15 The Groningen Radiocarbon Series from Tel Reḥov

OxCal Bayesian computations for the Iron IB–IIA Boundary and Iron IIA destruction events

Hendrik J. Bruins, Johannes van der Plicht, Amihai Mazar, Christopher Bronk Ramsey, and Sturt W. Manning

Abstract

The stratified series of Iron Age radiocarbon dates from Tel Reḥov, based on short-lived samples, measured in Groningen, is the most detailed and dense chronometric record currently available for the Levant in this period. The more detailed IntCal98 calibration curve was used, though some comparisons were made with the smoothed IntCal04 curve. The current Bayesian stratigraphic model for Tel Reḥov gave a number of significant results. The data strongly favour an early Iron Age IB–IIA transition, as the statistically sampled boundary in the 1σ range is 992–961 BCE (68.2%). Considering the 2σ range, the older time option, 998–957 BCE, further increases in probability to 75.2%, but a second option also appears, 953–921 BCE, albeit with a significantly lower relative probability of 20.2%. Our Bayesian model was also tested with the IntCal04 calibration curve, which gave similar but slightly older results: the 1σ range is 993–961 BCE (68.2%) and the 2σ range is 1001–927 BCE (95.4%). The peak probability remains the same at ca. 970 BCE. The Stratum VI dates have the most likely position within the 1σ range 971–958 BCE (62.4%). The City of Stratum V had a possible duration of 26 to 46 years, in the 1σ and 2σ ranges, respectively. The 1σ sampled destruction of City V is 924–902 BCE (68.2%). This time range could fit a possible association with the Asian campaign of Shoshenq I (Shishak), solely based on Egyptian criteria (see Shortland [Chapter 4, this volume]). Running the Bayesian model with the IntCal04 calibration curve yielded a slightly older date in the 1σ range: 929–906 BCE (68.2%). The latter range does include the date 925 BCE for the Shoshenq campaign as suggested by Kitchen (1986, 2000). The City of Stratum IV had a possible duration of 28–55 years, in the 1σ and 2σ ranges, respectively. The 1σ sampled destruction of City IV is 903–892 (13.4%), 885–845 BCE (54.8%). Thus, the Bayesian statistical computation results of the Tel Reḥov stratigraphic model generally strengthen earlier conclusions concerning a revised traditional chronology, and do not indicate support for the low chronology viewpoint.

Introduction

The purpose of this paper is to show the results of Bayesian statistical analysis of the Groningen radiocarbon dates from Tel Reḥov, which form the most detailed Iron Age chronometric record currently available from a single site for the Levant (Mazar *et al.* [Chapter 13, this volume]; van der Plicht and Bruins [Chapter 14, this volume]). The results are compared with previous results and conclusions (Bruins, van der Plicht and Mazar 2003a, 2003b), in which Bayesian statistics were not employed. The critique of this work by Finkelstein and Piasetzky (2003a, 2003b) is also evaluated in light of the Bayesian results.

The OxCal program (Bronk Ramsey 1995, 2001, 2003) provides the important ability to engage in Bayesian statistical analysis of radiocarbon datasets where other, prior, information is available, such as a stratigraphic sequence; see also Buck and Millard (2004). Thus, the program enabled the development of a Bayesian model that incorporated as well as possible the detailed available stratigraphic information of Tel Reḥov. Essentially, a succession of 'Phases' and 'Boundaries' needs to be defined in the correct stratigraphic order (note: 'Boundaries' are horizons we wish to be able to date between the identified 'Phases' with their ^{14}C dating information—these boundaries or transitions are quantified through the analysis). The program will assume *a priori* that the period from which the dates are selected has no limits. Therefore, the 'Boundary' command has to be used in the correct way in order to place limits in the model, according to the stratigraphy and other relevant information available. Any coherent group of dates should be contained within boundaries to signal to the program that they all belong to one period. A sequence is defined in the program as a group of successive phases with no possibility of overlap in time.

