Radiocarbon Dating of Archaeological Materials Excavated at Kaman-Kalehöyük: Second Report

Takayuki OMORI and Toshio NAKAMURA
Nagoya

1 INTRODUCTION

In a previous report (Omori and Nakamura 2006), we presented radiocarbon 14C dating results of archaeological materials excavated at the site of Kaman-Kalehöyük. The results of 14C dating are approximately in agreement with the archaeological chronology so far established at Kaman-Kalehöyük. However, in that previous study, we were not able to estimate precisely the boundary age of each stratum. In fact, the optimum range of some calibrated ages was not narrow enough. In order to estimate calendar age more precisely and accurately, we analyzed the measured 14C dates based on Bayesian statistics using an OxCal program. In this report, we would like to summarize briefly the use of Bayesian statistics to analyze the 14C dates, and discuss the results of the recalculation.

2 BAYESIAN STATISTICS FOR 14C DATE ANALYSIS

We would like to define “calibrated age” before we apply Bayesian statistics to 14C ages. A calibrated age is derived from a 14C age. The equation to calibrate 14C age is written as

\[ t_{14C} = -8033 \ln\left( \frac{A}{A_0} \right) \quad (1) \]

where \( t_{14C} \) is 14C age (years), 8033 is 14C lifetime in years, and \( A \) and \( A_0 \) (modern activity) are the 14C activities of a sample at the time of formation and at present, respectively. The obtained 14C age has a statistical meaning, i.e. the results of repeated measurements under the same conditions can scatter according to a smoothing spline with a Gaussian distribution of one sigma error (Fig. 1). We can measure 14C ages of samples with reasonable certainty. However, we cannot use the 14C age directly as the calendar age of a sample, because the 14C age is calculated based on the assumption that the initial sample 14C activity was constant, i.e. the same as the modern activity. Actually, 14C concentration of atmospheric CO2 has experienced complex secular variations. In order to translate the measured 14C age into its calendar age, we have to calibrate the 14C age of a sample using an exact \( A_0 \) value at the time of its formation. The atmospheric 14C variations are shown by a calibration data set, e.g. IntCal04 (Fig. 1, Reimer et al. 2004). Projecting the 14C age to the calibration curve, we can obtain the calibrated age (Fig. 1, Stuiver 1978). The calibrated age is given by potential age ranges and associated probabilities with which the sample age can belong to the relevant ranges. Probability distributions of the calibrated age are not

Fig. 1 Relationship between sample 14C age and calibrated age with IntCal04 calibration curve. This example illustrates the calibration when 14C age, 4000 ± 25 yr, is converted with IntCal04. Under bar of the calibrated age is a probable range with 2σ (95.4% probability).
described by a Gaussian curve, and thus are usually not accurately summarized by a mean and variance. The width of calibrated age range depends on the shape of the calibration curve. If we calibrate the $^{14}$C age accidentally on the flat part of the calibration curve, the calibrated age has a broad region or sometimes separated age ranges, even though its result is highly accurate.

Bayesian statistics provides a possibility tool to combine the $^{14}$C dating results with independent archaeological information, such as the chronological order which can be inferred from accurate stratigraphy, and to reduce the region of higher probability distribution (Buck et al. 1991 and 1992; Biasi et al. 1994; Steier et al. 2000). In evaluating experimental data, the so-called Bayes theorem plays a fundamental role. Bayes' theorem provides the following formula:

$$P_{\text{posterior}}(\text{true values} | \text{measured data}) = \frac{P_{\text{likelihood}}(\text{measured data} | \text{true values}) P_{\text{prior}}(\text{true values})}{U}$$  \hspace{1cm} (2)

where $P_{\text{posterior}}$ is a posterior probability, $P_{\text{likelihood}}$ is a likelihood function in Bayesian mathematics, $P_{\text{prior}}$ is a prior probability, and $U$ is a normalization constant. To understand equation (2), the simple models of the probability distribution are shown in Fig. 2. The histograms of Figs. 2A and 2B are the calibrated ages of Samples 1 and 2. If we have sample information that Sample 1 is older than Sample 2, the probability distributions of Figs. 2C and 2D can be derived from the probability distributions of Figs. 2A and 2B. For example, the probability of $x_2$ in Sample 1 is calculated in the following. If a true age of Sample 1 is $x_2$, a true age of Sample 2 is covered from $x_1$ to $x_3$ because Sample 2 is younger than Sample 1. Here, the probability of the true age in Sample 1 is $P_{\text{prior}}$, and the probability summed up from $x_1$ to $x_3$ in Sample 2 is represented by $P_{\text{likelihood}}$ in the Bayesian statistics. Hence, multiplying $P_{\text{prior}}$ by $P_{\text{likelihood}}$ by using equation (2), we can obtain the probability of $x_2$ as shown in Fig. 2C. Calculating all dates ($x_1$ to $x_5$) by a similar process and then normalizing, the probability distribution as shown in Fig. 2C, which possesses the context information, is given. Using the OxCal program, a boundary age between two successive cultural phases can also be

