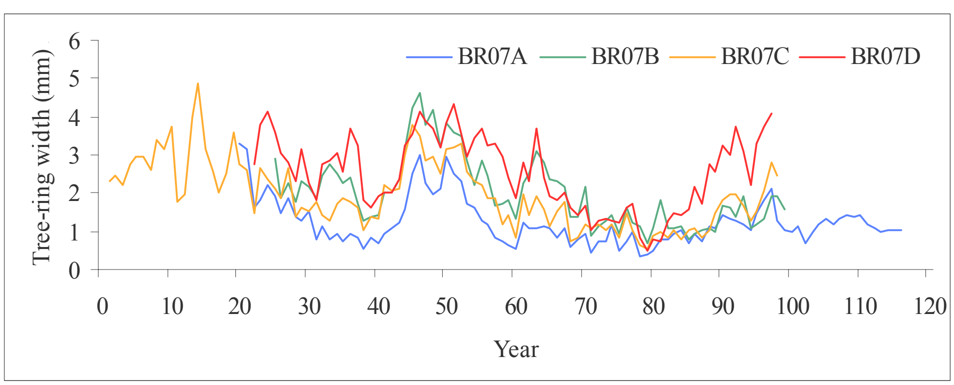



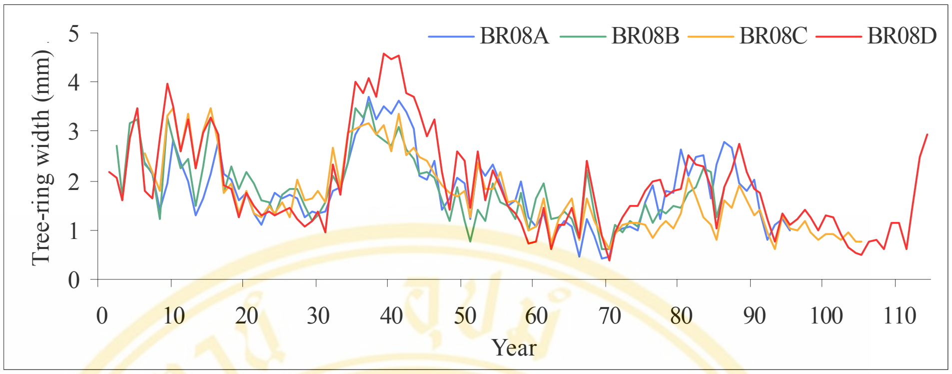



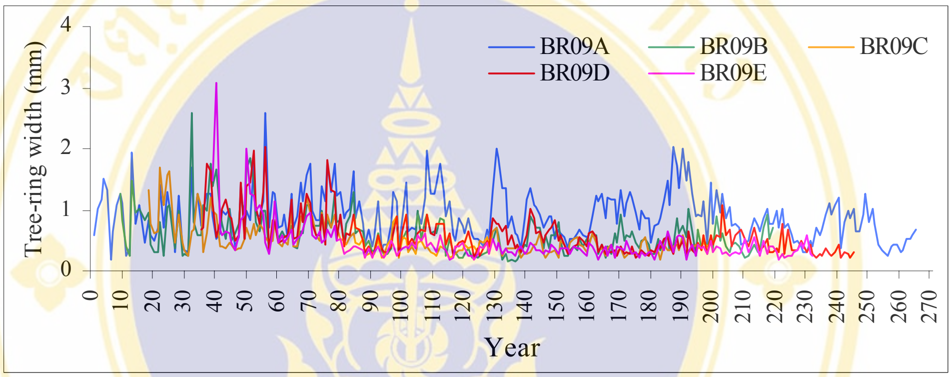

BR04A
BR04B
Tree-ring width (mm)
0 1 2 3 4 5
0 10 20 30 40 50 60 70 80 90 100 110 120
Year

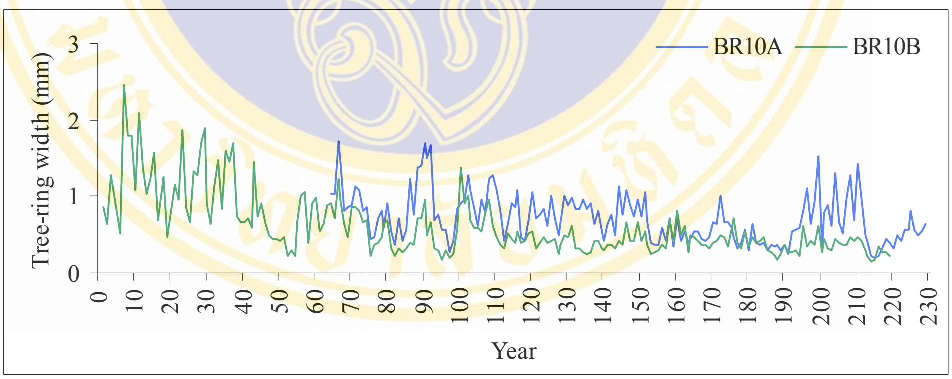

BR05A
BR05B
Tree-ring width (mm)
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240
Year