An OxCal Bayesian Model for the Stratigraphy of Tel Reḥov

The building of an appropriate Bayesian model that reflects as satisfactorily as possible the observed Iron Age stratigraphy at Tel Reḥov cannot incorporate all the 64 Groningen dates from Tel Reḥov. There are archaeological constraints in terms of some stratigraphic uncertainties (Mazar *et al.* [Chapter 13, this volume]). The dates used, therefore, are mainly from Area D and Area C on archaeological grounds. Moreover, the ^{14}C dates from a certain Locus or 'Phase' should be internally coherent in the sense that recognisable outliers should be removed *before* the Bayesian analysis. Yet samples that seem to have every stratigraphic reason to be correct but appear to have less ^{14}C coherence should not be arbitrarily withheld from the model. Such samples may end up as not agreeing *after* the Bayesian analysis. Their low agreement index indicates a problem (maybe instances of reworked material, humic acid infiltration, erroneous stratigraphic interpretation, and so on). Nevertheless, a few of such erroneous samples will have little impact on the overall Bayesian dating results, if the number of coherent dates is sufficiently large. This is an important strength of employing a holistic analytical framework.

The model that has been developed is presented in Table 15.1, showing all stratigraphic and ^{14}C date components. A concise description of the model is given below, as extensive information about each Stratum and Locus is available (Bruins, Mazar and van der Plicht, in press; Bruins, van der Plicht and Mazar 2003a; Mazar 1999, 2003; Mazar *et al.* [Chapter 13, this volume]; van der Plicht and Bruins [Chapter 14, this volume]). Most Groningen radiocarbon dates from Tel Reḥov are based on seeds. Therefore, a calibration curve based on single year dendrochronological measurements would have been preferable, as stated by Mook and Waterbolk (1985: 22): 'the ^{14}C sample and the calibration data should have the same time-width (growth-period)'. Such a curve is not available for the approximate time-period 1200–600 BCE of the Levantine Iron Age. Since the 1998 calibration curve (Stuiver *et al.* 1998; Stuiver and van der Plicht [eds.] 1998) is more detailed than the smoothed 2004 version (Reimer *et al.* 2004), the former has been used rather than the latter. The dendrochronological database for the IntCal04 curve is largely similar to the dataset of the IntCal98 curve, but also includes new measurements for the Iron Age period, for example, on German Oak samples run for the East Mediterranean Radiocarbon Intercomparison Project (see also Manning *et al.* [Chapter 10, this volume]). A trial run of the model against the IntCal04 calibration curve gave essentially similar results, albeit that the dates become slightly older. A few examples of these IntCal04 results are included for comparison in relation to the Iron IB–IIA boundary and the Stratum V destruction event.

There is another basic aspect that should be mentioned here briefly in relation to the Groningen ^{14}C dates of Tel Reḥov: 'The statistical (random) nature of radioactive decay causes the results of repeated measurements to spread around a "true" value. The possible discrepancy between a measured value and the "true" value is indicated by the standard deviation (σ)' (Mook and Waterbolk 1985: 10). Therefore, the midpoint value of a single date may be 1σ (68.2%) or 2σ (95.4%) away from the 'true' value. Making two or three measured values of the same sample (sub-samples), each with its own pre-treatment, results in a much firmer dating basis, which we consider important in Near Eastern archaeology, as the ^{14}C dating method is pushed to its very limit of resolution (van der Plicht and Bruins 2001). Though two midpoint dates on both ends of a mutual 2σ range are considered the same in physical–mathematical terms, the calibrated age of each of them may be substantially different from an archaeological–historical perspective. It is imperative in our methodology of duplicate or triplicate measurements of single samples, employed for many of the Tel Reḥov Loci, to calculate the weighted average of the separate dating measurements. Thus, the outcome will be more precise and possibly also more accurate, closer to the 'true' value, if the radiocarbon laboratory involved does not have any systematic measurement bias (van der Plicht and Bruins [Chapter 14, this volume]). Hence the 'R_Combine' command is often used in the developed Bayesian model, so that the weighted average results of multiple measurements of one sample of a certain Locus are calculated by the model prior to the Markov Chain Monte Carlo sampling process (Bronk Ramsey 2003; Gilks, Richardson and Speigelhalter 1996). The underlying assumption for calculation of the weighted average is that the organic materials from the Locus are truly contemporary.