Fig. 2 Simple models of the probability distributions. Calendric date units are arbitrary. Figs. 2A and 2B are the calibrated ages of Samples 1 and 2. Figs. 2C and 2D are calculated from Figs. 2A and 2B using Bayesian statistic (Biasi 1994: Fig. 2 or 3).
estimated with Bayesian analysis. More mathematical details of Bayesian statistics to analyze \(^{14}\)C ages are given in Buck et al. (1991 and 1992).

3 ANALYSIS

In this report, \(^{14}\)C dates from Omori and Nakamura (2006) are re-examined, along with the \(^{14}\)C results of six additional samples (Table 1). The sample preparation is discussed in detail in Omori and Nakamura (2006). \(^{14}\)C measurements were performed with an AMS system (HVEE, model 4130-AMS) at the Center for Chronological Research, Nagoya University (Nakamura et al. 2004).

To calculate the calibrated ages with Bayesian statistics, we defined the archaeological context of each sample, summarized in the next section.

The measured \(^{14}\)C ages were converted to calibrated dates by OxCal 4.0.1 (Ramsay 2006) with IntCal04 calibration curve (Reimer et al. 2004). In addition, an analysis based on Bayesian statistics using the OxCal program was performed to approximate the calibrated age to the realistic age. We constructed input data to the program, based on the stratigraphic order or additional archaeological information of the samples.

Table 1 Archaeological provenance data for each sample from Kaman-Kalehöyük

<table>
<thead>
<tr>
<th>Y. No.</th>
<th>Area</th>
<th>Sector</th>
<th>Grid</th>
<th>Provisional layer</th>
<th>Feature Information</th>
<th>Stratum</th>
<th>material</th>
</tr>
</thead>
<tbody>
<tr>
<td>94001635</td>
<td>North</td>
<td>XXVII</td>
<td>XLVII-52</td>
<td>2-5</td>
<td>P1156</td>
<td>I</td>
<td>Human bone</td>
</tr>
<tr>
<td>9501699</td>
<td>North</td>
<td>XXX</td>
<td>XLVII-51</td>
<td>2</td>
<td>T23</td>
<td>I</td>
<td>Human bone</td>
</tr>
<tr>
<td>9501704</td>
<td>North</td>
<td>XXVIII</td>
<td>XLVIII-52</td>
<td>1</td>
<td>G21</td>
<td>I</td>
<td>Human bone</td>
</tr>
<tr>
<td>9501707</td>
<td>North</td>
<td>XXVIII</td>
<td>XLIX-53</td>
<td>-</td>
<td>P1167, G29</td>
<td>I</td>
<td>Human bone</td>
</tr>
<tr>
<td>05000516</td>
<td>South</td>
<td>LVI-LVII</td>
<td>LIII-LIV-48,49</td>
<td>7-6</td>
<td>H137</td>
<td>I</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000518</td>
<td>South</td>
<td>LIX-LIV</td>
<td>LVIII-LIX-49,50</td>
<td>6</td>
<td>H139</td>
<td>I</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000522</td>
<td>South</td>
<td>LVI</td>
<td>LII-49</td>
<td>7-6</td>
<td>H62</td>
<td>I</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000779</td>
<td>North</td>
<td>V</td>
<td>XXXVII-54</td>
<td>2</td>
<td>Pit</td>
<td>Ia</td>
<td>Human bone</td>
</tr>
<tr>
<td>87001041</td>
<td>North</td>
<td>V</td>
<td>XXXVII-54</td>
<td>-</td>
<td>Pit</td>
<td>Ia</td>
<td>Animal bone</td>
</tr>
<tr>
<td>05000493</td>
<td>North</td>
<td>XVI</td>
<td>XXXV-53</td>
<td>3</td>
<td>H256</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000494</td>
<td>North</td>
<td>XVI</td>
<td>XXXV-52</td>
<td>6</td>
<td>H250</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000495</td>
<td>North</td>
<td>XIV</td>
<td>XXXVIII-52</td>
<td>9</td>
<td>H271</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000505</td>
<td>North</td>
<td>XV</td>
<td>XXXVI-52</td>
<td>9</td>
<td>P1671</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000511</td>
<td>North</td>
<td>XXIX</td>
<td>XLIV-50</td>
<td>9</td>
<td>P2860</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000513</td>
<td>North</td>
<td>XVI</td>
<td>XXXIV-52</td>
<td>5</td>
<td>H252</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000519</td>
<td>South</td>
<td>XXV</td>
<td>LX-53</td>
<td>-</td>
<td>P607</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000520</td>
<td>South</td>
<td>LV</td>
<td>LX-51</td>
<td>1</td>
<td>P564</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000521</td>
<td>South</td>
<td>XXV</td>
<td>LX-52</td>
<td>1-6</td>
<td>P543</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000525</td>
<td>North</td>
<td>XXXII</td>
<td>LIII-50</td>
<td>4</td>
<td>P2717</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000532</td>
<td>North</td>
<td>XXXII</td>
<td>LII-51</td>
<td>3</td>
<td>P2856</td>
<td>Ia</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000497</td>
<td>South</td>
<td>LVI</td>
<td>LII-49</td>
<td>3</td>
<td>H83</td>
<td>IIC</td>
<td>Charred grain</td>
</tr>
<tr>
<td>90000904</td>
<td>North</td>
<td>VI</td>
<td>XXX-55</td>
<td>4-9</td>
<td>-</td>
<td>IIC</td>
<td>Charcoal</td>
</tr>
<tr>
<td>92001527</td>
<td>North</td>
<td>VII</td>
<td>XXXIII-55</td>
<td>1-9</td>
<td>Burnt floor</td>
<td>IIC</td>
<td>Charcoal</td>
</tr>
<tr>
<td>05000512</td>
<td>South</td>
<td>XXIX</td>
<td>XLVII-60</td>
<td>3</td>
<td>H154</td>
<td>IIC</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000515</td>
<td>South</td>
<td>L</td>
<td>LI-53</td>
<td>-</td>
<td>P715</td>
<td>IIC</td>
<td>Charred grain</td>
</tr>
<tr>
<td>03001082</td>
<td>North</td>
<td>VIII</td>
<td>XXX-55</td>
<td>3</td>
<td>R345</td>
<td>IIC</td>
<td>Charcoal</td>
</tr>
<tr>
<td>05000500</td>
<td>North</td>
<td>VIII</td>
<td>XXX-55</td>
<td>3</td>
<td>R345</td>
<td>IIC</td>
<td>Charred grain</td>
</tr>
<tr>
<td>94001631</td>
<td>North</td>
<td>I</td>
<td>XLV-54</td>
<td>3</td>
<td>S4</td>
<td>IIC</td>
<td>Human bone</td>
</tr>
<tr>
<td>05000514</td>
<td>North</td>
<td>VIII</td>
<td>XXXI-55</td>
<td>9</td>
<td>P2886</td>
<td>IIC</td>
<td>Charred grain</td>
</tr>
<tr>
<td>05000499</td>
<td>North</td>
<td>IV</td>
<td>XXXIX-54</td>
<td>9</td>
<td>-</td>
<td>IV</td>
<td>Charred grain</td>
</tr>
</tbody>
</table>

