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^{14}C DATING OF HISTORICAL BUILDINGS IN JAPAN

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ABSTRACT. The radiocarbon dating method was applied to the study of Japanese traditional wooden buildings. The traditional Japanese architecture studied includes the Main Hall of Banna-ji Temple (Buddhist building), Sekisui-in of Kozan-ji Temple (noble house), Hakogi-ke house (farmhouse), and Kawai-ke house (townhouse). ^{14}C dating proved useful as a research method to better understand the history of these buildings and Japanese architecture as a whole.

INTRODUCTION

Traditional Japanese buildings are examples of religious architecture (temple, shrine, mausoleum), upper-class residences (noble samurai residence), homes of common people (farmhouse, townhouse), and ceremonial facilities (castle, tea room, government office). The lead author has been involved in research on Japanese architecture, particularly the history of farmhouses. Most of the traditional farmhouses of Japan were built in the early modern period (16th–19th century AD). Architectural history researchers postulate approximate times when these farmhouses were built, using the chronological style based on the change in development of their design and structure. For those buildings for which there are records of construction, we have documentation to determine the developmental history of building, and can thus develop a chronology of the wood structure and the design. However, there remain fewer building records as we go back in time (Nakao 2007a). The aim then becomes to determine the date of construction for those wooden buildings without surviving records by developing the chronologies of architectural development.

In 2004, we launched a research project of ^{14}C dating of historical buildings as a first attempt in Japan (Imamura 2005). This project applied ^{14}C dating to religious buildings (Nakao et al. 2012; Nakao and Sakamoto 2013), upper-class residences (Nakao and Sakamoto 2011), common people's houses (Nakao 2008; Nakao et al. 2012), and citadels (Nakao and Imamura 2008). We also developed a method of selecting wood members for dating and a method of interpreting analytical results appropriately.

At first, many government officials in charge of preserving cultural assets were hesitant about the application of ^{14}C dating because they thought that sampling for ^{14}C dating would damage the cultural assets. With the accumulation of our research results, however, they gradually understood that ages could be determined accurately with very small samples for accelerator mass spectrometry (AMS). Now in the research of Japanese historical buildings, ^{14}C dating is increasingly being recognized as a reliable method. This article describes the significance of ^{14}C dating of Japanese historical buildings, and introduces four typical study cases of a temple, residence, farmhouse, and urban house.

METHODS

The steps employed for studying the age of a historical building are described below. The full dating results are presented in the Appendix (online supplemental file).

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Gathering Information on the Building

Before conducting a field survey, available data on the building are collected. In addition to basic information such as the type, owner, manager, location, and status of the building and whether the building is designated as a cultural asset, historical information including historical records and legends, and architectural information such as repair records, plan views, and sectional views are collected.

Selection of Samples

When studying the age of a wooden building, the selection of a sample for dating is most important. The requirements for a suitable sample in this study are (1) the sample is wood used at the time of construction of the building; (2) bark is included in the sample; and (3) the sample contains enough tree rings to allow wiggle-matching.

If the wood is derived from a tree cut down at the time of construction, its age obtained by ^{14}C dating is the age of construction. We use a restoration method based on traces of repairs to judge whether the wood was used at the time of construction. An old wooden building must have experienced many repairs and modifications since it was built. Holes and scars left on wooden parts are traces of repairs and modifications conducted in the past. By observing the status of columns and beams and checking holes and scars, we differentiate samples that were originally used from wood that was added later during repairs. Based on the differentiated samples, and holes and scars left on them, we can reconstruct the initial form of the building, its first modified form, later modified forms, and repairs made in recent years. The method of reconstructing the initial form of the building from traces left on wooden parts, as described above, is called the "trace-based restoration method." This method was developed after World War II by researchers of Japanese architectural history to study wooden buildings (Cultural Properties Protection Committee 1967).

If the outermost tree ring of the sample is adjacent to bark or cambium, the age of the outermost layer represents the age when the tree was cut down. Therefore, preferably the sample should contain bark or the tree ring adjacent to the bark. The next preferable state is presence of sapwood in the sample. Even if the sample does not contain a surface adjacent to bark or sapwood, as in the case of boxed heart timber with large ring intervals, it may be possible to estimate the number of tree rings scraped off during lumbering within a dozen of years or so.

Wiggle-matching is effective for determining the calibrated age of the outermost ring of the sample. To increase the number of samples dated while keeping the cost of analysis low, ^{14}C ages are determined at about three points in each sample as a guide (Imamura and Nakao 2007).