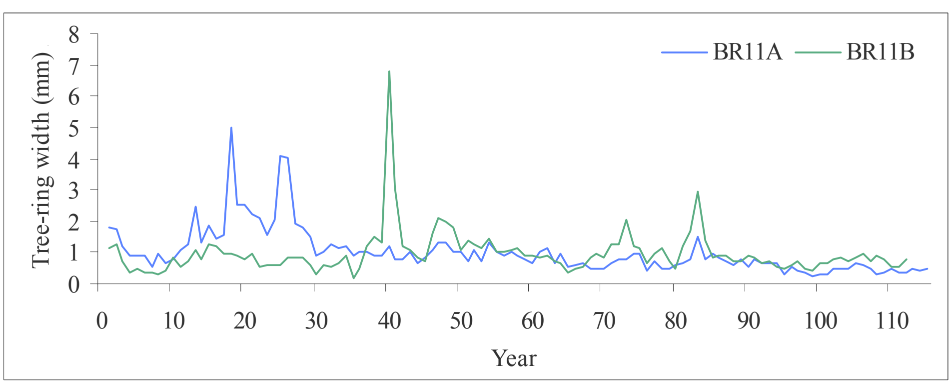

BR06A
BR06B
Tree-ring width (mm)
0 1 2 3 4 5 6
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Year

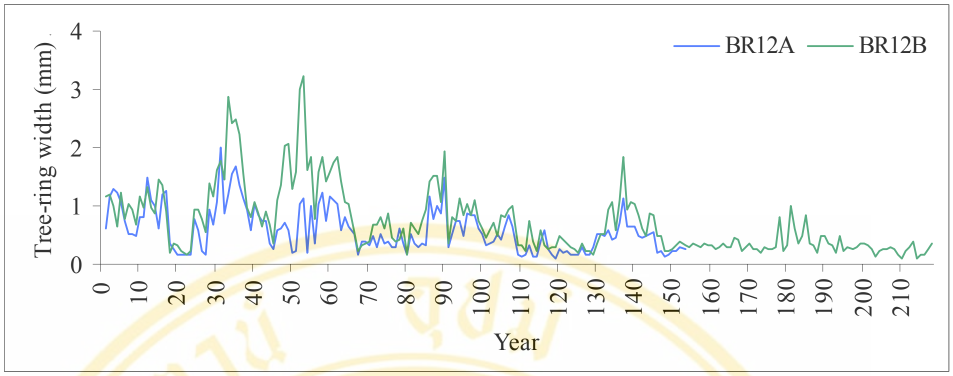

BR07A
BR07B
BR07C
BR07D
Tree-ring width (mm)
0 1 2 3 4 5 6
0 10 20 30 40 50 60 70 80 90 100 110 120
Year