*Same samples were drawn up from the previous report (Omori 2006: Table 1). The bold faces are the additional samples.*
4 CATALOG

We summarize below the archaeological provenance data and context for each sample, based on excavation diaries, provisional layer sheets, and annual excavation reports published in AAS.

4.1 Stratum I – Ottoman Period

Sample Number: 94001635
Sample Material: Human bone
Sampling Date: 940908
Coordinate: North, Sector XXVII, Grid XLVII-52, PL ②-③, P1156
Note: According to the excavation diary of Sector XXVII in 1994, P1156 is contemporary with R164, which belongs to the first building level of Stratum I (Omura 1995: 2-3, Fig. 3), or younger.

Sample Number: 95001699
Sample Material: Human bone
Sampling Date: 950627
Coordinate: North, Sector XXX, Grid XLVII-51, PL ②
Note: According to the excavation diary of Sector XXX in 1995, this individual was found from a layer higher than the second building level of Stratum I.

Sample Number: 95001704
Sample Material: Human bone
Sampling Date: 950630
Coordinate: North, Sector XXVIII, Grid XLVII-52, PL ②, G21
Note: G21 is contemporary with the pit cluster between the first and second building levels of Stratum I (Omura 1996: 4-7).

Sample Number: 95001707
Sample Material: Human bone
Sampling Date: 950704
Coordinate: North, Sector XXVIII, Grid XLIX-53, P1167, G29
Note: P1167 was found in a layer lower than the first building level (Omura 1995: 5-6). We cannot identify whether P1167 is contemporaneous with the pit cluster of Stratum I or not.

Sample Number: 05000516
Sample Material: Charred wheat and barley grains (Triticum sp. and Hordeum vulgare)
Coordinate: South, Sector LV-LVII, Grid LIII, LIV-49, 48, PL ②-③, H137
Note: Although we could not define the building level of H137, it is in a higher layer than the pit grave cluster.

