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

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1 INTRODUCTION

In a previous report (Omori and Nakamura 2006), we presented radiocarbon ^{14}C dating results of archaeological materials excavated at the site of Kaman-Kalehöyük. The results of ^{14}C 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 ^{14}C 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 ^{14}C dates, and discuss the results of the recalculation.

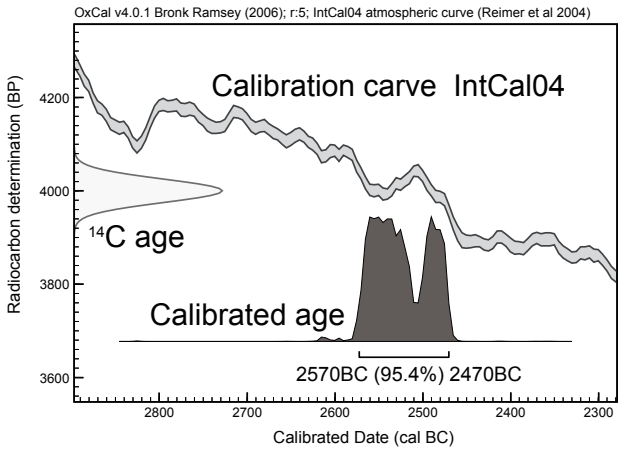

Fig. 1 Relationship between sample ^{14}C age and calibrated age with IntCal04 calibration carve. This example illustrates the calibration when ^{14}C age, 4000 ± 25 yr, is converted with IntCal04. Under bar of the calibrated age is a probable range with 2 σ (95.4% probability).

2 BAYESIAN STATISTICS FOR ^{14}C DATE ANALYSIS

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

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

where $t^{14}C$ is ^{14}C age (years), 8033 is ^{14}C lifetime in years, and A and A_0 (modern activity) are the ^{14}C activities of a sample at the time of formation and at present, respectively. The obtained ^{14}C 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 ^{14}C ages of samples with reasonable certainty. However, we cannot use the ^{14}C age directly as the calendar age of a sample, because the ^{14}C age is calculated based on the assumption that the initial sample ^{14}C activity was constant, *i.e.* the same as the modern activity. Actually, ^{14}C concentration of atmospheric CO_2 has experienced complex secular variations. In order to translate the measured ^{14}C age into its calendar age, we have to calibrate the ^{14}C age of a sample using an exact A_0 value at the time of its formation. The atmospheric ^{14}C variations are shown by a calibration data set, e.g. IntCal04 (Fig. 1, Reimer *et al.* 2004). Projecting the ^{14}C 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

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:

$$P^{posterior}\,(\text{true values}\,|\,\text{measured data}) = \frac{P^{likelihood}(\text{measured data}\,|\,\text{true values})\,P^{prior}(\text{true values})}{U} \quad (2)$$

where $P^{posterior}$ is a posterior probability, $P^{likelihood}$ is a likelihood function in Bayesian mathematics, P^{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 probability distribution 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_3 to x_5 because Sample 2 is younger than Sample 1. Here, the probability of the true age in Sample 1 is P^{prior}, and the probability summed up from x_3 to x_5 in Sample 2 is represented by $P^{likelihood}$ in the Bayesian statistics. Hence, multiplying P^{prior} by $P^{lilelihood}$ 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