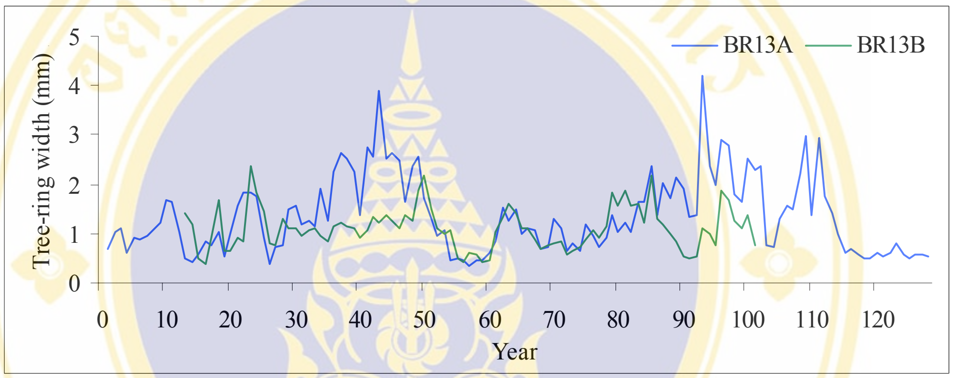

BR08A
BR08B
BR08C
BR08D
Tree-ring width (mm)
Year

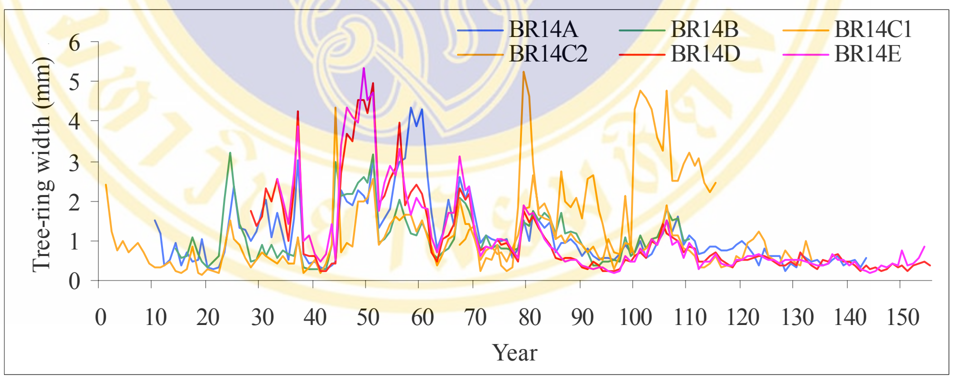

BR09A
BR09B
BR09C
BR09D
BR09E
Tree-ring width (mm)
Year

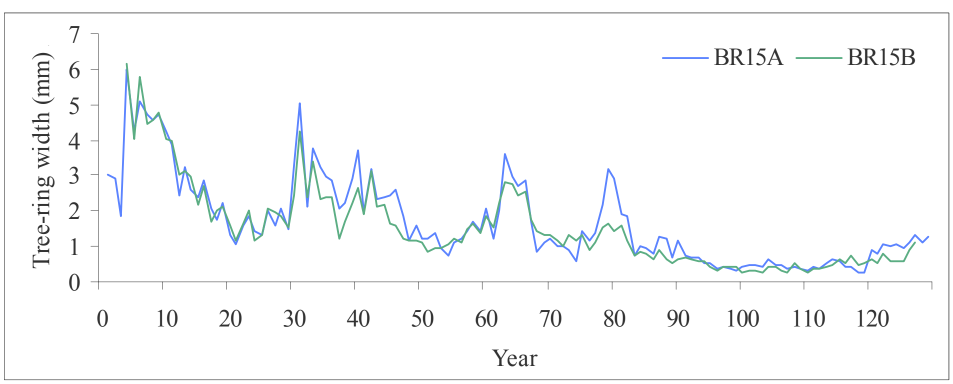

BR10A
BR10B
Tree-ring width (mm)
Year

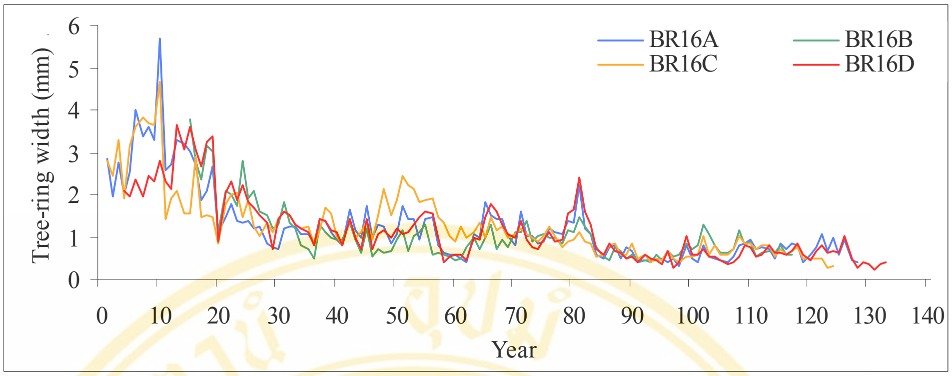

BR11A
BR11B
Tree-ring width (mm)
Year

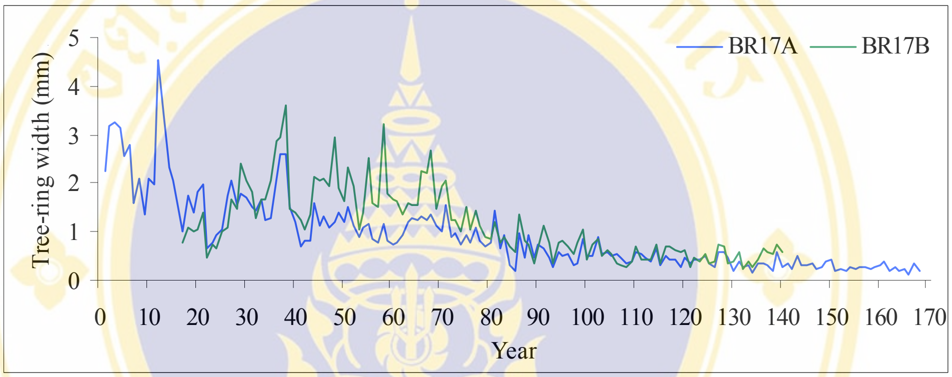

BR12A
BR12B
Tree-ring width (mm)