Sample Number: 05000518
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: South, Sector LIX-LIX, Grid LVIII, LIX-49, 50, PL ②, H139
Note: According to the excavation diary of Sector LIX-LIX in 2005, H139 is contemporary with R127, which belongs to the first building level of Stratum I (Omura 1999: 10-11, Fig. 15).

Sample Number: 05000522
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: South, Sector LVI, Grid LIII-49, PL ②, H62
Note: H62 belongs to the first building level of Stratum I (Omura 1998: Fig. 50).

4.2 Stratum IIa – Iron Age

Sample Number: 86000779
Sample Material: Human bone
Sampling Date: 86000779
Coordinate: North, Sector V, XXXVII-54, PL ②
Note: According to the Harris Matrix, the pit where this individual and animal skeleton No. 87001041 were found belongs to the first building level of Stratum II (Matsumura 2005).

Sample Number: 87001041
Sample Material: Animal bone
Coordinate: North, Sector V, Grid XXXVII-54
Note: According to the Harris Matrix, the pit where this individual and human skeleton No. 86000779 were found belongs to the first building level of Stratum II (Matsumura 2005).
Sample Number: 05000493
Sample Material: Charred wheat grains (Triticum sp.)
Coordinate: North, Sector XVI, Grid XXXV-53, PL 5, H256
Note: H256 is contemporary with R366, which belongs to Stratum IIa (Omura 2005: Fig. 22). According to the excavation diary of XVI, R366 was cut by R361 (05000494) and R363 (05000513).

Sample Number: 05000495
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: North, Sector XIV, Grid XXXVIII-52, PL 5, H271
Note: According to the excavation diary of Sector XIV in 2005, H271 is contemporary with the architecture remains belonging to R361 (05000494) or R363 (05000513) (Omura 2005: Fig. 22).

Sample Number: 05000511
Sample Material: Charred wheat grains (Hordeum vulgare)
Coordinate: North, Sector XXXI, Grid XLIV-50, PL 6, P2860
Note: P2860 was from R371, called a kitchen (Omura 2006: Fig. 39). R371 belongs to Stratum IIa under the corridor structure, which belongs to the first building level (Omura 2006: 21-23).

Sample Number: 05000513
Sample Material: Charred wheat grains (Triticum aestivum or T. durum)
Coordinate: North, Sector XVI, Grid XXXIV-52, PL 1, H252
Note: H252 is contemporary with R363 (Omura 2003: Fig. 29), and approximately contemporary with R361 (05000513).

Sample Number: 05000515
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: North, Sector XV, Grid XXXVI-52, PL 5, P1671
Note: According to the excavation diary of Sector XV in 1997 and preliminary report (Omura 1998 and 2000), P1671 was found in a layer lower than the first building level of Stratum IIa.

Sample Number: 05000519
Sample Material: Charred wheat and barley grains (Triticum sp. and Hordeum vulgare)
Coordinate: South, Sector XXV, Grid LX-53, P607
Note: P607 belongs to Stratum IIa (Omura 1998: Fig. 26). P607 is contemporaneous with P564 (05000520).

Sample Number: 05000520
Sample Material: Charred wheat and barley grains (Triticum sp. and Hordeum vulgare)
Coordinate: South, Sector LV, Grid LX-51, PL 1, P564
Note: P564 belongs to the pit cluster of Stratum IIa (Omura 1998: Fig. 26). P564 is contemporaneous with P607 (05000519).

Sample Number: 05000521
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: South, Sector XXV, Grid LX-52, PL 5, P543
Note: According to the preliminary report in 1998 (Omura 1998), P543 is contemporaneous with P607 (05000519) and P564 (05000520).

Sample Number: 05000525
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: South, Sector XXXII, Grid XLIII-50, PL 1, P2717
Note: According to the 2005 preliminary report (Omura 2005), P2717 belongs to Stratum IIa. We could not define the building level.
Sample Number: 05000532  
Sample Material: Charred wheat grains (Triticum aestivum or T. durum)  
Coordinate: North, Sector XXXII, Grid XLII-51, PL $\text{H}1$, P2856  
Note: P2856 was found beneath the corridor structures of Stratum IIa (Omura 2006).

4.3 Stratum IIc – Iron Age  
Sample Number: 05000497  
Sample Material: Charred wheat grains (Triticum sp.)  
Coordinate: South, Sector LVI, Grid LIII-49, PL $\text{H}83$  
Note: According to the preliminary report, H83 belongs to the architecture remains under the first building level (Omura 2006: 46 and Fig. 97).

