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RESEARCH ARTICLE

Optimal Bayesian chronological modeling for high resolution chronology for the Middle Jomon of Kanto region (Honshu Island, Japan) approaching a generational scale

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Abstract
In recent years, the increasing accumulation of radiocarbon dating data in Jomon research has progressed, creating a foundation for more detailed chronological estimates of the Jomon period's high-resolution typo-chronology. However, there remains a gap between relative chronologies based on typology and radiocarbon data. A key issue arises from discrepancies between the concept of *keishiki* ("type" in Japanese) as a time unit of relative chronology, defined based on production period, and the radiocarbon dates, which reflect various events that occurred to the pottery after its production. To overcome the gap, this study introduced a new Bayesian chronological model, the one-sided sequential model, which sequentially orders only the start boundaries of each typological group. When this model was applied to a case study from the Middle Jomon period in the Kanto region, it estimated more reasonable date ranges for each phase of the typo-chronology than the contiguous model. Additionally, the resulting estimated duration of each pottery type was shorter during periods of higher estimated populations and longer during periods of lower estimated populations, providing new insights into the temporal aspects of Jomon society While Bayesian chronological modeling is not prevalent in Jomon research, appropriate models make it possible to make chronological estimates consistent with the high-resolution Jomon chronology, which is considered to approach a generational scale. Such attempts enable detailed clarification of various social and cultural changes. The temporality of the past thus revealed provides a new approach to a deeper understanding of Jomon society.

Introduction

The Jomon period, an epoch in prehistoric Japan from approximately 16–2.3 k BP (2380 BP in the East Japan region), is notable for its early developments in sedentary village life, which predate the introduction of agriculture across the Japanese archipelago. During this era, people primarily subsisted as hunter-gatherers. However, evidence of rudimentary plant cultivation exists, indicating an incipient mixed subsistence strategy. By the Middle Jomon period (about 5.5BP–4.5 k BP), the construction of extensive circular settlements and emergence of monumental architecture suggest the development of a notably complex society (Habu 2004).

The various achievements in Jomon studies have largely relied on the construction of a sophisticated relative chronology. Since the pioneering research of Sugao Yamanouchi, relative chronology based on

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pottery typology has been highly developed in Jomon studies (T. Kobayashi 1994; T. Kobayashi 2004, 30–31). The Jomon typo-chronology was constructed with the aim of "subdivision to the extreme" (Yamanouchi 1937) of chronological units called *keishiki* ("type" in Japanese, to be discussed later). Currently, the Jomon period is divided into approximately 46 typological phases nationwide (K. Kobayashi 2017, 2019). Particularly in the Kanto region, which is one of the most intensively studied areas of the Middle Jomon period (ca. 5500–4500 BP), the typo-chronology has been subdivided into 19 phases and 31 sub-phases within a span of 1000 years (K. Kobayashi 2017, 2019). If divided evenly, the average of the duration of each sub-phase would be approximately 32 years, approaching the resolution of a single generation (ca. 30 years).

The objective of this study is to propose an optimal Bayesian chronological modeling approach to assign numerical dates to this extremely high-resolution Jomon relative chronology. This study provides a brief overview of the history of estimating absolute dates for Jomon pottery types. We examine the system of Jomon typo-chronology in detail, discussing the systematic discrepancies between *keishiki* defined in this system and radiocarbon dates. Finally, we outline the direction for constructing a new Bayesian chronological model optimized for Jomon typo-chronology.

Radiocarbon dating in Jomon research began in the 1950s when Libby (1951) analyzed carbonized material from the Ubayama shell midden in Chiba Prefecture, revealing an uncalibrated date of ca. 4.5 k BP. In the 1980s, with the advent of accelerator mass spectrometry, the application of radiocarbon dating to the Jomon sites increased dramatically. Since the 21st century, significant progress has been made in accumulating radiocarbon dating data, spearheaded by the National Museum of Japanese History's dating project, with the data pool reaching approximately over 3000 samples (K. Kobayashi 2004, 2017; Kudo et al. 2018).

However, the attempt to assign dates to each of these finely subdivided types did not immediately become widespread with the advent of radiocarbon dating. Originally, Yamanouchi (1937) estimated the absolute dates of each *keishiki* by determining the approximate start and end dates of each period and then evenly dividing them by the number of subdivided *keishiki*. This approach was justified based on the premise that, by "subdivision to the extreme" of pottery types, the difference of duration of each individual type could ultimately be ignored (Yamanouchi 1937). Moreover, up to the 1980s–1990s, there was a prevailing cautious attitude toward the use of absolute chronology in academic circles of Jomon study. While absolute dates were referenced for the beginning and end of periods, relative chronology based on typology without numerical dates was generally preferred for detailed chronological subdivision (for details on the history of the treatment of radiocarbon dates in Jomon chronological research, see K. Kobayashi 2019).