Year

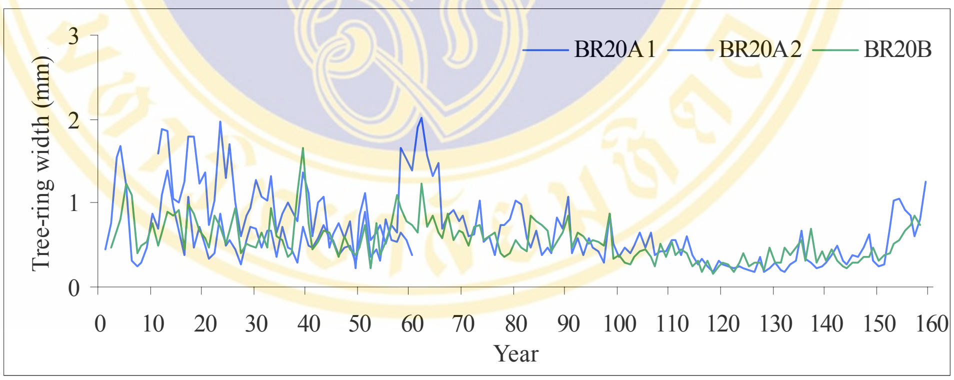

BR13A
BR13B
Tree-ring width (mm)
Year

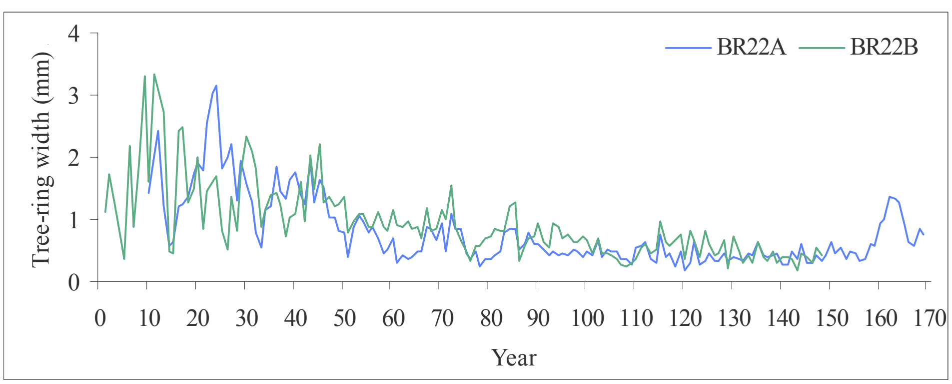

BR14A
BR14B
BR14C1
BR14C2
BR14D
BR14E
Tree-ring width (mm)
Year

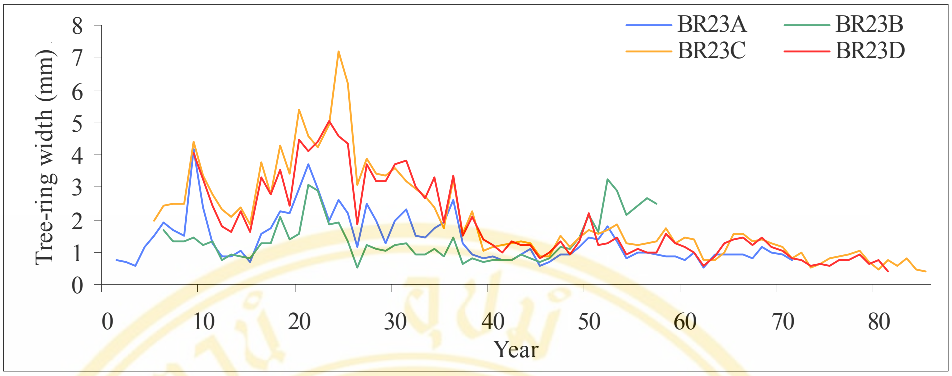

BR15A
BR15B
Tree-ring width (mm)
Year

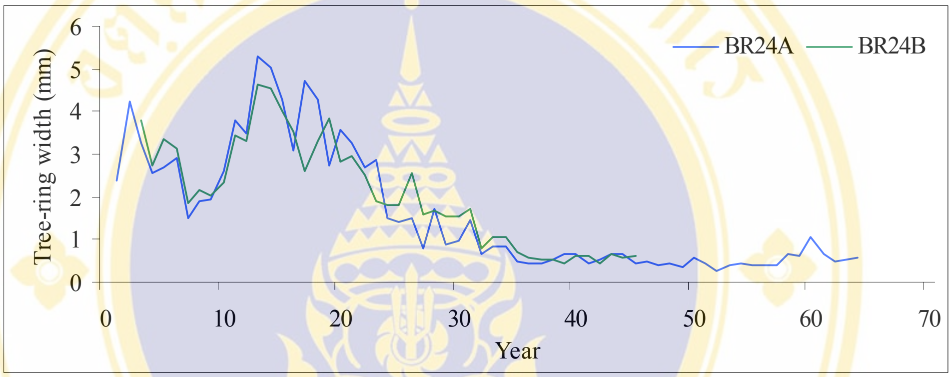

BR16A
BR16B
BR16C
BR16D
Tree-ring width (mm)
Year

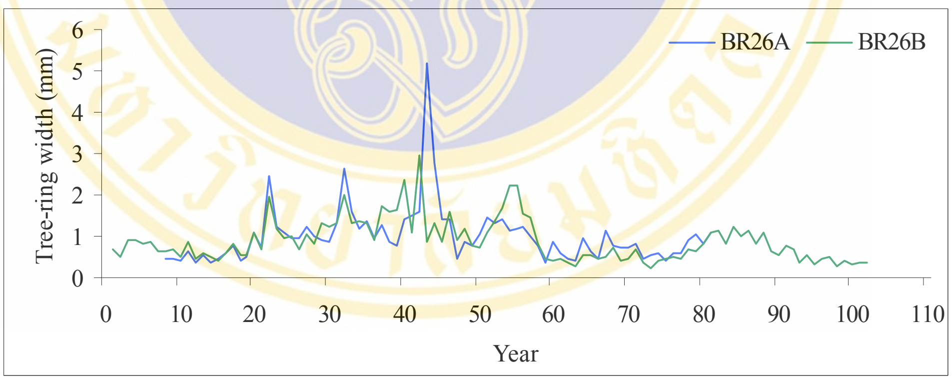

BR17A