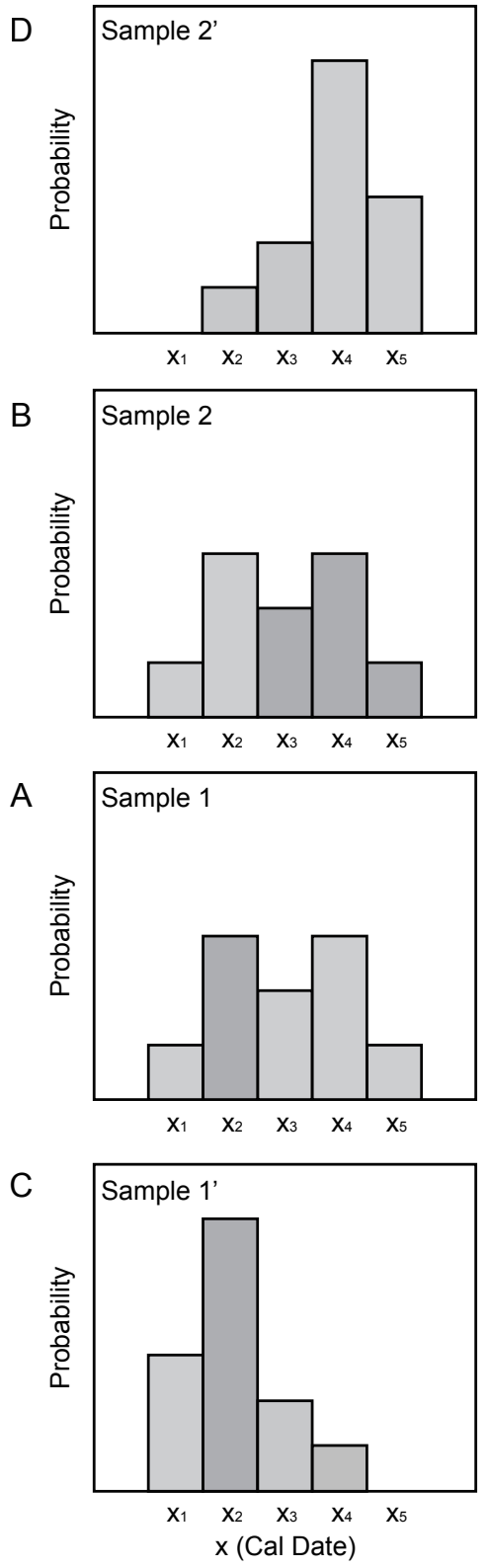

Fig. 2 Simple models of the probability distributions. Calendric date units are arbitrary. Figs. 2A and 2B are the calibrated ages of Samples 1 and 2. Figs. 2C and 2D are calculated from Figs. 2A and 2B using Bayesian statistic (Baiasi 1994: Fig. 2 or 3).

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

Y. No.	Area	Sector	Grid	Provisional layer	Feature Information	Stratum	material
94001635	North	XXVII	XLVII-52	②-ⓐ	P1156	I	Human bone
95001699	North	XXX	XLVII-51	②	T23	I	Human bone
95001704	North	XXVIII	XLVIII-52	①	G21	I	Human bone
95001707	North	XXVIII	XLIX-53	-	P1167, G29	I	Human bone
05000516	**South**	**LVI-LVII**	**LIII,LIV-48,49**	**⑦-ⓑ**	**H137**	**I**	**Charred grain**
05000518	**South**	**LIX-LIV**	**LVIII,LIX-49,50**	**⑥**	**H139**	**I**	**Charred grain**
05000522	**South**	**LVI**	**LIII-49**	**⑦-ⓑ**	**H62**	**I**	**Charred grain**
86000779	**North**	**V**	**XXXVII-54**	**㉑**	**Pit**	**IIa**	**Human bone**
87001041	North	V	XXXVII-54	-	Pit	IIa	Animal bone
05000493	North	XVI	XXXV-53	㉟	H256	IIa	Charred grain
05000494	North	XVI	XXXV-52	㊻	H250	IIa	Charred grain
05000495	North	XIV	XXXVIII-52	㉙	H271	IIa	Charred grain
05000505	North	XV	XXXVI-52	⑨	P1671	IIa	Charred grain
05000511	North	XXXI	XLIV-50	㊴	P2860	IIa	Charred grain
05000513	North	XVI	XXXIV-52	㊶	H252	IIa	Charred grain
05000519	South	XXV	LX-53	-	P607	IIa	Charred grain
05000520	South	LV	LX-51	①	P564	IIa	Charred grain
05000521	South	XXV	LX-52	⑪-ⓐ	P543	IIa	Charred grain
05000525	North	XXXII	XLIII-50	⑭	P2717	IIa	Charred grain
05000532	North	XXXII	XLII-51	㊱	P2856	IIa	Charred grain
05000497	South	LVI	LIII-49	㉘	H83	IIc	Charred grain
90000904	**North**	**VI**	**XXXV-55**	**㊽-ⓐ**	**-**	**IId**	**Animal bone**
92001527	North	VII	XXXIII-55	⑬-ⓐ	Burnt floor	IId	Charcoal
05000512	North	XXIX	XLVII-50	⑬	H154	IId	Charred grain
05000515	South	L	LII-53	-	P715	IId	Charred grain
03001082	North	VIII	XXX-55	㉑	R345	IIIb	Charcoal
05000500	North	VIII	XXX-55	⑲	R345	IIIb	Charred grain
94001631	North	I	XLV-54	㉗	S4	IIIc	Human bone
05000514	North	VIII	XXXI-55	㊺	P2886	IIIc	Charred grain
05000499	**North**	**IV**	**XXXIX-54**	**㊼**	**-**	**IV**	**Charred grain**