Sample Investigation and Sampling

The samples selected are first photographed. Then, the characteristics of each sample are recorded, including the type, dimensions, tree species, number of rings, presence or absence of sapwood, average ring interval, traces, and the extent of contamination visually checked. From the number of rings and using a calibration curve, sampling points suitable for wiggle-matching are determined.

Sampling wooden structures can be conducted in three different ways: sampling in a laboratory from a supplied block wood sample, sampling from a piece dismantled at a site of repair work; and sampling under the floor or in the attic of a standing building. Sampling in a laboratory is most preferable because of the suitable laboratory conditions to prevent contamination during sampling. When collecting a small amount of wood sample directly from a dismantled piece that had been placed in a building material yard, although it is relatively easy to count tree rings on an exposed

butt end, care must be taken to avoid contamination during sampling. The most unfavorable condition is collecting a sample from a standing building. Because pieces are assembled, their butt ends are mostly unexposed, prohibiting observation of tree rings. Samples are therefore collected from straight-grain of flat-grain surfaces. Due care must be exercised to avoid contamination and incorrectly counting the rings.

Each sample is collected across five rings. The sampling surface is cleaned with a brush and marked with pins at intervals of 10 rings, and a sample is collected by carving an appropriate area with an engraving knife. The collected sample is wrapped in aluminum foil and sealed in a zipper bag on which the sample number is written. This is sent to the dating laboratory. At the laboratory, they pretreat the sample and conduct accelerator mass spectrometry (AMS) ^{14}C dating (Nakao 2011).

Age Estimation of the Building

The age of the outermost tree-ring layer in each analyzed sample is first determined. If bark or sapwood is left in the analyzed pieces, and if the age of the outermost layer is mostly the same for each sample, it can be estimated that the building was constructed at an age close to the age of the outermost layer. If different ages are found in the outermost layers of different members within one building, a number of hypotheses are suggested. If there are initial pieces prepared at the time of construction and auxiliary members added later at the time of repair, the age of the outermost layer of the older one represents the construction age of building. On the other hand, if there are initial samples prepared at the time of construction and reused members obtained from an older building, the age of the outermost layer of the newer one represents the construction age of the building. The ^{14}C-dating results are then discussed with repair work managers, local history researchers, and archaeologists.

RESULTS

In the following, four typical studies of Japanese historical wooden buildings are described.

Main Hall of Banna-ji Temple

Banna-ji Temple is located in Ashikaga City, Gunma Prefecture, in the north of Tokyo. It is a temple associated with the Ashikaga clan who founded the Muromachi Shogunate. The Main Hall of Banna-ji Temple (Figure 1), an important cultural property, is a large enshrinement hall constructed in 1299 that underwent major repairs from 1407 to 1432. Later, the roof was rethatched, the Buddhist altar was enlarged, and the *gohai* (a roof built over the steps leading up to the temple building) in the front and back side of the building was extended several times: in the 16th century, around 1600, around 1700, the first half of the 18th century, and in the 1850s. The roof was rethatched and the building was partly repaired in 2009 and 2010, and this opportunity allowed carrying out the survey with ^{14}C dating for the Main Hall of Banna-ji Temple.

Ten wooden members were dated: an old architrave diverted to a member of the roof (1) (Figure 2); an old rafter discovered in the attic (2); part of the old shaft that was diverted to a door stopper (3); a horizontal brace in the gable in the east side (currently in the same position) (4); a girder (currently in the same position) (5); a cross-piece of the capital part (currently in the same position) (6); an abacus (currently in the same position) (7); a capital (currently in the same position) (8); a molding (currently in the same position) (9); and a tie beam (currently in the same position) (10). Sample pretreatment and ^{14}C measurement by AMS was conducted by Paleo Labo, Co. Ltd., Japan. As the result of an analysis of wiggle-matching onto IntCal09 (Reimer et al. 2009) using our own calibration program (Sakamoto 2012), it was revealed that samples (1), (6), (7), (8), and (9) were building

Figure 1 Main Hall of Banna-ji Temple, the Middle Ages temple which was appointed to a national treasure by dating research.