BR17B
Tree-ring width (mm)
Year

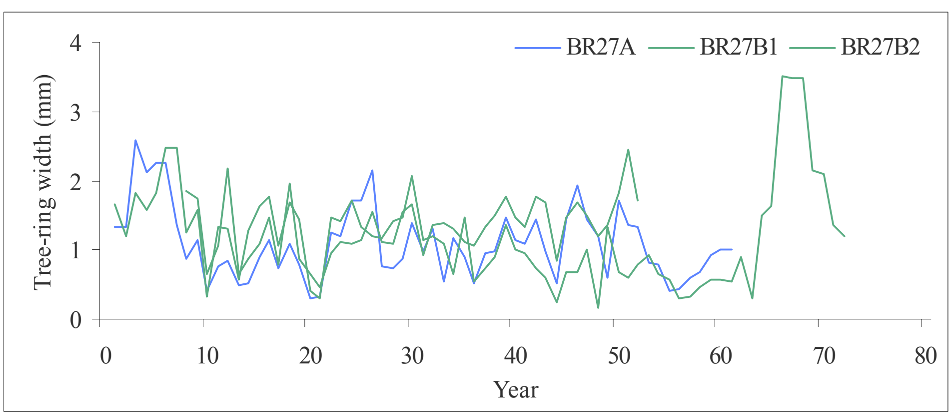

BR20A1
BR20A2
BR20B
Tree-ring width (mm)
Year

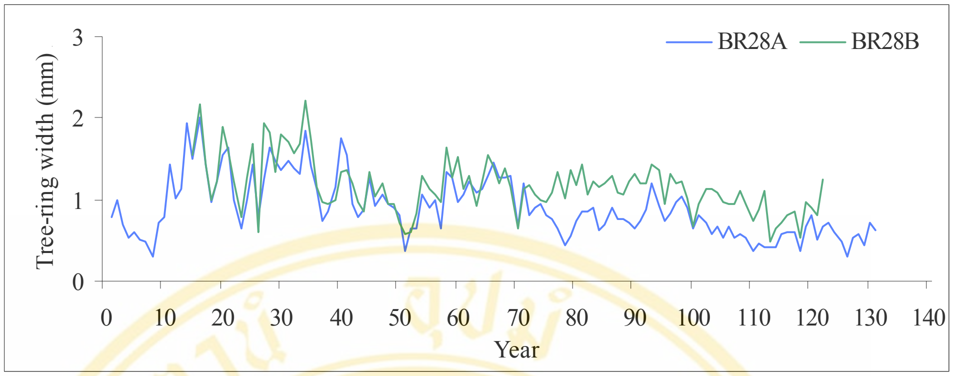

BR22A
BR22B
Tree-ring width (mm)
Year

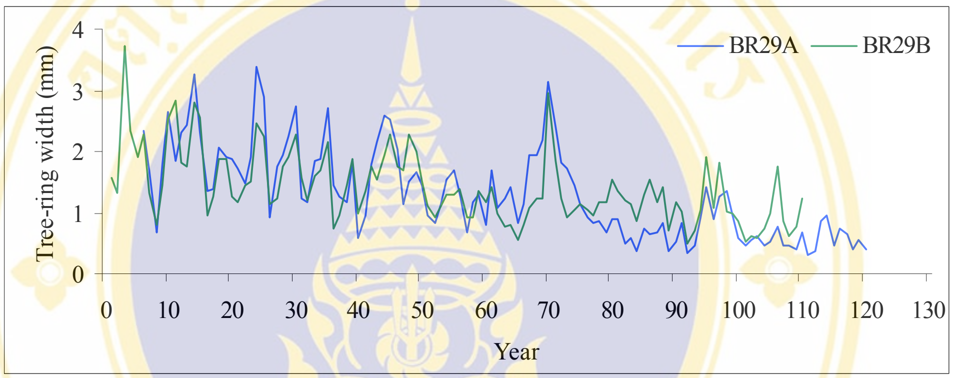

BR23A
BR23B
BR23C
BR23D
Tree-ring width (mm)
Year

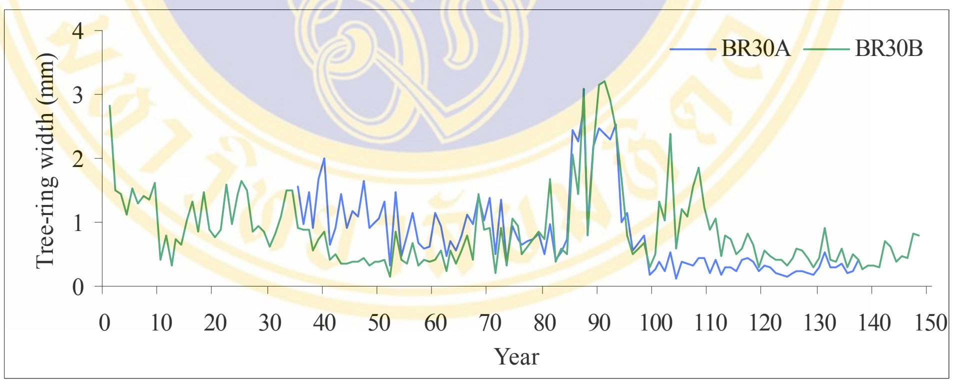

BR24A
BR24B
Tree-ring width (mm)
Year

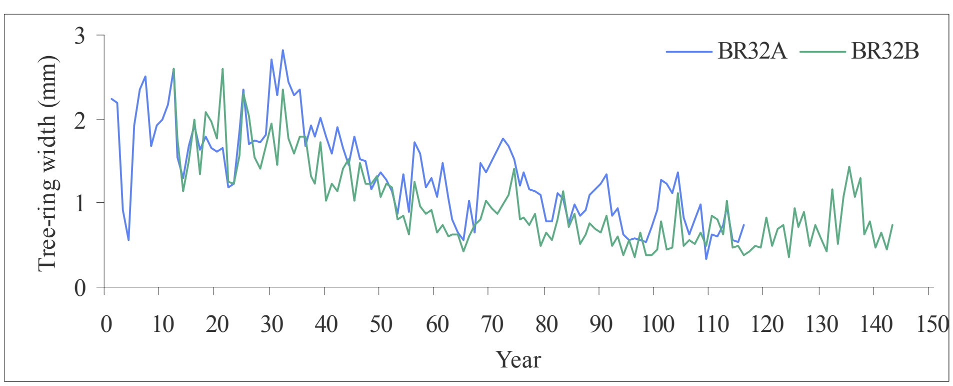

BR26A