*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-ⓐ, 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 XLVIII-52, PL ①, 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 LVI-LVII, Grid LIII, LIV-48, 49, PL ⑦-ⓑ, 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-LIV, Grid LVIII, LIX-49, 50, PL ⑥, H139
Note: According to the excavation diary of Sector LIX-LIV 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 ⑦-ⓑ, 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
Coordinate: North, Sector V, XXXVII-54, PL ㉑
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 ㉟, 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: 05000494
Sample Material: Charred wheat grains (Triticum sp.)
Coordinate: North, Sector XVI, Grid XXXV-52,
PL ㊻, H250
Note: H250 is contemporary with R361 (Omura 2003: Fig. 29), and approximately contemporary with R363 (05000513).

Sample Number: 05000495
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: North, Sector XIV, Grid XXXVIII-52,
PL ㉙, 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: 05000513
Sample Material: Charred wheat grains (Triticum aestivum or T. durum)
Coordinate: North, Sector XVI, Grid XXXIV-52,
PL ㊺, H252
Note: H252 is contemporary with R363 (Omura 2003: Fig. 29), and approximately contemporary with R361 (05000494).

Sample Number: 05000505
Sample Material: Charred wheat grains (Triticum sp.)
Coordinate: North, Sector XV, Grid XXXVI-52,
PL ⑨, 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: 05000511
Sample Material: Charred wheat grains (Hordeum vulgare)
Coordinate: North, Sector XXXI, Grid XLIV-50,
PL ㊴, 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: 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). We could not define the building level.

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 ⑪-ⓐ, 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: North, Sector XXXII, Grid XLIII-50,
PL ⑭, 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 ㊱, 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 ㉘, H83
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 IId – Dark Age, Iron Age

Sample Number: 90000904
Sample Material: Animal bone (boar or pig)
Coordinate: North, Sector VI, Grid XXXV-55, PL ㊽-ⓐ
Note: This individual was found in R39 in Sector VI. According to the Harris Matrix, R39 belongs to the first building level of Stratum IId (Matsumura 2005; Omura 1992: Fig. 2).

Sample Number: 92001527
Sample Material: Charcoal
Coordinate: North, Sector VII, Grid XXXIII-55, PL ⑬-ⓐ
Note: The charcoals were found in R131 in Sector VII. According to the Harris Matrix, R131 is under the first building level of Stratum IId (Matsumura 2005).

Sample Number: 05000512
Sample Material: Charred barley grains (Hordeum vulgare)
Coordinate: North, Sector XXIX, Grid XLVII-50, PL ⑬, 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 IId.

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 IId and Stratum IIIb.

4.5 Stratum IIIb – Hittite Empire Period

Sample Number: 03001082
Sample Material: Charcoal
Coordinate: North, Sector VIII, Grid XXX-55, PL ㉑
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 ⑲
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 ㉗, S4
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 ㊺, P2886
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 ㊼
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.

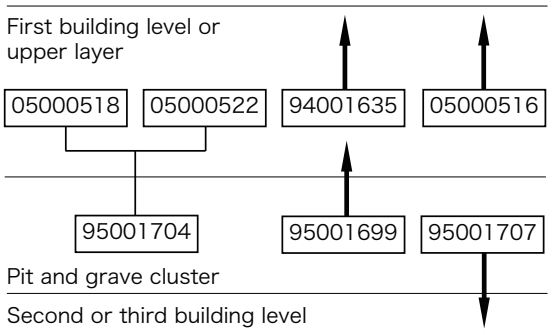

Fig. 3 The archaeological context of the samples in Stratum I. Arrows imply possible sample movement to other terms: the upward arrows mean that the sample may belong to the next upper layer.