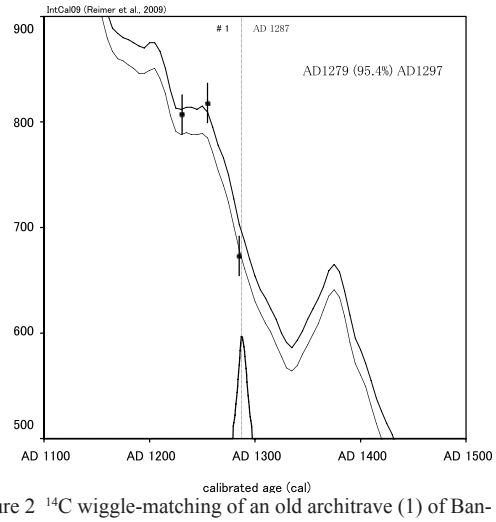

Figure 2 ^{14}C wiggle-matching of an old architrave (1) of Banna-ji Temple.

materials from the end of the 13th century and (2), (3), (4), (5), and (10) were materials used for repairs in the 15th century.

Through an architectural survey and ^{14}C dating, it was proven that Banna-ji was the oldest Zen-style Buddhist temple in eastern Japan, in which the latest architectural style of the Kamakura period was adopted (Ueno and Nakao 2012). Because of the high value of the Main Hall of Banna-ji Temple, the Japanese Government designated it a national treasure in 2013. We thus achieved a breakthrough result: ^{14}C dating enhanced the value of the protected building and had an impact on the designation of a cultural property by the national government.

Sekisui-in Sub-Temple of Kozan-ji Temple

Kozan-ji Temple, a national treasure, is located in the suburbs of Kyoto City. It was restored by Myoe Shonin, a famous Buddhist philosopher, in 1206. The only building remaining in Kozan-ji Temple is Sekisui-in Sub-Temple (Figure 3), which was thought to be Myoe Shonin's priest lodge. In the old material survey associated with the repairs in 2009 and 2010, we carried out ^{14}C dating on two shingles. Sample pretreatment and ^{14}C measurement by AMS was conducted by Paleo Labo. For the outermost annual ring layers, one (1) was dated to cal AD 1046–1075 and the other (2) was from cal AD 1191–1224 (Figure 4). There was no sapwood in either of them, and the materials were identified as Japanese umbrella pine cut down after the first half of the 13th century. The architectural survey discovered that the shingles were used in the roof of the west corridor, and these long shingles had the possibility of tracking back to 1235 yr when the west corridor was established. This was consistent with the result of ^{14}C dating, providing evidence that Sekisui-in was constructed in the mid-Kamakura period, the age of Myoe Shonin (Nagai et al. 2012).

Hakogi-ke House

Hakogi-ke House (Figure 5) is an important cultural property located in the suburbs of Kobe City. It is said to be Japan's oldest farmhouse in existence today, and records show that it was an especially old house as it was already called Sennen-ya ("thousand-year-old house") around 1700. The building date of Hakogi-ke House cannot be estimated based on similar cases because there is no other house of the same age, but the house is considered to have been built in the Middle Ages according

Figure 3 Sekisui-in Sub-Temple of Kozan-ji Temple, a noble house of the Middle Ages (courtesy of Kozan-ji Temple).

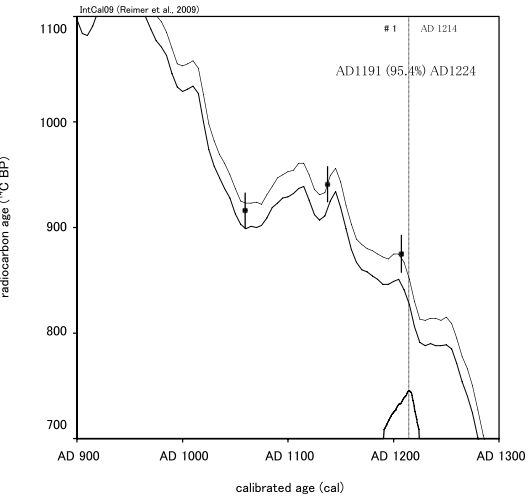

Figure 4 ^{14}C wiggle-matching of shingle (2) of Sekisui-in Sub-Temple.

to the building techniques and the conditions of the wood samples, and to have been built around the 15th century according to the Hakogi family tree. So, ^{14}C dating was carried out for wooden pillars and beams of Hakogi-ke House to confirm and clarify the historical dating. Sample pretreatment and ^{14}C measurement by AMS were conducted by Beta Analytic (Miami, USA) and YU-AMS of Yamagata University, Japan. Calibrated ages of the outermost tree ring ranged from about the 13th to 14th century AD. All are pine with a large ring width and a center core with fewer annual rings. The pillar (6) has a surface area where the tree bark was removed, and the data obtained from the ^{14}C dating (cal AD 1281–1307, 1374–1387) was very close to the date when the tree was cut (Figure 6).