Such an evenly divided chronological framework posed significant challenges for research objectives, such as investigating population fluctuations over time. Naturally, the actual duration of a given period could directly affect estimates of population size (e.g., a longer duration would result in more houses and a higher apparent population). Therefore, Ken'ichi Kobayashi, one of the authors of this paper, systematically attempted to estimate absolute dates for each subdivided *keishiki* using radiocarbon dates as part of the *Shinchihei* ("new horizon" in Japanese) research project (Kuroo et al. 1995; see also the "Data and Settings" subsection), which focused on settlement studies in the Middle Jomon period (K. Kobayashi 2004). This research project has continued, and in recent years, their efforts have extended to estimating dates for the entire Jomon period using Bayesian chronological modeling (Crema and K. Kobayashi 2020; K. Kobayashi 2017, 2019)

As is widely known, Bayesian chronological modeling is a statistical approach used in various scientific disciplines, including archaeology, to refine dating techniques. In Bayesian estimation for radiocarbon dating, constraints such as the archaeological context can be applied to the calibrated dates given as probabilities, allowing for the refinement of specific event dates (Bronk Ramsey 2009a; Kanezaki and Omori 2019; Omori 2013). Furthermore, Bayesian modeling enables the statistical estimation of the duration of a given period without relying on visual inspection (Bayliss 2009). Therefore, Bayesian chronological modeling is an effective approach for assigning numerical dates to Jomon typo-chronology. In previous research, two major modeling approaches have been employed: a

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multi-phase model treating transitions between *keishiki* as contiguous (K. Kobayashi 2017, 2019) and a model using a trapezoidal prior distribution for each *keishiki*, where absolute dates were estimated separately without explicitly modeling sequential relationships between phases (Crema and K. Kobayashi 2020). These attempts represent the first systematic statistical estimation of absolute dates for Jomon typo-chronology, marking a significant advancement compared to earlier estimates based on equal subdivision.

Systematic Discrepancies Between Jomon Typo-chronology and Radiocarbon Dating

In the Bayesian modeling attempts applied to typo-chronology, in which relative chronology assumes a duration close to a single generation, a critical issue has emerged: the estimated duration of pottery phases often significantly exceeds—or, in some cases, falls well short of—what is assumed in relative chronology (i.e., the average duration of *keishiki* as calculated above). This discrepancy appears to be because of the distribution of the obtained radiocarbon dates, which often significantly surpass the short duration assumed in the relative chronology. Contributing factors include displacement from the original sample context, old wood effects, and marine reservoir effects. However, even when these factors are unlikely to appear, discrepancies between the relative chronology and radiocarbon data persist.

Thus, this study explores another possible factor by examining the discrepancy between the *keishiki* defined in relative chronology and the nature of radiocarbon data, based on previous discussions in Jomon chronological research. To gain a detailed understanding of this issue, the study first reexamines the fundamental characteristics of the Jomon chronological system, focusing primarily on the arguments presented by Suzuki (1969).

In the Jomon chronology system, *keishiki* refers to the classified pottery group based on morphological features that are particularly sensitive to temporal change. At the same time, it is an abstract concept that serves as a unit of time, constructed with the aim of establishing a time scale or temporal yardstick. Each unit represents the duration for which a particular pottery type was produced. Because *keishiki* is conceptualized as a collective entity, differences of time within this unit are omitted. Suzuki described such a time unit integrated by the production of a particular type of pottery using the term "simultaneity of production."

Therefore, when two types, A and B, are defined in a sequential relationship, this system inherently excludes the passage of time within each type, making it impossible by definition for the "later part" of Type A pottery to overlap with the "earlier part" of Type B pottery (although such phenomena may occur in reality). Similarly, because the divisions A-B are arbitrarily defined by archaeologists within the flow of time, discontinuities between these transitions are not considered[1]. In other words, *keishiki* can be understood as a conceptual construct that, while based on actual phenomena, is reconstructed within a specific chronological framework to serve as a structured unit of time (for further explanations on *keishiki*, see, e.g., Yokoyama 1985; Tanaka 1988).

Suzuki (1969) pointed out that typo-chronology, which relies on the concept of "simultaneity of production" as conceptualized in this way, and stratigraphic contexts, which are based on "simultaneity of discard"—the deposition of artifacts produced at different times but ultimately buried together—possess distinct temporal attributes. While the former purely corresponds to the time of pottery production, the latter encompasses the time of various events that occur between a vessel's production and its final deposition, including primary use, secondary reuse, and discard. This distinction is crucial when assigning numerical dates to the relative chronology of the Jomon period, as the temporal attributes of pottery *keishiki* belong to the former, whereas the charred organic materials used for dating belong to the latter.

Radiocarbon dates obtained from charred remains on or associated with pottery may reflect various sources, such as the age of firewood used in cooking, the age of plants or animals processed in the

[1] If an intermediate form between A and B is newly recognized, it is accommodated by subdividing the sequence into A1-A2-B or A-B1-B2.

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vessel, or soot deposited when the pottery was burned during discard. In some cases, these dates may closely approximate the production period, but for various reasons, discrepancies can occur. Such cases include pottery types that continued to be used long after production had ceased, situations in which the abandonment of dwellings caused older refuse to mix with more recent deposits, or instances whereby certain pots were deliberately curated over multiple generations. Indeed, Jomon studies have documented cases in which pottery of different typological phases was used simultaneously (K. Kobayashi et al. 2005a), pottery was buried in reverse chronological order (K. Kobayashi 1997), and older pottery was retrieved from refuse deposits for reuse (K. Kobayashi et al. 2005b; K. Kobayashi 2019, 155). Therefore, it can be assumed that the distribution of radiocarbon dates accumulated for the Jomon period to some extent reflects the influence of the discrepancy discussed above.

Our goal is to assign numerical dates for this defined time scale. Therefore, a new Bayesian chronological model must be developed to effectively address these systematic discrepancies between *keishiki* and radiocarbon data. To this end, this study proposes a novel approach, the one-sided sequential model. Furthermore, we demonstrate how the results obtained using this model provide new insights into the temporal aspects of Jomon society.