4.4 Stratum IIId – Dark Age, Iron Age  
Sample Number: 90000904  
Sample Material: Animal bone (boar or pig)  
Coordinate: North, Sector VI, Grid XXXV-55, PL $\text{R}39$, H83  
Note: This individual was found in R39 in Sector VI. According to the Harris Matrix, R39 belongs to the first building level of Stratum IIId (Matsumura 2005; Omura 1992: Fig. 2).

Sample Number: 92001527  
Sample Material: Charcoal  
Coordinate: North, Sector VII, Grid XXXIII-55, PL $\text{R}39$, H83  
Note: The charcoals were found in R39 in Sector VII. According to the Harris Matrix, R39 is under the first building level of Stratum IIId (Matsumura 2005).

Sample Number: 05000512  
Sample Material: Charred barley grains (Hordeum vulgare)  
Coordinate: North, Sector XXIX, Grid XLVII-50, PL $\text{H}154$, H154  
Note: According to the excavation diary of Sector XXIX in 2005 and a preliminary report (Omura 1998: 12 and Fig. 11), H154 belongs to the first building level of Stratum IIId.

Sample Number: 05000515  
Sample Material: Charred wheat grains (Triticum aestivum or T. durum)  
Coordinate: South, Sector L, Grid LII-53, P715  
Note: P715 was in the pit cluster between Stratum IIId and Stratum IIIb.

4.5 Stratum IIIb – Hittite Empire Period  
Sample Number: 03001082  
Sample Material: Charcoal  
Coordinate: North, Sector VIII, Grid XXX-55, PL $\text{R}345$  
Note: The charcoal materials were from R345. R345 belongs to Stratum IIIb (Omura 2004: Figs. 37-38).

Sample Number: 05000500  
Sample Material: Charred wheat grains (Triticum aestivum or T. durum)  
Coordinate: North, Sector VIII, Grid XXX-55, PL $\text{R}345$  
Note: The charred grains were from R345. R345 belongs to Stratum IIIb (Omura 2004: Figs. 37-38).

4.6 Stratum IIIc – Old Hittite Period  
Sample Number: 94001631  
Sample Material: Human bone  
Sampling Date: 940826  
Coordinate: North, Sector I, Grid XLV-54, PL $\text{S}4$  
Note: The individual was found in the architecture remains (Omura 1996: 10-11 and Fig. 15).

Sample Number: 05000514  
Sample Material: Charred wheat and barley grains (Triticum sp. and Hordeum vulgare)  
Coordinate: North, Sector VIII, Grid XXXI-55, PL $\text{P}2886$  
Note: P2886 was in the pit cluster between Stratum IIIb and Stratum IIIc (Omura 2006: Fig. 72).

4.7 Stratum IV – Early Bronze Age  
Sample Number: 05000499  
Sample Material: Charred wheat grains (Triticum aestivum or T. durum)  
Coordinate: North, Sector IV, Grid XXXIX-54, PL $\text{P}2886$  
Note: Omura 2003: Fig. 58 and 23-25
5 RESULTS AND DISCUSSION

In order to analyze the $^{14}$C results with the Bayesian method, we arranged our samples stratigraphically using the above archaeological information. Figs. 3, 4 and 5 illustrate the stratigraphical order of the samples. Each sample was arranged by stratum, building level, or relationship between old and young architecture remains in a building level. The contemporaneous samples, found in the same layer, were grouped into the same phase. If we could not arrange samples because of insufficient information, we extended the minimum unit of the phase to the next larger phase: e.g., in the case of a sample whose building level cannot be identified, the sample is grouped into the stratum.

Using the stratigraphic context, we carried out the Bayesian analysis as well as the common calibration of $^{14}$C results by the OxCal program. The comparison between the normally calibrated ages and Bayesian analysis results are shown in Table 2. Probability distributions of both calibrated results are illustrated in Figs. 6, 7, 8 and 9. We would like to remark on each result below, in particular focusing on the calibrated age with Bayesian statistics.

5.1 Stratum I – Ottoman Period

According to archaeological work, Stratum I has three building levels and one pit grave cluster between the first and second building levels. The samples belonging to Stratum I are classified into the first building level, and pit cluster or lower building level (Fig. 3). We did not calibrate the $^{14}$C ages of samples 95001707 and 95001699 with Bayesian statistics, because the archaeological provenance of these samples could not be identified correctly. The first building level dates to 1470 to 1640 cal AD, and the pit and grave cluster dates to 1450 to 1530 cal AD based on $^{14}$C dating. We discussed the calibrated age of the 95001707 sample in a previous report (Omori and Nakamura 2006: 266).