The oldest Iron Age layer at Tel Reḥov is Stratum D-6, containing Iron IA ceramics. This Stratum is represented in the model as 'Phase D6'. The term 'Phase' here is the OxCal model language terminology to characterise an archaeological layer that cannot overlap in time with another 'Phase', due to stratigraphic succession (Bronk Ramsey 2003). Hence, each Phase is contained within an upper and lower boundary in the model. 'Phase D6' is represented by two Loci (2874 and 2836), as each Locus has two coherent radiocarbon dates. The sample of charred olive stones from Locus 2874 was split and subsequently separately pre-treated and dated by the two different radiocarbon dating systems available at Groningen (van der Plicht and Bruins [Chapter 14, this volume]): Proportional Gas Counting (PGC) and Accelerator Mass Spectrometry (AMS). Thus, we have two dates from the same sample (Basket 28701) and, therefore, the 'R_Combine' command is used in the Bayesian model, as only the calculation of the weighted average of the same sample renders the correct representation for this Locus. The same procedure was followed for Locus 2836, as the charred olive stones from Basket 28352 were dated by both PGC and AMS. Such a procedure does not only increase precision but probably also accuracy, because two independent pre-treatment and radiocarbon dating systems are involved. Both Groningen systems having an ongoing record of accuracy against one another and against other high precision laboratories active in the field of calibration of the Radiocarbon timescale (Seattle, Belfast, Heidelberg, Groningen-conventional, Pretoria, and Tucson-conventional). Differences between the above laboratories are in the range of 0–20 ^{14}C years, with the difference between Pretoria and Groningen (conventional) being only 7 ^{14}C years, Groningen being slightly younger. The results of an intercomparison (LeClercq, van der Plicht and Gröning 1998) between Seattle, Belfast, Heidelberg, Groningen (both conventional and AMS), Waikato and Tucson (conventional) are available (see van der Plicht and Bruins [Chapter 14, this volume] for more details).

No ^{14}C dates are available for Stratum D-5, but the layer has been represented in the model in its stratigraphic order as 'Interval Phase D5', placed within boundaries. The introduction of the 'Interval' query in the model does not by itself alter the outcome of the computation results—the significant addition being the two 'Boundaries', which indicate that some time (period unknown) must have elapsed between Strata D-6 and D-4.

Stratum D-4, belonging to Iron Age IB in terms of material remains, yielded five radiocarbon dates from two Loci (1845 and 1836). This layer is termed 'Phase D4' in the model, contained within boundaries. Each Locus has coherent ^{14}C results. Locus 1845 yielded a sample of charred seeds (Basket 48556), which were dated by AMS in triplicate. A sample of charred olive stones (Basket 48450) was found at a somewhat higher level in Locus 1836. The sample was split, pre-treated separately and subsequently measured by PGC and AMS, respectively. The somewhat younger coherent dates fit well with the relative stratigraphy within Stratum D-4. The calculation of the weighted average of the available dates for each Locus is again signified by the 'R_Combine' command, which is appropriate in each case. Thus, the increased dating precision for each Locus (before calibration and Bayesian analysis) is based on multiple dates of the same sample material, respectively.

The refuse or storage pits of Stratum D-3 contain material remains that seem typical of the last part of Iron Age IB. Boundaries contain this stratigraphic period, defined as 'Phase D3' in the model. There are nine coherent radiocarbon dates available for Phase D3, derived from three Loci (4830, 2862 and 4815). The two dates for Locus 4816 are internally consistent but appear to be significantly older than the other D-3 Loci. Yet there is no obvious stratigraphic reason not to include this Locus in the model. Thus, we allow the Bayesian analysis to make the judgement and eleven D-3 dates are included. However, one date for Locus 2862 (GrN-26119) is clearly too young, because the sample was too small for Proportional Gas Counting, as explained by van der Plicht and Bruins (Chapter 14, this volume). This date is not included in the model. The same sample was subsequently measured by AMS and this result (GrA-19033) matches with the other dates and is included to represent Locus 2862. It was appropriate here to use the 'R_Combine' command in the model, as in previous cases, for each Locus that has multiple dates of the *same* sample.

The lower boundary of Phase D3 is of special importance, because it signifies the boundary between Iron I and Iron II. The Bayesian model calculates a time value for each boundary.