Materials and methods

Bayesian analysis of pottery type chronology

Bayesian analysis, which combines radiocarbon dates with archaeological contexts, is often employed to link pottery type chronologies with absolute dates. The calibration program OxCal applies statistical constraints to radiocarbon dates based on the relationships between sample contexts and calculates the most likely posterior (Bronk Ramsey 2009a). The context provided by pottery type chronology offers groupings for each typological set and their relative relationships, allowing for a multifaceted evaluation of dates. The trapezium model, which accounts for gradual chronological changes, has been introduced in recent years, allowing for more detailed quantification of temporal transitions in the data (Lee and Bronk Ramsey 2012).

In the Jomon chronological system described in the previous section, the transition in the pottery typology can be depicted as shown in the upper part of Figure 1. Therefore, in previous studies by K. Kobayashi (2017, 2019), a contiguous sequential (CS) model was adopted. The relative order of the data grouped by pottery type is defined by the sequence using the boundary dates marking the start and end of each group. For example, the start date of Type B is related to either the same time as the end date of Type A, whereas the end date of Type B is related to either the same time the start date of Type C. Based on these relationships when we conduct Bayesian analysis, the dates grouped under Type B and their boundaries are assigned a probabilistic weighting that makes them younger than the Type A group and older than the Type C group.

Meanwhile, the period from when the pottery was manufactured to when it was discarded can be represented as shown in the middle section of Figure 1. Similarly, the radiocarbon dates reflecting various events during this period can be illustrated as shown in the lower section of Figure 1. If the durations of Types A, B, and C are estimated using a contiguous model, a subset of the more recent dates within each type's radiocarbon date distribution would significantly influence the estimated start date of Type B. As previously mentioned, in Jomon research, the radiocarbon date distribution associated with a single pottery type often extends well beyond the expected duration inferred from relative chronology. A part of these more recent dates likely represents events related to the use and disposal of pottery after its "production period" had ended. Therefore, if these more recent dates, which "trail behind" within a given type, have a strong influence on determining the start date of the subsequent type, there is a risk that the estimated start date of a type would be shifted to a younger age than what is expected based on relative chronology.

Therefore, we adopt a new Bayesian model. The sequence is analyzed using only one boundary to determine the chronological order; hence, this approach is referred to as a one-sided sequence (OSS)

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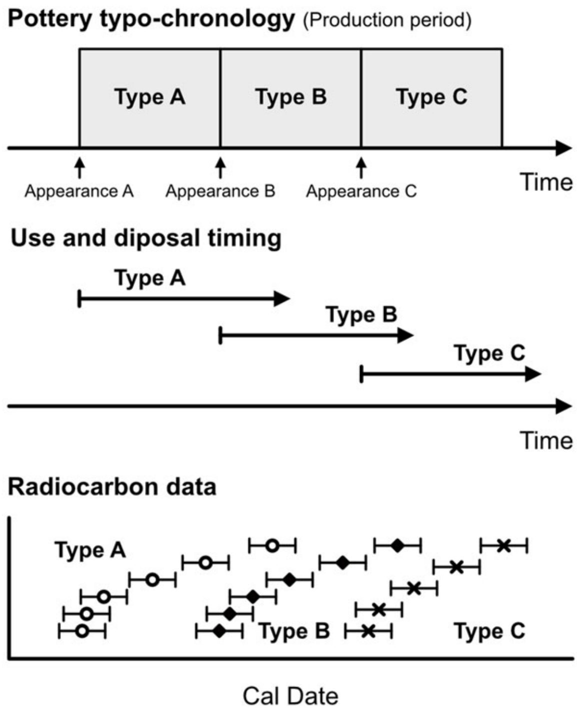

Figure 1. *Conceptual model of pottery type chronology and corresponding radiocarbon data. The top section depicts the archaeological sequence of pottery types, where each set's start is defined by its first appearance, ending with the following type's emergence. This timeline represents the period in which each pottery type was prevalent in production rather than the exact manufacturing date. The middle section shows the anticipated periods of pottery use and disposal, and the bottom section illustrates the expected spread of radiocarbon dates for the charred residue attached to the pottery.*

model. The process is as follows. Within the OxCal program, radiocarbon ages are grouped by pottery type and each group's start and end boundaries were defined in the sequence. The model is then constructed by sequentially ordering only the start boundaries of each typological group instead of sequencing the start and end or transitional boundaries (Figure 2). In other words, in this model, a phase is identified by the timing from the appearance of one pottery type to the appearance of the next rather than the beginning and cessation of the utilization of a type. Furthermore, the groups were ordered based on the appearance of types. The end boundary of one type is considered equivalent to the start boundary of the following type. Therefore, the end boundary is expected to be closer to the end of the production period, even if the group contains scattered ages that extend toward the more recent periods because the pottery existed longer than typologically expected.

Data analysis is conducted to identify outliers using a Bayesian approach (general outlier analysis; Bronk Ramsey 2009b), with the prior probability for outliers set at 0.5. The duration of each pottery type was calculated as the difference between the start boundaries of types in the sequence. For example, the duration of Type B is defined by the period between the start boundary of Type B and that of Type C. The characteristics and probability of the results from the OSS model are verified via comparisons with conventional estimates, wherein the sequence is ordered using a CS model.