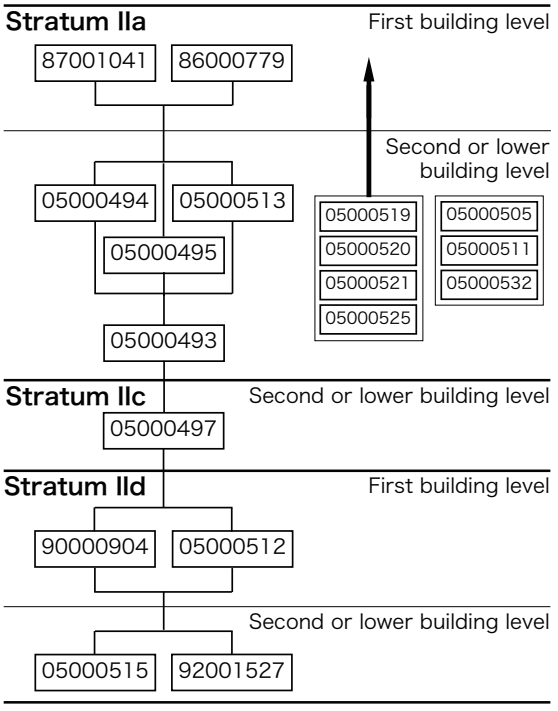

Fig. 4 The archaeological context of the samples in Stratum II

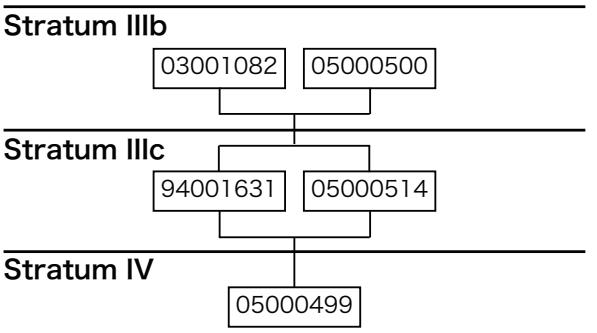

Fig. 5 The archaeological context of the samples in Stratum IV-III

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)