The oldest Iron IIA layer in the model is 'Phase Stratum VI City', contained within boundaries. Notice that the two Loci of Stratum D-2 are not placed in the model, because it cannot be decided on stratigraphic archaeological grounds whether these refuse layers belong to Stratum VI or V, all being Iron IIA. There are five radiocarbon dates from Stratum VI, all organic sample material coming from exactly the same position below a bowl above a floor in Locus 4426. The five dates pass the chi-squared test for a hypothesis of contemporaneity and, therefore, a weighted average seems a reasonable time representation for Stratum VI, as signalled to the model with the 'R_Combine' command. The organic materials at this stratigraphic spot (Basket 44166) consist of charred cereal grains, fine charcoal and a small bone. Since they were all found together below a bowl and above a floor, the three organic constituents could well have been from a single meal. The fine charcoal involved is certainly not old wood, as is clear from the radiocarbon dates, but may possibly relate to the grains. The very small bone is also short-lived. These organic constituents below the bowl might represent the same time period, but this is only one possible interpretation. Therefore, two alternative Bayesian model options were tested: (1) each date included separately, (2) the three triplicate dates on the fine charcoal with 'R_Combine' but the grains and bone dates separately. The Bayesian computations of the three model options were hardly different in outcome with regard to the Iron IB–IIA boundary and the destruction events that terminated City V and City IV.

Stratum V represents the next Iron IIA City at Tel Reḥov, overlying Stratum VI. Most secure ^{14}C dates available relate in stratigraphic terms to the destruction at the end of its lifespan. However, the duration of City V must also be represented in the model. Its lifespan can in fact be queried by inserting a line 'Interval Duration City V', separated by a boundary from the destruction phase. Only Locus 4218 from Area B seems to belong stratigraphically to the duration of City V and its three ^{14}C dates on charred olive stones are placed within the same 'Phase' as the 'Interval Duration City V' (see Table 15.1). The olive stones were split in three sub-samples, each pre-treated and dated separately by AMS. The results are coherent and the 'R_Combine' command gives the best possible time representation for Locus 4218.

Concerning the destruction Phase of City V, the charred cereal grains from Loci 2425, 2441 and 2444 are all from the same topographic level from building G (Mazar *et al.* [Chapter 13, this volume]). The Groningen radiocarbon results for Loci 2425 and 2441 are very similar and seem to suggest that the charred cereal grains from these Loci represent the same archaeological layer and destruction event, as also indicated by the similar height level. However, there may be a possibility (Mazar *et al.* [Chapter 13, this volume]) that Loci 2425 and 2444 belong to Stratum IV, and Mazar advised us not to include these Loci in the Bayesian model. Locus 2441 of building G has been included in the model. The weighted average (R_Combine) is the best time representation of the charred cereal grains of Locus 2441, which were split into two complete sub-samples, each pre-treated and dated separately by PGC.

Locus 2422 from a different building in Area C, with three coherent dates on charred cereal grains, is also placed in the model. Here we have an exceptional case of calculated precision that requires some additional explanation. The amount of charred cereal grains (Basket 24408) was quite large and three sub-samples were dated separately by PGC. Concerning the standard deviation of individual radiocarbon dates, the Proportional Gas Counters at Groningen (Mook 1983; van der Plicht, Streurman and Schreuder 1992) and Heidelberg (Kromer and Münnich 1992) are radiocarbon dating systems capable of delivering the highest possible precision (i.e. the smallest possible standard deviation). The lowest possible limit of about 10–15 ^{14}C years BP is determined by scatter, precision in standards, as well as the amount of available sample material, its age and measurement time. A sample consisting of 25 grams C that is measured routinely for two days (2700 minutes) in specific counters of the Groningen laboratory can give a low standard deviation of 9 ^{14}C years BP for modern samples and 12 ^{14}C years BP for samples of about 5000 years old (Mook and Waterbolk 1985: 12). The three PGC dates of Locus 2422 have standard deviations of 11 ^{14}C years BP (GrN-27361), 13 ^{14}C years BP (GrN-27362) and 28 ^{14}C years BP (GrN-27412), which are all within the capability of the Groningen PGC system and there is nothing extraordinary here (see also Bruins and van der Plicht 1995). However, averaging these dates does decrease the error to only 8 ^{14}C years BP. Since we have one single archaeological sample of charred cereal grains that was split into three sub-samples, the weighted average (R_Combine command in the model) calculation is appropriate.

Concerning the destruction phase of Stratum V, there are altogether five secure radiocarbon dates for this important event, which was tentatively associated with the campaign of Shoshenq I (Shishak), as discussed previously (Bruins, van der Plicht and Mazar 2003a). A line 'Event Destruction City V' was added into the model together with the above ^{14}C dates in order to signal to the model to make a specific calculation for this event.