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(A) **CQL2 command lines**

```
Plot()
{
 Outlier_Model("General",T(5),U(0,4),"t");
 Sequence("A")
 {
  Boundary("Start A");
  Phase("A")
  {
   R_Date("Sample name", 14C age, error)
   {
    Outlier("General", 0.05);
   };
        ⋮
  };
  Boundary("End A");
 };
 Sequence("B")
 {
  Boundary("Start B");
  Phase("B")
  {
   R_Date("Sample name", 14C age, error)
   {
    Outlier("General", 0.05);
   };
        ⋮
  };
  Boundary("End B");
      ⋮
 };

 Sequence("One-Side Sequence")
 {
  Boundary();
  Date("=Start A");
  Date("=Start B");
      ⋮
  Boundary();
 };
};
```

(B) **Block diagram view**

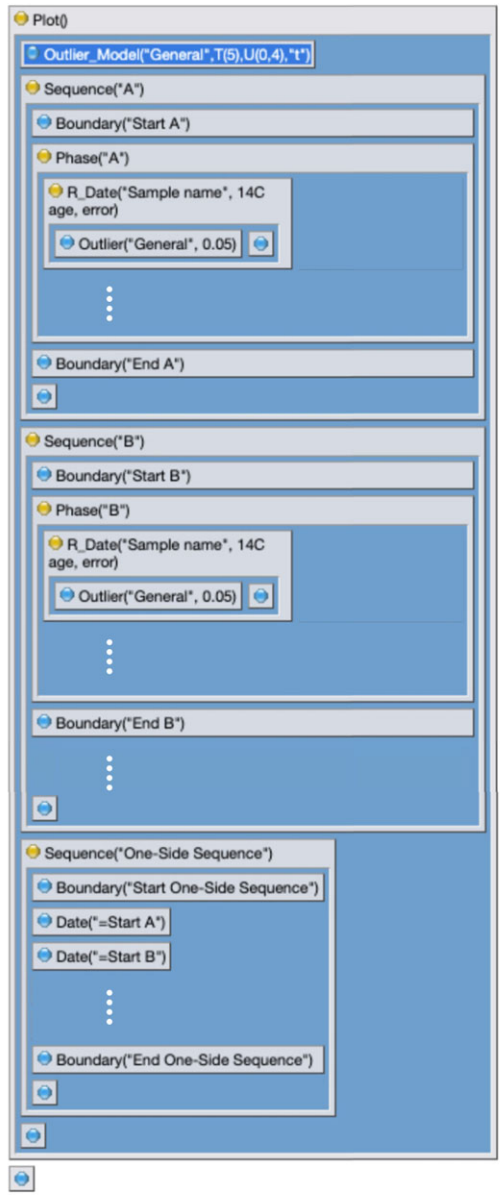

Figure 2. *CQL2 command and block diagram for Bayesian analysis using a one-sided sequence in OxCal. Panel (A) presents the CQL2 command lines, and Panel (B) shows the equivalent block diagram view. Radiocarbon ages are grouped by type set and ordered sequentially based on the start boundaries.*

Data and settings

This study focuses on the Middle Jomon period (approximately 5.5–4.5 k BP) in the Kanto region (Figure 3), where a detailed pottery chronology was established. This study is based on the chronological framework known as the Shinchihei chronology, which was established primarily through typological methods for the purpose of creating a fine-scale chronological framework for

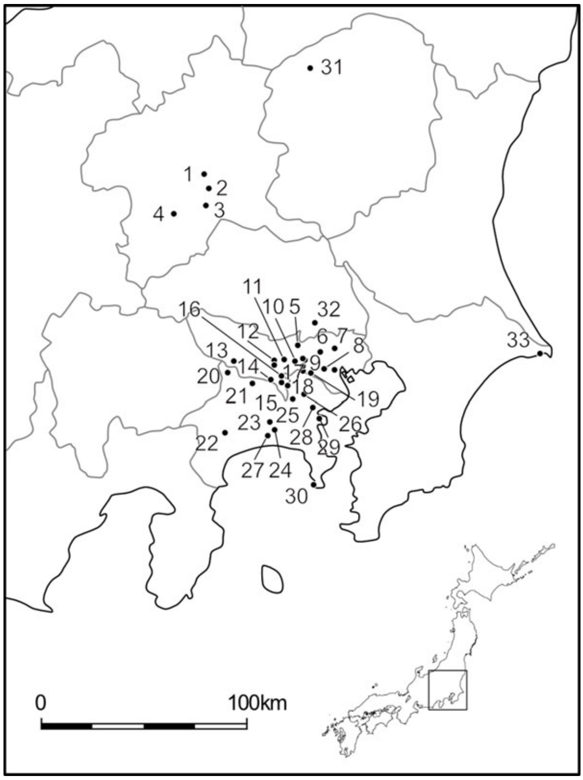

Figure 3. *Locations of Middle Jōmon period sites in the Kanto region discussed in the text. Numbers correspond to the following archaeological sites: 1: Kamimiharadahigashimine; 2: Asahikubo C; 3: Gotanda and Hara; 4: Kaminokubo; 5: Kawagishi; 6: Kitaekoda; 7: Nishigahara Shell Mound; 8: Ōhashi; 9: Inokashiraike A and Maruyama A; 10: Icu.L43; 11: Musashikokubunjiato; 12: Mukaigō; 13: Midorikawahigashi; 14: Tadao; 15: Miyata; 16: Tama New Town No. 520; 17: Takisaka; 18: Bentenzaitenike; 19: Ōkura; 20: Obinoppara; 21: Harahigashi and Kawashirinakamura; 22: Mikurubehigashikōchi and Yanagawatakenoue; 23: Iseyama; 24: SFC; 25: Inagahara A; 26: Kōhoku New Town nai Shinzakimachi; 27: Shitanone; 28: Shinoharaōhara; 29: Motomachi Shell Mound; 30: Aburatsubo; 31: Nakauchi II and Nakauchi; 32: Minamikōnuma; 33: Awashimadai.*

settlement studies. This was established based on pottery from the Musashino Plateau to the Kanagawa region in the Kanto area (Kuroo et al. 1995). Shinchihei is currently regarded as the most refined and detailed chronology of the Middle Jomon period, dividing the entire period into 13 phases and 31 sub-phases (for details, see K. Kobayashi 2019).