Year No.	^{14}C age BP ± 1 δ	Lab. Code (NUTA2-)	Calibrated age Unmodelled	Probability (%)	Calibrated age Modelled	Probability (%)	Agreement (%)
94001635	348 ± 23	10594	1460 - 1530 cal AD 1540 - 1630 cal AD	40.1 55.3	1480 - 1530 cal AD 1540 - 1640 cal AD	32.1 63.3	101.9
95001699	323 ± 23	10595	1490 - 1600 cal AD 1610 - 1640 cal AD	75.2 20.2	-	-	-
95001704	364 ± 23	10598	1450 - 1530 cal AD 1560 - 1630 cal AD	54.0 41.4	1450 - 1530 cal AD	95.4	102.4
95001707	994 ± 24 943 ± 20	10599 11002	1020 - 1050 cal AD 1080 - 1130 cal AD 1140 - 1150 cal AD	39.6 42.5 13.4	-	-	-
05000516	240 ± 19 291 ± 23	10988 10577	1530 - 1670 cal AD 1790 - 1800 cal AD	93.2 2.2	1530 - 1670 cal AD	95.4	96.4
05000518	357 ± 24	10581	1450 - 1530 cal AD 1550 - 1630 cal AD	48.1 47.3	1470 - 1530 cal AD 1540 - 1630 cal AD	36.4 59.0	100.9
05000522	374 ± 23	10585	1450 - 1520 cal AD 1570 - 1630 cal AD	64.1 31.3	1470 - 1520 cal AD 1560 - 1630 cal AD	44.6 50.8	91.6
86000779	2205 ± 20 2211 ± 22	10995 10996	360 - 200 cal BC	95.4	380 - 270 cal BC 260 - 240 cal BC 230 - 220 cal BC	86.7 4.0 4.7	89.5
87001041	2491 ± 21	10994	770 - 540 cal BC	95.4	500 - 410 cal BC 260 - 240 cal BC 230 - 210 cal BC	91.8 1.0 2.6	94.5
05000493	2540 ± 25	10560	800 - 740 cal BC 690 - 660 cal BC 650 - 550 cal BC	42.7 19.4 33.3	830 - 800 cal BC	95.4	0.6
05000494	2552 ± 26	10561	800 - 750 cal BC 690 - 660 cal BC 640 - 590 cal BC 580 - 560 cal BC	56.5 17.5 16.7 4.7	800 - 750 cal BC 690 - 660 cal BC 640 - 590 cal BC	70.0 16.0 9.4	111.6
05000495	2555 ± 25	10564	800 - 750 cal BC 690 - 670 cal BC 640 - 590 cal BC 580 - 560 cal BC	62.5 16.8 13.4 2.8	800 - 750 cal BC 690 - 670 cal BC 640 - 600 cal BC	73.7 14.6 7.1	109.9
05000505	2547 ± 25 2492 ± 21	10569 10982	780 - 740 cal BC 690 - 660 cal BC 650 - 550 cal BC	21.6 18.9 54.9	780 - 740 cal BC 690 - 660 cal BC 650 - 550 cal BC	17.2 23.2 55.1	101.2
05000511	2469 ± 25	10573	760 - 680 cal BC 670 - 490 cal BC 460 - 420 cal BC	30.1 58.6 6.7	760 - 680 cal BC 670 - 550 cal BC	38.5 56.9	107.7
05000513	2726 ± 21	10986	910 - 820 cal BC	95.4	820 - 800 cal BC	95.4	5.5
05000519	2333 ± 25	10582	480 - 460 cal BC 450 - 440 cal BC 420 - 370 cal BC	1.9 0.4 93.1	510 - 440 cal BC 420 - 370 cal BC	12.0 83.4	86.1
05000520	2449 ± 25	10583	750 - 690 cal BC 670 - 640 cal BC 620 - 610 cal BC 600 - 410 cal BC	26.1 9.3 1.1 58.9	750 - 690 cal BC 670 - 640 cal BC 620 - 610 cal BC 600 - 410 cal BC	18.4 8.8 1.5 66.8	98.3
05000521	2525 ± 25	10584	790 - 730 cal BC 690 - 660 cal BC 650 - 540 cal BC	29.5 18.4 47.5	790 - 740 cal BC 690 - 660 cal BC 650 - 540 cal BC	15.0 17.4 62.9	93.8
05000525	2480 ± 21	10990	770 - 510 cal BC	95.4	740 - 510 cal BC 440 - 430 cal BC	94.6 0.8	99.0
05000532	2504 ± 21	10992	780 - 720 cal BC 700 - 540 cal BC	20.0 75.4	770 - 720 cal BC 700 - 550 cal BC	16.9 78.5	101.8
05000497	2756 ± 26 2723 ± 22	10566 10978	920 - 830 cal BC	95.4	890 - 830 cal BC	95.4	109.8
90000904*	2694 ± 58 2748 ± 44	- -	970 - 960 cal BC 930 - 810 cal BC	1.9 93.5	980 - 960 cal BC 950 - 850 cal BC	6.2 89.2	92.3
92001527	2878 ± 25 2911 ± 26	10586 10587	1190 - 1180 cal BC 1160 - 1150 cal BC 1130 - 1010 cal BC	1.1 1.2 93.1	1190 - 1180 cal BC 1160 - 1150 cal BC 1130 - 1010 cal BC	1.0 1.1 93.2	100.1
05000512	2742 ± 25 2695 ± 22	10574 10985	900 - 820 cal BC	95.4	910 - 850 cal BC	95.4	94.3
05000515	3086 ± 26	10576	1430 - 1290 cal BC	95.4	1420 - 1270 cal BC	95.4	92.4
03001082	3360 ± 26 3324 ± 22	10593 10998	1690 - 1610 cal BC 1580 - 1540 cal BC	78.6 16.8	1690 - 1600 cal BC 1580 - 1540 cal BC	82.7 12.7	102.7
05000500	3346 ± 26	10568	1730 - 1720 cal BC 1690 - 1600 cal BC 1590 - 1530 cal BC	2.6 73.7 19.1	1690 - 1600 cal BC 1590 - 1530 cal BC	79.9 15.5	105.2
94001631	3473 ± 22	10999	1880 - 1840 cal BC 1820 - 1800 cal BC 1780 - 1750 cal BC	26.0 15.4 26.7	1880 - 1740 cal BC	95.4	100.1
05000514	3511 ± 26	10575	1910 - 1750 cal BC	95.4	1890 - 1750 cal BC	95.4	101.5
05000499	3717 ± 27	10567	2200 - 2160 cal BC 2150 - 2030 cal BC	18.0 77.4	2200 - 2030 cal BC	95.4	99.5