5.2 Stratum IIa – Iron Age

The samples belonging to Stratum IIa are classified into the first building level, and second or lower building level (Fig. 4). The second or lower building level is
Table 2  The comparison between commonly calibrated ages and the Bayesian analysis results. In order to test for intrusion and outliers, we used the Oxcal agreement index defined by Ramsey (1995 and 2001)

<table>
<thead>
<tr>
<th>Year No.</th>
<th>¹⁴C age BP ± 1 d</th>
<th>Lab. Code (NUTAz-2)</th>
<th>Calibrated age Unmodelled</th>
<th>Probability (%)</th>
<th>Calibrated age Modelled</th>
<th>Probability (%)</th>
<th>Agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>94001635</td>
<td>348 ± 23</td>
<td>10594</td>
<td>1460 - 1530 cal AD</td>
<td>40.1</td>
<td>1460 - 1530 cal AD</td>
<td>32.1</td>
<td>101.9</td>
</tr>
<tr>
<td>95001699</td>
<td>323 ± 23</td>
<td>10595</td>
<td>1490 - 1600 cal AD</td>
<td>55.3</td>
<td>1540 - 1640 cal AD</td>
<td>63.3</td>
<td></td>
</tr>
<tr>
<td>95001704</td>
<td>364 ± 23</td>
<td>10598</td>
<td>1450 - 1530 cal AD</td>
<td>54.0</td>
<td>1450 - 1530 cal AD</td>
<td>95.4</td>
<td>102.4</td>
</tr>
<tr>
<td>95001707</td>
<td>994 ± 24</td>
<td>10599</td>
<td>1020 - 1050 cal AD</td>
<td>39.6</td>
<td>1020 - 1050 cal AD</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>10000216</td>
<td>240 ± 19</td>
<td>10568</td>
<td>1920 - 1670 cal AD</td>
<td>93.2</td>
<td>1530 - 1670 cal AD</td>
<td>95.4</td>
<td>96.4</td>
</tr>
<tr>
<td>10000518</td>
<td>357 ± 24</td>
<td>10581</td>
<td>1450 - 1530 cal AD</td>
<td>48.1</td>
<td>1470 - 1530 cal AD</td>
<td>36.4</td>
<td>100.9</td>
</tr>
<tr>
<td>10000522</td>
<td>374 ± 23</td>
<td>10585</td>
<td>1450 - 1530 cal AD</td>
<td>47.3</td>
<td>1540 - 1630 cal AD</td>
<td>53.0</td>
<td>100.0</td>
</tr>
<tr>
<td>88000779</td>
<td>2205 ± 20</td>
<td>10995</td>
<td>360 - 200 cal BC</td>
<td>95.4</td>
<td>380 - 270 cal BC</td>
<td>86.7</td>
<td></td>
</tr>
<tr>
<td>87001041</td>
<td>2491 ± 21</td>
<td>10994</td>
<td>770 - 540 cal BC</td>
<td>95.4</td>
<td>770 - 540 cal BC</td>
<td>94.5</td>
<td></td>
</tr>
<tr>
<td>10000493</td>
<td>2540 ± 25</td>
<td>10560</td>
<td>800 - 740 cal BC</td>
<td>42.7</td>
<td>800 - 740 cal BC</td>
<td>4.0</td>
<td>89.5</td>
</tr>
<tr>
<td>10000494</td>
<td>2552 ± 26</td>
<td>10561</td>
<td>690 - 660 cal BC</td>
<td>19.4</td>
<td>690 - 660 cal BC</td>
<td>95.4</td>
<td>0.6</td>
</tr>
<tr>
<td>10000495</td>
<td>2555 ± 25</td>
<td>10564</td>
<td>640 - 590 cal BC</td>
<td>17.5</td>
<td>630 - 590 cal BC</td>
<td>111.6</td>
<td></td>
</tr>
<tr>
<td>10000505</td>
<td>2547 ± 25</td>
<td>10659</td>
<td>580 - 560 cal BC</td>
<td>13.4</td>
<td>580 - 560 cal BC</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>10000511</td>
<td>2469 ± 25</td>
<td>10653</td>
<td>760 - 680 cal BC</td>
<td>13.4</td>
<td>760 - 680 cal BC</td>
<td>94.6</td>
<td></td>
</tr>
<tr>
<td>10000513</td>
<td>2726 ± 21</td>
<td>10968</td>
<td>450 - 440 cal BC</td>
<td>1.0</td>
<td>450 - 440 cal BC</td>
<td>83.4</td>
<td></td>
</tr>
<tr>
<td>10000519</td>
<td>2333 ± 25</td>
<td>10582</td>
<td>420 - 370 cal BC</td>
<td>0.4</td>
<td>420 - 370 cal BC</td>
<td>86.1</td>
<td></td>
</tr>
<tr>
<td>10000520</td>
<td>2449 ± 25</td>
<td>10583</td>
<td>750 - 690 cal BC</td>
<td>26.1</td>
<td>750 - 690 cal BC</td>
<td>16.9</td>
<td></td>
</tr>
<tr>
<td>10000521</td>
<td>2525 ± 25</td>
<td>10584</td>
<td>700 - 730 cal BC</td>
<td>29.5</td>
<td>700 - 730 cal BC</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>10000525</td>
<td>2480 ± 21</td>
<td>10990</td>
<td>770 - 510 cal BC</td>
<td>95.4</td>
<td>770 - 510 cal BC</td>
<td>94.6</td>
<td></td>
</tr>
<tr>
<td>10000532</td>
<td>2504 ± 21</td>
<td>10992</td>
<td>780 - 720 cal BC</td>
<td>20.0</td>
<td>780 - 720 cal BC</td>
<td>16.9</td>
<td></td>
</tr>
<tr>
<td>10000497</td>
<td>2756 ± 26</td>
<td>10966</td>
<td>920 - 830 cal BC</td>
<td>95.4</td>
<td>920 - 830 cal BC</td>
<td>95.4</td>
<td></td>
</tr>
<tr>
<td>90000904</td>
<td>28264 ± 58</td>
<td>-</td>
<td>970 - 960 cal BC</td>
<td>1.9</td>
<td>970 - 960 cal BC</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>2748 ± 64</td>
<td>-</td>
<td>930 - 810 cal BC</td>
<td>93.5</td>
<td>930 - 810 cal BC</td>
<td>93.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>92001527</td>
<td>2878 ± 25</td>
<td>10586</td>
<td>1110 - 1150 cal BC</td>
<td>1.1</td>
<td>1110 - 1150 cal BC</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2911 ± 25</td>
<td>10587</td>
<td>1110 - 1150 cal BC</td>
<td>1.2</td>
<td>1110 - 1150 cal BC</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30001062</td>
<td>3234 ± 22</td>
<td>10998</td>
<td>1580 - 1540 cal BC</td>
<td>16.8</td>
<td>1580 - 1540 cal BC</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td>3346 ± 26</td>
<td>10568</td>
<td>1660 - 1600 cal BC</td>
<td>7.3</td>
<td>1660 - 1600 cal BC</td>
<td>79.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>94001631</td>
<td>3473 ± 22</td>
<td>10999</td>
<td>1880 - 1740 cal BC</td>
<td>26.0</td>
<td>1880 - 1740 cal BC</td>
<td>95.4</td>
<td></td>
</tr>
<tr>
<td>95000514</td>
<td>3511 ± 26</td>
<td>10975</td>
<td>1910 - 1750 cal BC</td>
<td>15.4</td>
<td>1880 - 1740 cal BC</td>
<td>95.4</td>
<td></td>
</tr>
<tr>
<td>90000499</td>
<td>3717 ± 27</td>
<td>10567</td>
<td>2200 - 2160 cal BC</td>
<td>48.0</td>
<td>2200 - 2160 cal BC</td>
<td>95.4</td>
<td></td>
</tr>
</tbody>
</table>