Owing to the limited availability of radiocarbon dates in some sub-phases, this study grouped several sub-phases into broader phases, resulting in a ceramic chronology divided into 23 phases (Figure 4). Additionally, we added the data from the last phase of the Early Jomon (Jusanbodai type, Z07) and the first phase from the Late Jomon (Shomyoji style, K01-1) for the boundary estimations. A total of 158 radiocarbon dates were analyzed after excluding 14 apparent outliers identified by experts' judgement, including those suspected of marine reservoir effects (see Supplementary Table 1). These dates were drawn from the existing list that comprehensively collects radiocarbon dates from archaeological sites in the Kanto region, ensuring that they were clearly associated with the chosen phases and sub-phases. Owing to the limited availability of data, the number of radiocarbon dates available for estimating the duration of each type varied considerably (n=1–21).

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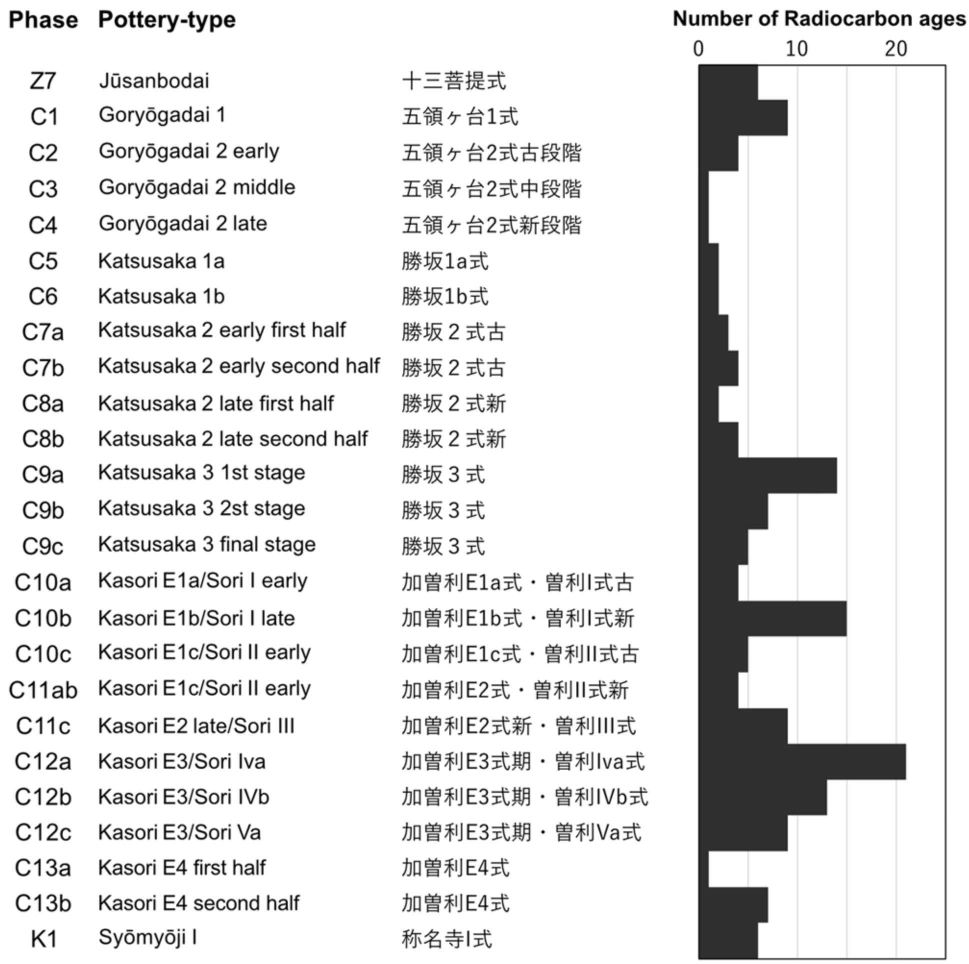

Figure 4. *Overview of pottery type sets and radiocarbon age number. The left side shows each pottery type's abbreviation codes and names, with the right panel indicating the distribution of radiocarbon dates for each type set.*

Additionally, for certain types, the data were concentrated in a single site (e.g., in the case of C09a, 11 out of 14 dates were derived from the same SFC site, albeit from multiple contexts). These limitations impose certain constraints on the estimated dates for each type, and future improvements through additional data accumulation are necessary.

Results

Characteristics of the model dates estimated using the one-sided sequence model

The modeled dates and boundaries estimated by the OSS indicate relatively older dates than those estimated by the CS (Figure 5). The difference is averaged over approximately 100 years because the starting boundary of each group constrains the dates grouped by pottery type. Compared with the distribution of calibration (unmodeled) dates, the start boundaries tend to be estimated at the earlier part of the distribution in the OSS, whereas in the CS, they are estimated to be closer to the period where the data are concentrated.