Stratum IV was the last Iron Age IIA City at Tel Reḥov. Datable organic material was only found in Locus 5498 in the form of charred cereal grains, representing the destructive end of City IV. The seven AMS dates from this single sample of cereal grains (Basket 54702) are placed in the model, with the ‘R_Combine’ command determining the weighted average. Similar in procedure to the stratigraphic situation for City V, a separate Phase was placed in the model, albeit without ^{14}C dates, representing the duration of City IV, while an ‘Event Destruction City IV’ was placed together with the seven ^{14}C dates.

Table 15.1. A Bayesian model of the secure Groningen ^{14}C dates arranged according to the stratigraphy of Tel Reḥov.

```
Plot
{
 Sequence
{
Boundary;
Phase ‘D6’
{
R_Combine ‘D6b Locus 2874’
{
R_Date ‘GrN-26120’ 2880 30;
R_Date ‘GrA-19034’ 2935 45;
};
R_Combine ‘D6a Locus 2836’
{
R_Date ‘GrN-26118’ 2920 30;
R_Date ‘GrA-18826’ 2950 50;
};
};
Boundary;
Interval ‘Phase D5’;
Boundary;
Phase ‘D4’
{
R_Combine ‘D4b’
{
R_Date ‘GrA-21046’ 2905 35;
R_Date ‘GrA-21057’ 2945 35;
R_Date ‘GrA-21184’ 2920 50;
};
R_Combine ‘D4a’
{
R_Date ‘GrN-26121’ 2890 30;
R_Date ‘GrA-18825’ 2870 50;
};
};
Boundary;
Phase ‘D3’
{
R_Combine ‘Locus 4816’
{
R_Date ‘GrA-12889’ 2870 70;
R_Date ‘GrA-16848’ 2895 40;
};
R_Combine ‘Locus 4830’
{
R_Date ‘GrA-21044’ 2845 35;
R_Date ‘GrA-21056’ 2825 35;
R_Date ‘GrA-21183’ 2820 50;
R_Date ‘GrA-22302a’ 2730 50;
```

```
R_Date ‘GrA-22302b’ 2820 40;
R_Date ‘GrA-22329a’ 2810 50;
R_Date ‘GrA-22329b’ 2760 40;
};
R_Date ‘L2862 GrA-16757’ 2820 50;
R_Date ‘L4815 GrA-19033’ 2835 45;
};
Boundary;
Phase ‘Stratum VI City’
{
R_Combine ‘Locus 4426’
{
R_Date ‘GrN-27366’ 2761 14;
R_Date ‘GrA-21043’ 2755 35;
R_Date ‘GrA-21054’ 2805 35;
R_Date ‘GrA-21182’ 2800 50;
R_Date ‘GrA-21417’ 2840 45;
};
};
Boundary;
Phase ‘Stratum V City’
{
Interval ‘Duration City V’;
R_Combine ‘Locus 4218’
{
R_Date ‘GrA-21034’ 2760 35;
R_Date ‘GrA-21047’ 2820 35;
R_Date ‘GrA-21179’ 2770 50;
};
};
Boundary;
Phase ‘Stratum V Destruction’
{
R_Combine ‘Locus 2422’
{
R_Date ‘GrN-27361’ 2764 11;
R_Date ‘GrN-27362’ 2777 13;
R_Date ‘GrN-27412’ 2785 28;
};
R_Combine ‘Locus 2441’
{
R_Date ‘GrN-26116’ 2810 20;
R_Date ‘GrN-26117’ 2775 25;
};
Event ‘Destruction City V’;
};
Boundary;
Phase ‘Stratum IV City’
{
Interval ‘Duration City IV’;
};
Boundary;
Phase ‘Stratum IV Destruction’
{
R_Combine ‘Locus 5498’
{
R_Date ‘GrA-21152’ 2770 50;
```

```
R_Date 'GrA-21154' 2730 50;
R_Date 'GrA-21267' 2760 35;
R_Date 'GrA-22301a' 2710 45;
R_Date 'GrA-22301b' 2775 40;
R_Date 'GrA-22330a' 2760 50;
R_Date 'GrA-22330b' 2785 40;
};
Event 'Destruction City IV';
};
Boundary;
};
;
```

Bayesian Modelling Results

The computation results are shown in Table 15.2. The standard calibrated ages appear in the first half of the table, often with a calculation of the weighted average and the related chi-squared test results. T is the chi-squared value calculated and the value given in brackets is the level above which T should not rise in order to be acceptable. The degrees of freedom are given by df (the number of dates minus one). All T results in Table 15.2 are well below the respective values for rejection of the contemporaneity hypothesis at 95% confidence.