*cf. Omori 2005
Fig. 6 The results of calibration (in outline) of \(^{14}C\) age for the samples from Stratum I. The solid black distributions are the result of a Bayesian analysis as by using the chronological context given in Fig. 3, and the under bars are the age range with 2\(\sigma\) (95.4% probability). We used some CQR2 commands; “R_Date” calculates the calibrated date as function of \(^{14}C\) concentration, “R_Combine” combines \(^{14}C\) dates, “Sequence” defines an order for events and groups of events, and “Phase” defines unordered group of events in which members are unordered (Ramsey 2006). The sample marked with “?” has been excluded from a Bayesian analysis. Each boundary age was also calculated by Bayesian statistics, and illustrated as probability distribution.

Fig. 7 The results from Stratum IIa; see the caption in Fig. 6 for details.
Fig. 8  The results from Stratum IIc-d; see the caption in Fig. 6 for details

Fig. 9  The results from Stratum IV-III; see the caption in Fig. 6 for details
divided into two architectural contexts, based on the excavation diary. We could not identify the building level of seven samples so far. The first building level dates to 500 to 210 cal BC, and the second or lower building level dates to 830 to 410 cal BC based on “C dating. Samples 05000493 show poor agreement in resulting values; in this report, we do not discuss the detail of this result. The calibrated age of sample 05000511, which is from the remains of R371, considered to be a kitchen (Omura 2006: 21), is 760 to 550 cal BC. Though we cannot place this architectural remain to any building level, it is possible that the result of sample 05000511 will supply important evidence to determine the date of the start of Stratum IIa, because R371 was located close to the architectural remains of Stratum IIc (Omura 2006: 23).