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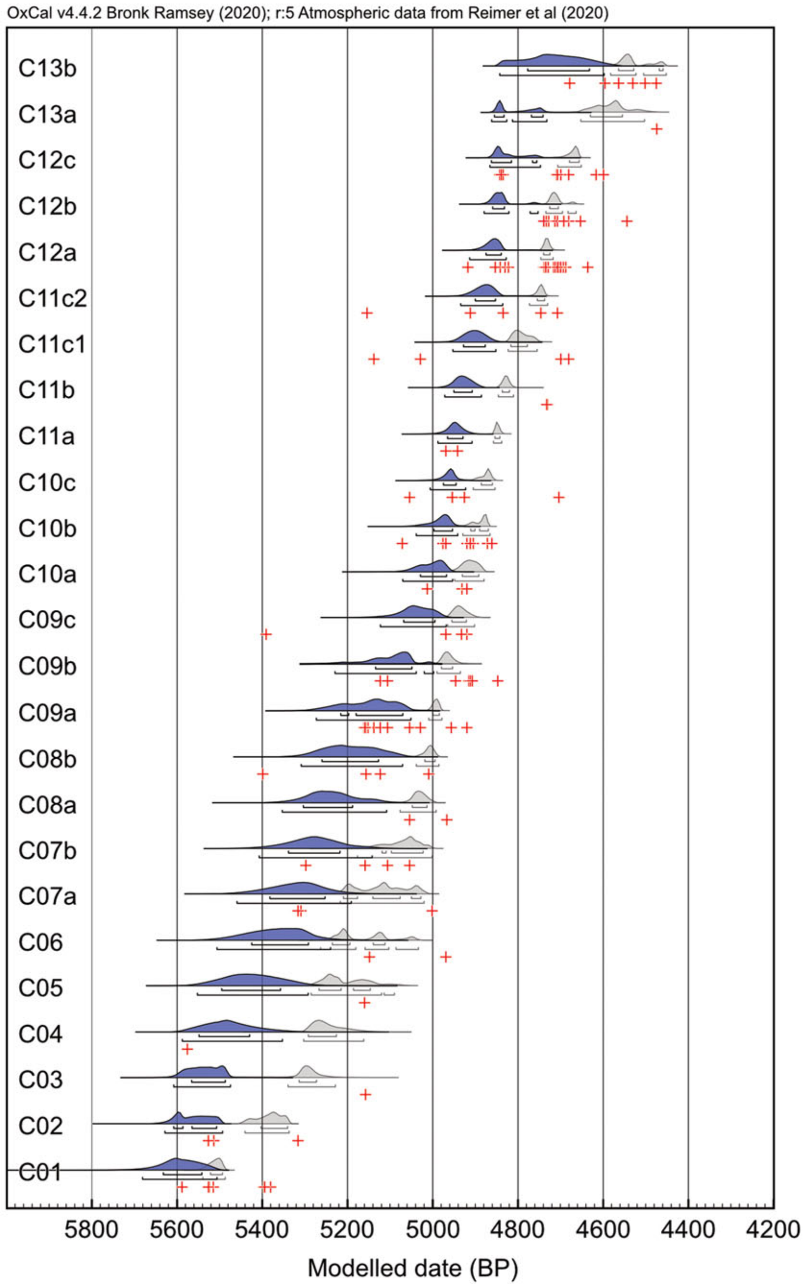

Figure 5. *Comparison of boundaries for Middle Jomon pottery type sets, calculated using OSS (blue) and CS (gray), overlaid with calibrated dates. The calibrated dates are marked with red crosses at the mode of each distribution.*

In principle, when data are lacking, the boundaries tend to reflect the characteristic patterns of the individual probability density functions (PDF) of the calibrated date, as observed in the CS boundaries for C05 to C07a. Groups with short durations and rapid transitions are more likely to yield sharp patterns that appear as calculation artifacts. For example, the CS boundaries between 11a and 12a display extreme boundaries relative to the distribution of the calibrated dates. By contrast, the OSS boundaries

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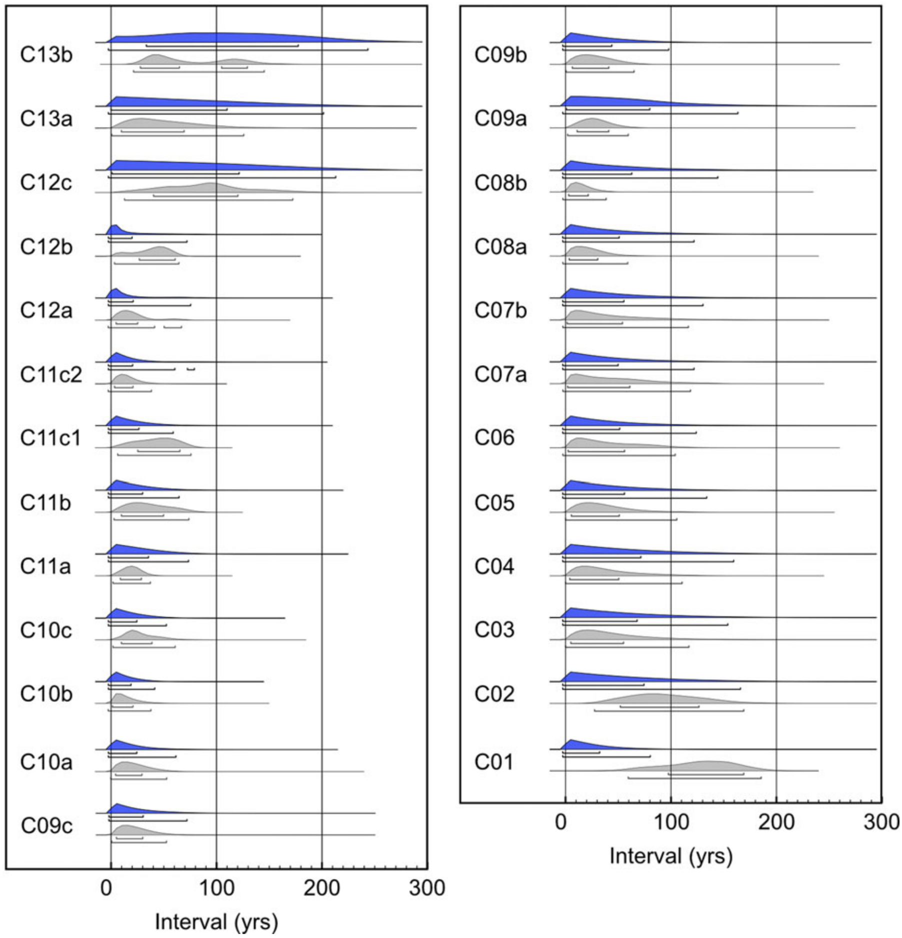