BR26B
Tree-ring width (mm)
Year

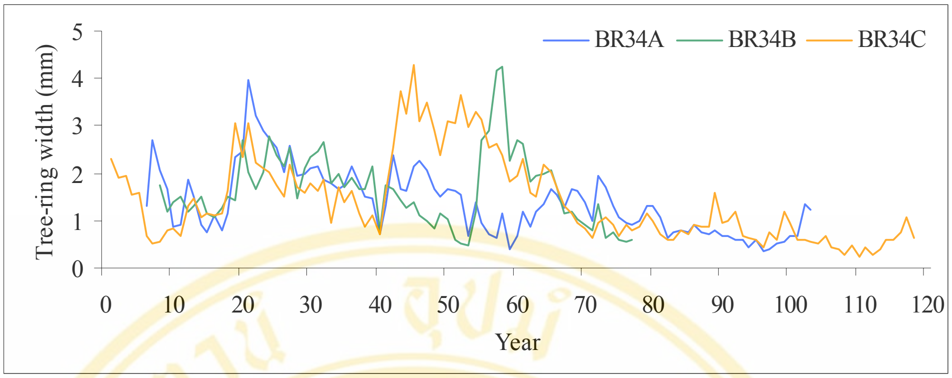

BR27A
BR27B1
BR27B2
Tree-ring width (mm)
Year

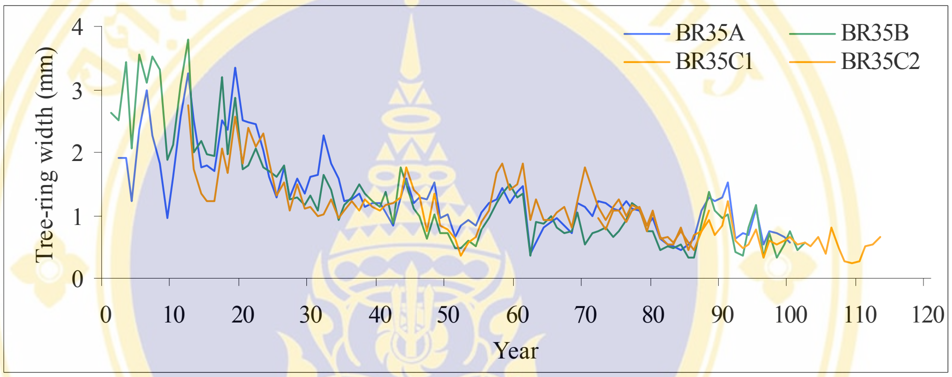

BR28A
BR28B
Tree-ring width (mm)
Year

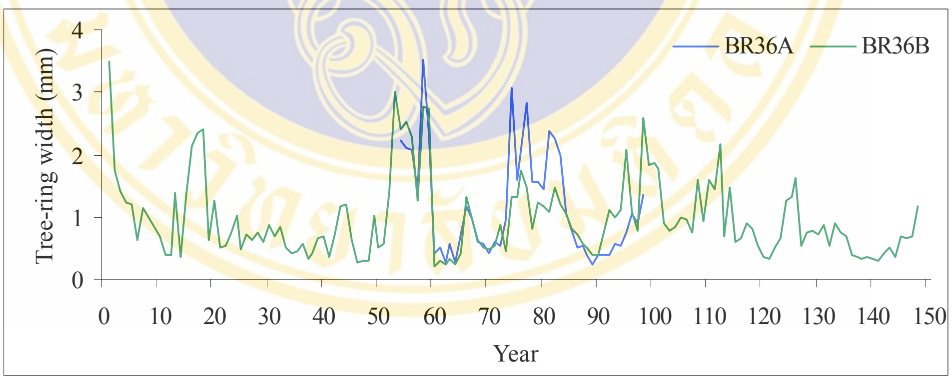

BR29A
BR29B
Tree-ring width (mm)
Year

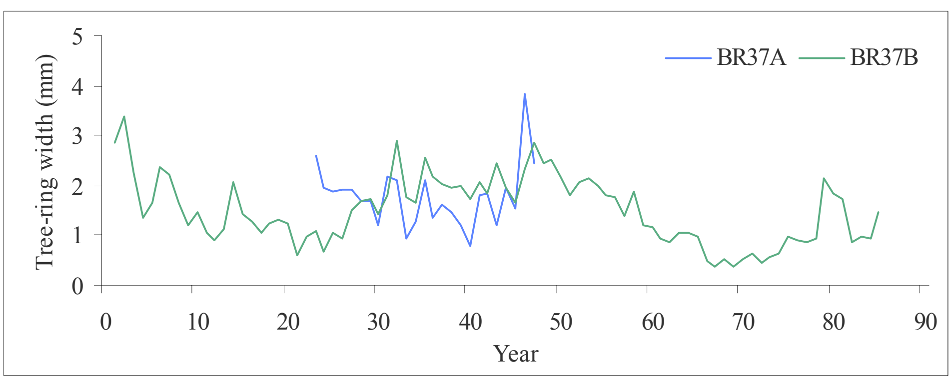

BR30A
BR30B
Tree-ring width (mm)
Year

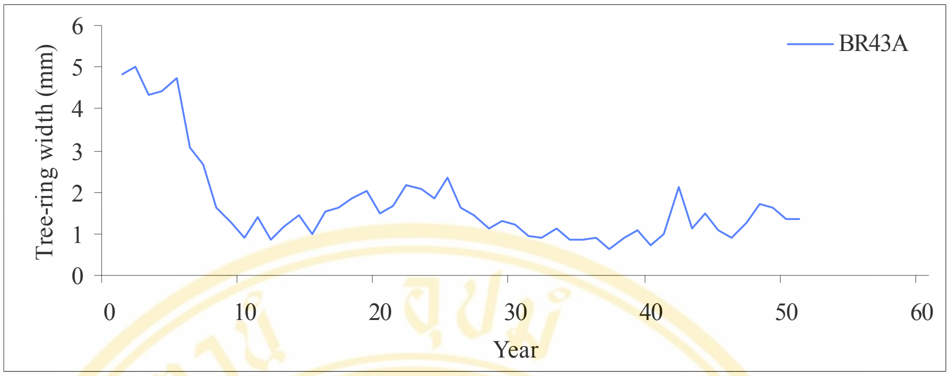

BR32A
BR32B