5.3 Stratum IIc – Iron Age

We have only one sample that belongs to the Stratum IIc (Fig. 4). This calibrated age is approximately 890 to 830 cal BC. Because of close archaeological context surrounding Stratum IIc, the age range could be greatly narrowed down by the application of Bayesian statistics. In the case of sample 05000497, the age range of 90 yr could be reduced to 60 yr. The result of Stratum IIc is the typical case in this report to optimize Bayesian analysis for “C dating.

5.4 Stratum IId – Dark Age, Iron Age

The samples belonging to Stratum IId are classified into the first building level, and second or lower building level (Fig. 4). The first building level dates to 980 to 850 cal BC. It is inferred from the results of samples 05000515 and 92001527 that Stratum IId started in approximately the 14th c. BC.

5.5 Stratum III and IV – Early, Middle, and Late Bronze Ages

We do not have enough “C results to revise Bayesian analysis at the moment (Fig. 5). Therefore, the calibrated ages with Bayesian analysis are unchanged from the original analyses. Stratum IIIb dates to 1690 to 1530 cal BC (1730 to 1530 cal BC without Bayesian analysis), and Stratum IIIc dates to 1890 to 1740 cal BC (1910 to 1740 cal BC without Bayesian analysis).

In the case of Stratum IV, we report only one sample. The calibrated age is 2200 to 2030 cal BC. Here, the application of Bayesian analysis to reduce the range of calibrated age is of no use.

5.6 Each Boundary Age

The OxCal program can also provide the boundary ages by using Bayesian statistics. The boundary ages estimated from “C results are shown in Table 3. We have obtained good agreements of our results with archaeological considerations, except for the boundaries of Ila-IIc and IId-IIc.

6 CONCLUSION

We have obtained the absolute ages of some building levels and of the boundary of each cultural stratum at Kaman-Kalehöyük by analyzing the accurately measured “C dates of archaeological materials excavated from the site, based on the Bayesian statistics method. It is important to measure many samples, but it is also necessary to collect samples with detailed archaeological context. At Kaman-Kalehöyük, a Harris Matrix, which diagrams detailed archaeological contexts, has been established. An examination of “C ages by using Bayesian analysis with the Harris Matrix would strengthen the accuracy of the absolute dates. We would like to continue this kind of work toward obtaining more accurate dates.

<table>
<thead>
<tr>
<th>Boundary</th>
<th>Calibrated age</th>
<th>Probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratum I End</td>
<td>1570 AD - Present</td>
<td>95.4</td>
</tr>
<tr>
<td>Stratum I Start</td>
<td>670 - 1150 AD</td>
<td>95.4</td>
</tr>
<tr>
<td>Stratum IIa End</td>
<td>370 - 100 Cal BC</td>
<td>95.4</td>
</tr>
<tr>
<td>Stratum IIc - IIa</td>
<td>880 - 820 Cal BC</td>
<td>95.4</td>
</tr>
<tr>
<td>Stratum IId - IIC</td>
<td>890 - 840 Cal BC</td>
<td>95.4</td>
</tr>
<tr>
<td>Stratum IIb - IId</td>
<td>1660 - 1340 Cal BC</td>
<td>95.4</td>
</tr>
<tr>
<td>Stratum IIc - IIb</td>
<td>1850 - 1620 Cal BC</td>
<td>95.4</td>
</tr>
<tr>
<td>Stratum IV - IIIc</td>
<td>2030 - 1760 Cal BC</td>
<td>95.4</td>
</tr>
</tbody>
</table>
7 ACKNOWLEDGEMENTS

For providing us samples, assistance, collaboration and comments, we are grateful to Sachihiro Omura, Andrew Fairbairn, Veronica Hunt and Koji Okumura. We also thank all of the members of the CCR who worked on the 14C dating, and JIAA staff. This study was supported partly by Fukutake Academic and Cultural Financial Group and by the “Grant-In-Aid for Scientific Research” of the Japan Society of the Promotion of Science (JSPS) (Subject No: 16320108, 19300300).

8 BIBLIOGRAPHY

Biasi, G.P. and R. Weldon

Buck, C.E., C.D. Litton and A.F.M. Smith

Buck, C.E., J.B. Kenworthy, C.D. Litton and A.F.M. Smith

Matsumura, K.

Nakamura, T.

Omura, S.

Omori, T. and T. Nakamura

Ramsey, C.
2006 “Oxcal 4.0.1.” html://c14.arch.ox.ac.uk/oxcal.html

Reimer, P.J. et al.

Steier, P. and W. Rom

Stuiver, M.
Takayuki Omori and Toshio Nakamura
Center for Chronological Research AMS Group
Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8602
Japan
Tel : +81-52-789-2579
Fax : +81-52-789-3092
E-mail : omori@nendai.nagoya-u.ac.jp (Omori)