*cf. Omori 2005

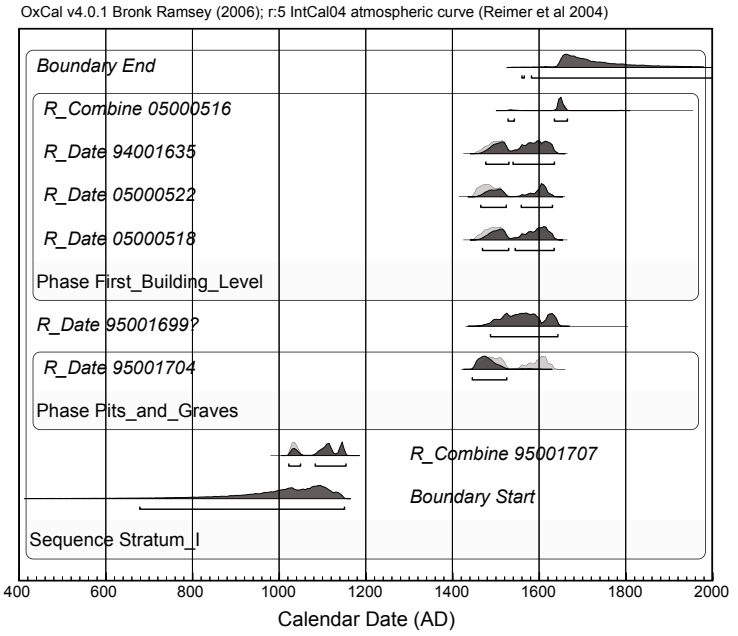

Fig. 6 The results of calibration (in outline) of ^{14}C age for the samples from Stratum I.
The solid black distributions are the result of a Bayesian analysis as by using the chronological context given in Fig. 3, and the under bars are the age range with 2σ (95.4% probability). We used some CQR2 commands; "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