Tree-ring width (mm)
Year

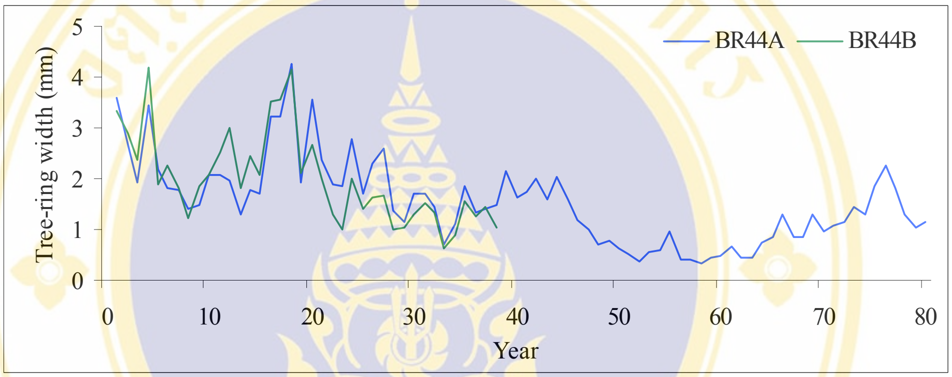

BR34A
BR34B
BR34C
Tree-ring width (mm)
Year

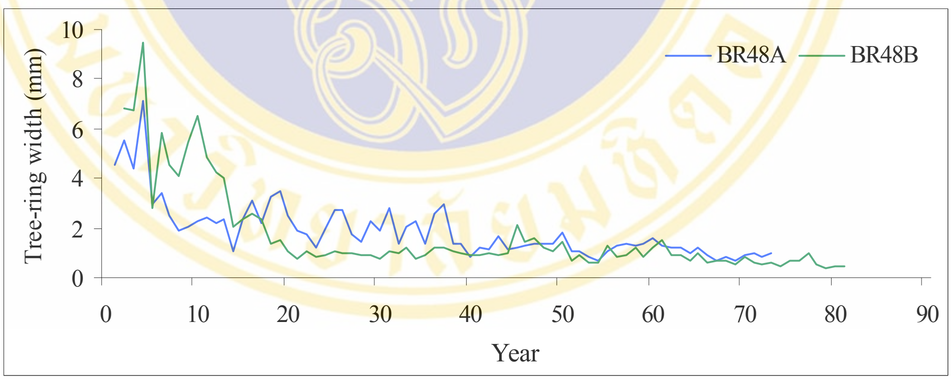

BR35A
BR35B
BR35C1
BR35C2
Tree-ring width (mm)
Year

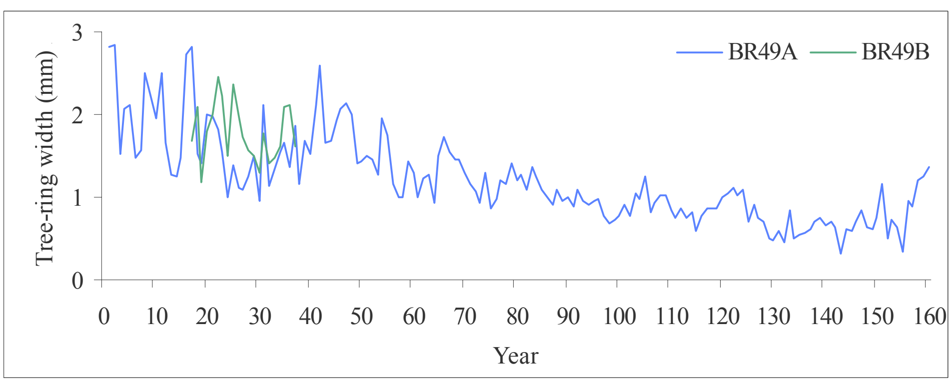

BR36A
BR36B
Tree-ring width (mm)
Year

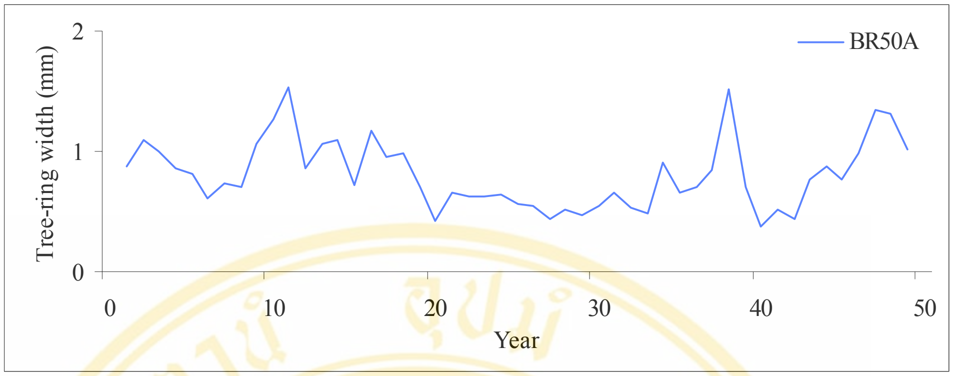

BR37A
BR37B
Tree-ring width (mm)
Year

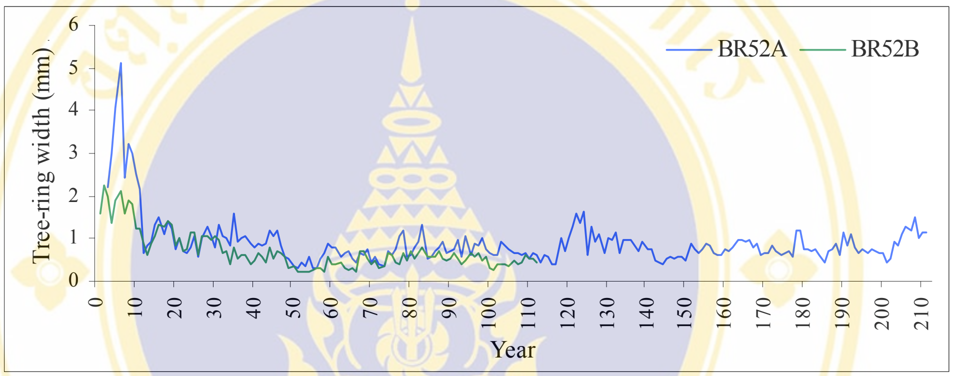

BR43A
Tree-ring width (mm)