The Bayesian computation results appear in Table 15.2 after the line MCMC, which is the acronym for the Markov Chain Monte Carlo sampling process (Gilks, Richardson and Speigelhalter 1996). The MCMC technique allows samples to be taken that properly reflect the probability distributions and constraints. The program uses a mixture of the Metropolis-Hastings algorithm and the more specific Gibbs sampler (Bronk Ramsey 2003). In our case the program made 227,094 iterations for the sampling computations.

Table 15.2. The computation results of the above Bayesian model of secure Groningen ^{14}C dates arranged according to the stratigraphy of Tel Reḥov.

INFORM: References—Atmospheric data from Stuiver *et al.* (1998); OxCal v3.9 Bronk Ramsey (2003); cub r:1 sd:12 prob usp[chron]

```
(Sequence
Boundary _Bound
(Phase D6
R_Combine D6b Locus 2874: 2897.04±24.9616BP
 68.2% probability
 1125.7BC (60.6%) 1040.3BC
 1031.9BC (7.6%) 1020.1BC
 95.4% probability
 1209.5BC (2.0%) 1200.5BC
 1190.5BC (4.5%) 1177.2BC
 1160.7BC (4.6%) 1141.1BC
 1130.3BC (84.3%) 999.6BC
 X2-Test: df=1 T=1.0(5% 3.8)
R_Combine D6a Locus 2836: 2927.97±25.7248BP
 68.2% probability
 1209.4BC (5.1%) 1201.1BC
 1190.1BC (8.0%) 1177.9BC
 1158.8BC (11.3%) 1141.1BC
 1130.2BC (13.9%) 1107.7BC
 1102.2BC (20.7%) 1067.1BC
```

1065.5BC (9.1%) 1050.2BC
95.4% probability
1256.7BC (4.8%) 1238.6BC
1213BC (7.4%) 1197BC
1193.6BC (28.1%) 1137.9BC
1132.9BC (55.1%) 1018.5BC
X2-Test: df=1 T=0.3(5% 3.8)
) Phase D6
Boundary _Bound
Interval Phase D5
Boundary _Bound
(Phase D4
R_Combine D4b: 2924.08±22.1804BP
68.2% probability
1208.1BC (3.7%) 1202.3BC
1189.2BC (7.2%) 1179.1BC
1153.8BC (8.1%) 1142.1BC
1129.4BC (15.0%) 1107.7BC
1102.3BC (23.7%) 1066.8BC
1065.7BC (10.5%) 1050.1BC
95.4% probability
1254.6BC (2.4%) 1243.4BC
1211.6BC (6.2%) 1198.6BC
1192.1BC (25.7%) 1139.2BC
1131.8BC (61.0%) 1019.8BC
X2-Test: df=2 T=0.7(5% 6.0)
R_Combine D4a: 2884.72±25.7248BP
68.2% probability
1124.5BC (3.1%) 1119.4BC
1112BC (9.9%) 1097.8BC
1086.7BC (17.7%) 1059.6BC
1052.8BC (37.4%) 1004.6BC
95.4% probability
1189.1BC (2.8%) 1179.1BC
1153.3BC (2.0%) 1142.7BC
1129.2BC (86.7%) 996.3BC
989.4BC (2.4%) 974.3BC
954.7BC (1.5%) 943.9BC
X2-Test: df=1 T=0.1(5% 3.8)
) Phase D4
Boundary _Bound
(Phase D3
R_Combine Locus 4816: 2888.87±34.7298BP
68.2% probability
1125.4BC (4.9%) 1116.5BC
1114.7BC (33.4%) 1056.7BC
1055.1BC (29.9%) 1006.2BC
95.4% probability
1210.7BC (2.3%) 1199.4BC
1191.3BC (4.4%) 1175.5BC
1167.3BC (5.5%) 1140BC
1131.1BC (80.1%) 971.5BC
958BC (3.1%) 937.9BC
X2-Test: df=1 T=0.1(5% 3.8)
R_Combine Locus 4830: 2807.26±15.6507BP
68.2% probability
997BC (10.3%) 987.7BC