Figure 6. *The estimated duration of each Middle Jomon pottery type set is calculated using the difference between start boundaries. The blue distributions represent the durations calculated with the OSS model, whereas the gray distributions show those calculated with the CS model. Each distribution reflects the probability of the estimated interval for the persistence of each pottery type.*

reflect the clustering of early dates and their chronological sequences, allowing for a more gradual transition without being overly influenced by individual PDF shapes. This contrast is also evident in the agreement indices and outlier probabilities, which provide quantitative insights into the consistency between the model constraints and the radiocarbon data. In the CS model, 38 data points exhibited agreement indices below 60%, and 26 were identified as outliers exceeding the 5% threshold, suggesting that the model structure strongly constrains the modeled dates. In the OSS model, however, only 11 data points had agreement indices below 60%, and 12 were flagged as outliers, indicating a closer fit between the model and the underlying data (Supplementary Table 3).

Differences between the OSS and CS are also observed in the duration derived from the start boundary differences (Figure 6). The boundaries in the OSS are estimated at consistent intervals with overlapping PDFs. Consequently, within the 68% confidence interval, the calculated durations start from 0 years owing to the overlap in PDFs, spanning up to approximately 100 years and mostly concentrated within 50 years. By contrast, the durations and patterns of CS exhibit distinct characteristics for each group. While some features may reflect actual changes in pottery types, several seem to be artifacts caused by the sharp estimation pattern of the boundaries (e.g., between Types C10c and C12b).

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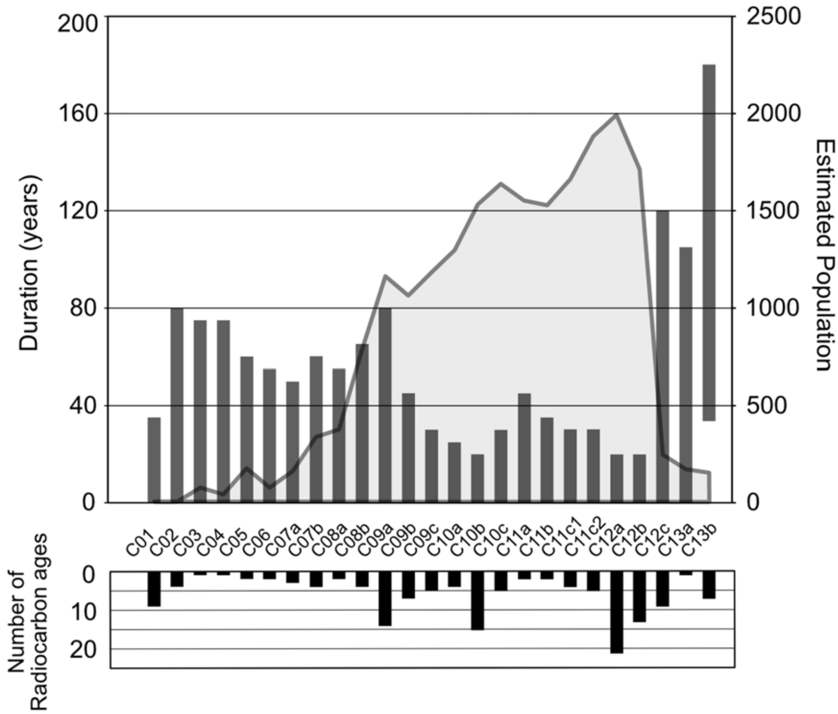

Figure 7. *Estimated population of each phase in the Middle Jomon period of the eastern Musashino Plateau (Kanto region) and the duration of pottery types as estimated by Model 4. For the population estimation method, refer to Kobayashi (2004).*

Based on the OSS, the dates for the Middle Jomon period begin at approximately 5.6 k BP, supporting a transition to the Late Jomon at approximately 4.6 k BP. Considering the 68% confidence interval, each type changes within approximately 100 years in the first half from Type C01 to C09b (the Early to mid-Middle Jomon period); within 50 years in the latter half from Type C09b to C12b (the mid-Middle to late-Middle Jomon period); and within 150–200 years in the final stages (the Late Jomon period; for details on individual modeled dates, see Supplementary Table 2).

Comparison with archaeological evidence

In this subsection, we explore how the results obtained using the OSS model can provide new insights into the temporal aspects of Jomon society. To this end, we compare the duration of each pottery type in the Middle Jomon period with that of the archaeologically estimated population dynamics model for the Kanto region (Figure 7). Based on the scale of the settlements, the estimated population is derived from archaeological data from the eastern Musashino Plateau in southern Kanto, where extensive archaeological surveys have been conducted (K. Kobayashi 2004)[2].