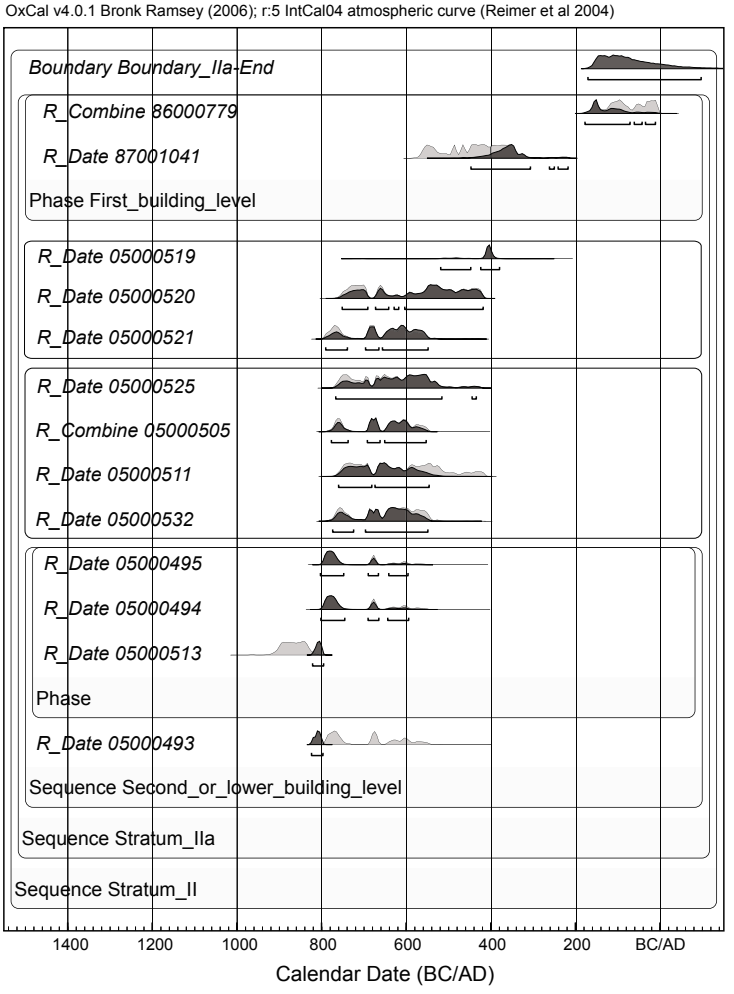

Fig. 7 The results from Stratum IIa; see the caption in Fig. 6 for details

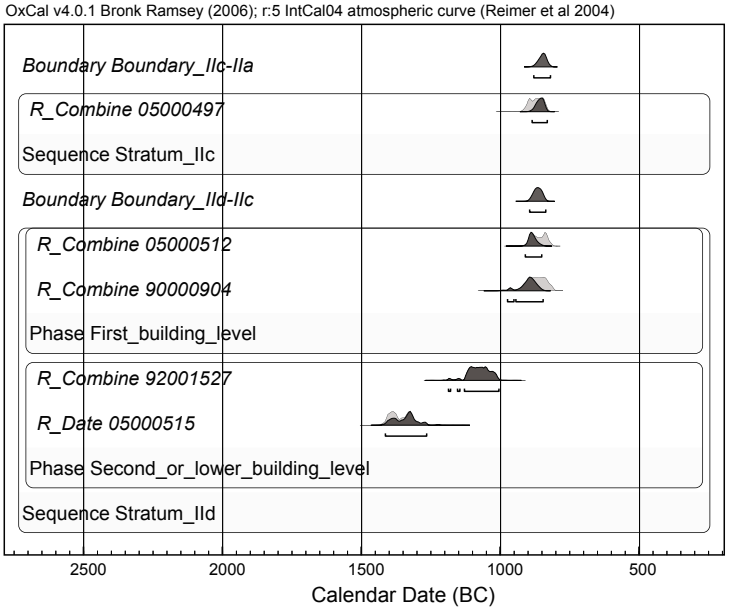

Fig. 8 The results from Stratum IIc-d; see the caption in Fig. 6 for details

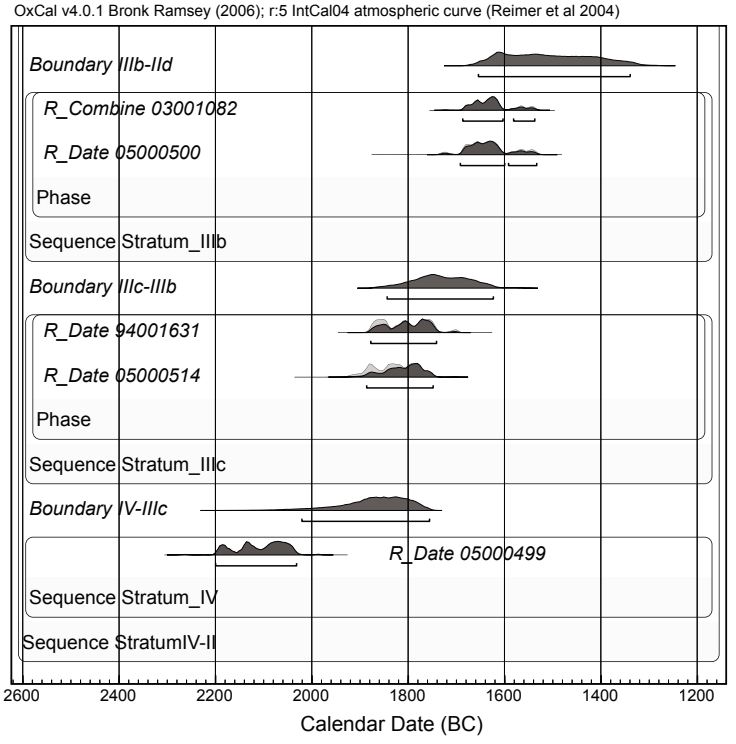

Fig. 9 The results from Stratum IV-III; see the caption in Fig. 6 for details

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 ^{14}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 ^{14}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 ^{14}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.

Table 3 The results of each boundary age calculated by a Bayesian analysis

Boundary	Calibrated age	Probability (%)
Stratum I End	1570 AD - Present	95.4
Stratum I Start	670 - 1150 AD	95.4
Stratum IIa End	370 - 100 Cal Bc	95.4
Stratum IIc - IIa	880 - 820 Cal Bc	95.4
Stratum IId - IIc	890 - 840 Cal Bc	95.4
Stratum IIIb - IId	1660 - 1340 Cal Bc	95.4
Stratum IIIc - IIIb	1850 - 1620 Cal Bc	95.4
Stratum IV - IIIc	2030 - 1760 Cal Bc	95.4

5.6 Each Boundary Age

The OxCal program can also provide the boundary ages by using Bayesian statistics. The boundary ages estimated from ^{14}C results are shown in Table 3. We have obtained good agreements of our results with archaeological considerations, except for the boundarys of IIa-IIc and IIc-IId.

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 ^{14}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 ^{14}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.

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