Year

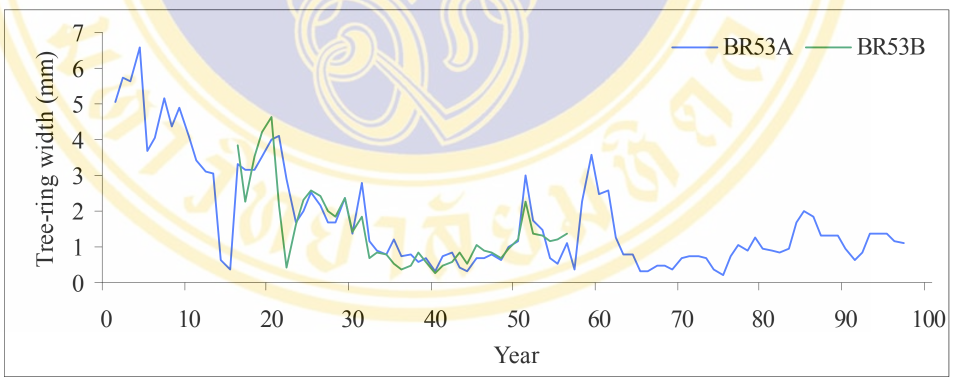

BR44A
BR44B
Tree-ring width (mm)
Year

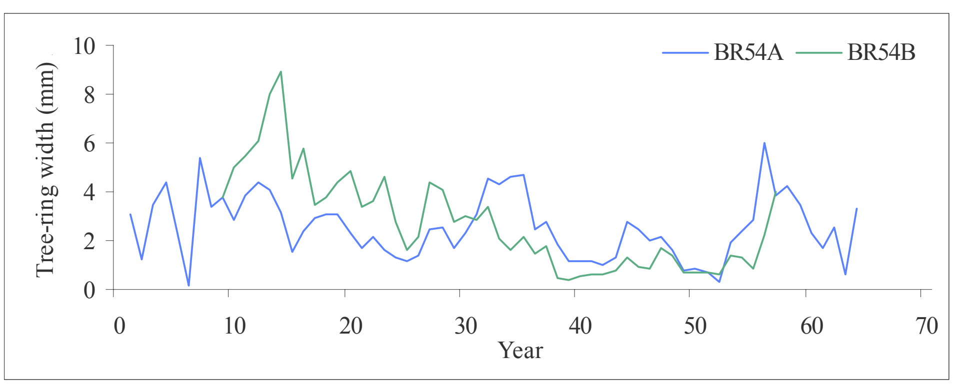

BR48A
BR48B
Tree-ring width (mm)
Year


BR49A
BR49B
Tree-ring width (mm)
Year


BR50A
Tree-ring width (mm)
Year


BR52A
BR52B
Tree-ring width (mm)
Year


BR53A
BR53B
Tree-ring width (mm)
Year


BR54A
BR54B
Tree-ring width (mm)
Year

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