The obtained results of Hakogi-ke House correspond to the late Kamakura period, which is 100 or more years older than the previous estimate based on old documents and the family tree. However, an earthen bowl that had been buried for building ceremony was excavated from the basement of the house, and estimated to be from the late 13th century by pottery typology, coinciding with ^{14}C

Figure 5 Hakogi-ke House, the oldest farmhouse in Japan

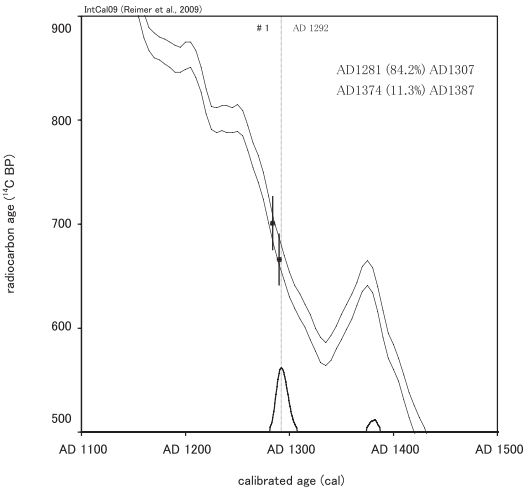

Figure 6 ^{14}C wiggle-matching of pillar (6) of Hakogi-ke House.

dating. The building of Hakogi-ke House dating back to the Kamakura period confirmed it as the oldest farmhouse in Japan (Nakao 2007b).

Kawai-ke House

Kawai-ke House (Figure 7) is a townhouse in Kyoto City built along the Nishi-no-Kyo street. An ancestor of the Kawai family was a lower-class Shinto priest of Kitano-jinja shrine that was active in the Middle Ages. Kawai-ke House has an oral tradition stating that the house was built in 1467 and major reconstruction was carried out from 1711 to 1716. Since Kyoto had long been a Japanese capital and a field of battle countless times, only remains from after the 18th century had been confirmed with respect to townhouses in Kyoto. With a view to verifying the oral tradition, ^{14}C dating was carried out for pillars, a lintel, and a ceiling joist. Sample pretreatment and ^{14}C AMS measurement was conducted by Paleo Labo.

Although wiggle-matching was applied for only one sample, the calibrated ages of the outermost tree ring were between the 16th century and the first half of the 17th century. The time lag between the revealed dates and the dates when the trees were cut down is estimated to be small, because these samples contain sapwood or are considered to be close to the cambium. The calibrated age of the ceiling joist suggests a lower limit of the building date of Kawai-ke House of the first half of the Edo period (Figure 8), which means the house was not built in 1467. Nonetheless, as the conditions of the townhouses in Kyoto before the 18th century had been unknown, Kawai-ke House represents the oldest townhouse in Kyoto with an important historical and cultural value (Nakao and Nagai 2013).

Figure 7 Kawai-ke House, the oldest townhouse in Kyoto

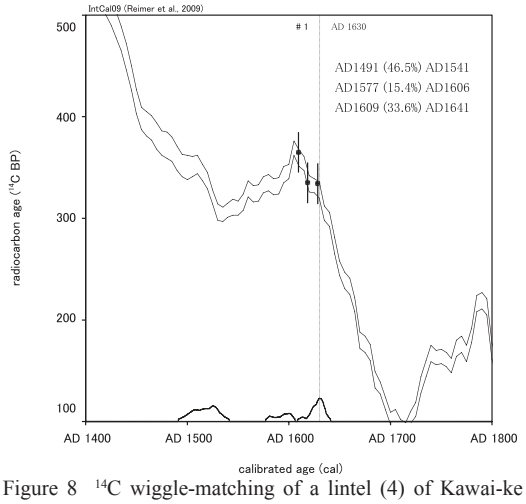

Figure 8 ^{14}C wiggle-matching of a lintel (4) of Kawai-ke House.

CONCLUSIONS

^{14}C dating has been mainly applied for archaeological research in Japan but was not considered important in the research of historic times. However, as dating becomes more accurate, the application to the materials in historic times is increasingly effective. In the study of Japanese architectural history, ^{14}C dating has been applied to the important historical buildings and has achieved breakthrough results such as for that of the Main Hall of Banna-ji Temple. We improved the method of dating, from the sample selection and analysis to the interpretation. These results enriched the understanding of the ^{14}C dating among those involved in the cultural property preservation and those interested in historical buildings and the area's history.

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