[2] A brief explanation of the population estimation method is as follows. The eastern Musashino Plateau region has been densely investigated for a long time, making it one of the most well-documented areas in terms of archaeological site distribution. At the time of the 2004 study, 98 settlement sites had been identified. These settlements were categorized into phases based on the Shinchihei chronology. The number of pit dwellings attributed to each settlement was used to classify them into large, medium, and small settlements, with estimated simultaneous functional dwelling units set at 20, 10, and 3, respectively. Assuming an average household size of 5 people, the estimated populations for these categories would be 100, 50, and 15 people, respectively.

A clear inverse correlation is observed between the duration of the pottery types and population dynamics, with no clear evidence that the estimated durations are affected by the quantity of radiocarbon data—even in types with many dates, such as C9a, C10b, and C12a, or in those with fewer dates, such as C03 and C04 (see Figure 7). For Types C01–C05, where the population size is relatively small, the duration of each type is longer. By contrast, more rapid changes are observed for Types C09–C12b, where a rapid increase in the population has been suggested. Additionally, the increasing trend in population from C01 to C12b, along with variations in duration that may correspond to the short-term changes observed in C11a and C11b, are noteworthy. This correlation implies that periods with higher population levels are associated with shorter durations of pottery type or faster transitions in pottery style.

The rapid pace of pottery type transitions suggests that specific morphological features recognizable by archaeologists appear more frequently. This suggests that during the Middle Jomon period in the Kanto region, new morphological features in pottery were more likely to appear during periods of population growth. This finding represents a novel insight that has not been identified in previous studies.

The influence of such factors as population size, population density, mobility, and the intensity of social interactions on the rate of cultural change and technological innovation has been widely discussed (e.g., Shennan 2001; Henrich 2004; Grove 2016). In the case of the Middle Jomon period in the Kanto region, periods of population growth might have led to an increase in pottery production and a more concentrated exchange of pottery, facilitating the emergence of new morphological traits.

Of course, the tempo of typological transitions reflects various social aspects related to pottery production in each society, and comparisons with demographic trends alone cannot fully elucidate these processes. Nevertheless, the new possibilities derived from this model provide an empirical basis for discussing the temporal dynamics of cultural change in pottery production. In this sense, the results presented here underscore the utility of this model.

Discussion and conclusion

This study obtains a consistent chronological framework based on the alignment of relative chronology, which is thought to reflect stylistic changes in pottery production, with the OSS model focused on emergence periods. Compared to the CS model, the OSS model estimated the start boundaries at earlier points within the uncalibrated date distribution. Additionally, unlike the CS model, which exhibited overly abrupt shifts in typological transitions (likely a calculation artifact), the OSS model demonstrated a more gradual transition of pottery styles. These findings suggest that, for this dataset, the OSS model produced results more closely aligned with archaeological interpretations than the CS model. Furthermore, the duration of each typological phase, as calculated using the OSS model, showed a negative correlation with demographic trends—an intriguing outcome. This finding indicates that the model has potential to offer new insights into the temporal dynamics of cultural change within the studied society.

When attempting to estimate absolute dates for a relative chronology that has been subdivided to a generational scale, it is necessary to consider more nuanced issues, such as discrepancies between the interpretive framework of archaeologists regarding typology and the nature of the analyzed data. Drawing on Suzuki (1969), this study highlights the systematic discrepancy between the abstract concept of *keishiki*, which focuses on "production periods," and radiocarbon data, which reflect various events that occurred after production. To address this discrepancy, we develop a new Bayesian model, the OSS model. As a result, it is possible to estimate dates that align with archaeological contexts while maintaining the temporal resolution assumed in relative chronology within Jomon typo-chronology.

This study should be regarded as a first step rather than a definitive model for constructing high-resolution Jomon chronology. The primary significance of this study lies in showing a way of bridging the gap between Jomon's "high-resolution relative chronology" and radiocarbon dating data, which

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For example, in the peak phase of period 12b, there were an estimated 4 large settlements, 24 medium settlements, and 26 small settlements, yielding an estimated total population of approximately 1990. For further details, see Kobayashi (2004).

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have been accumulating increasingly and rapidly in recent years. This study successfully estimates the time scale of *keishiki* of Jomon chronology, which approaches a generational time scale, as previously hypothesized. However, as a matter of course, considering the uncertainty of posterior estimation, it is not easy to improve the accuracy and precision of model dates to within a couple of decades. In this sense, a truly generation-scale chronology remains a distant challenge at present.

This study constructs the model to conform to the Jomon typo-chronology system, which has been developed over approximately a century and serves as the foundation of Jomon research. Accordingly, several uncertainties commonly associated with pottery typology and periodization, such as phase transition (overlaps, discontinuities, or divergences), are intentionally excluded from consideration (for discussions on these uncertainties, see Crema 2012 and Crema and K. Kobayashi 2020; see also Kanezaki and Omori 2024 for comparison). The characteristics of this time scale can be verified in future research by accumulating radiocarbon data and comparing it with Bayesian modeling results conducted from different perspectives.

The effort to establish a high-resolution temporal framework for Jomon research enables a more detailed understanding of social and cultural changes during the Jomon period, including pottery and artifact production, burial practices, and demographic changes. As this study demonstrates, Bayesian chronological modeling will play an essential role in future research efforts, providing deeper insights into the temporality of Jomon societies.

Supplementary Material. To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2025.10114

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