974.6BC (11.2%) 965.9BC
963.8BC (13.3%) 952.8BC
945.7BC (33.3%) 920BC
95.4% probability
999.9BC (92.6%) 913.9BC
911.4BC (2.8%) 905.3BC
X2-Test: df=6 T=5.3(5% 12.6)
L2862 GrA-16757: 2820±50BP
68.2% probability
1042.2BC (3.8%) 1030.8BC
1021.5BC (64.4%) 901.2BC
95.4% probability
1126BC (87.0%) 890.8BC
880.9BC (8.4%) 835.1BC
L4815 GrA-19033: 2835±45BP
68.2% probability
1045.6BC (68.2%) 919.5BC
95.4% probability
1128BC (93.5%) 895.6BC
876.5BC (1.9%) 856.9BC
) Phase D3
Boundary _Bound
(Phase Stratum VI City
R_Combine Locus 4426: 2772.33±11.4494BP
68.2% probability
969.3BC (12.7%) 960BC
927.8BC (52.3%) 897BC
873BC (3.3%) 868.3BC
95.4% probability
970.8BC (14.4%) 958BC
937.2BC (59.2%) 893.2BC
879BC (21.8%) 838.2BC
X2-Test: df=4 T=4.4(5% 9.5)
) Phase Stratum VI City
Boundary _Bound
(Phase Stratum V City
Interval Duration City V
R_Combine Locus 4218: 2786.21±22.1805BP
68.2% probability
995BC (2.2%) 991.2BC
972.9BC (19.4%) 955.6BC
941.8BC (46.7%) 898.7BC
95.4% probability
998.6BC (83.8%) 895.3BC
876.9BC (11.6%) 841.6BC
X2-Test: df=2 T=1.6(5% 6.0)
) Phase Stratum V City
Boundary _Bound
(Phase Stratum V Destruction
R_Combine Locus 2422: 2770.72±8.04333BP
68.2% probability
968.6BC (11.0%) 960.7BC
925BC (55.7%) 897.1BC
871.9BC (1.5%) 869.9BC
95.4% probability
969.9BC (12.5%) 959BC
934.2BC (61.6%) 894.1BC

878.3BC (21.3%) 839.9BC
X2-Test: df=2 T=0.9(5% 6.0)
R_Combine Locus 2441: 2796.4±15.6174BP
68.2% probability
972.6BC (23.7%) 956.3BC
940.9BC (44.5%) 904.9BC
95.4% probability
998.6BC (95.4%) 900.4BC
X2-Test: df=1 T=1.2(5% 3.8)
) Phase Stratum V Destruction
Boundary _Bound
(Phase Stratum IV City
Interval Duration City IV
) Phase Stratum IV City
Boundary _Bound
(Phase Stratum IV Destruction
R_Combine Locus 5498: 2758.06±16.3079BP
68.2% probability
917.7BC (28.8%) 895.3BC
876.9BC (23.9%) 856BC
854.2BC (15.5%) 840.2BC
95.4% probability
968.7BC (4.7%) 960.5BC
925.7BC (90.7%) 833.3BC
X2-Test: df=6 T=2.1(5% 12.6)
) Phase Stratum IV Destruction
Boundary _Bound
) Sequence
(MCMC
Sampled _Bound
68.2% probability
1133.8BC (68.2%) 1060.8BC
95.4% probability
1198.2BC (95.4%) 1042.7BC
Sampled D6b Locus 2874: 2897.04±24.9616
68.2% probability
1125.4BC (67.1%) 1067.9BC
1066.2BC (1.1%) 1065BC
95.4% probability
1188.6BC (2.4%) 1179.8BC
1156BC (4.5%) 1141.7BC
1130.2BC (88.5%) 1036.3BC
Agreement 109.9%
Sampled D6a Locus 2836: 2927.97±25.7248
68.2% probability
1122.2BC (61.3%) 1068.8BC
1061BC (6.9%) 1053.6BC
95.4% probability
1190BC (2.4%) 1177BC
1162.2BC (6.6%) 1139BC
1132.8BC (86.4%) 1036.3BC
Agreement 110.6%
Sampled _Bound
68.2% probability
1105BC (68.2%) 1047.1BC
95.4% probability
1151BC (3.0%) 1133.7BC

1129BC (92.4%) 1021.9BC
Sampled Phase D5
68.2% probability
-0.5 (68.2%) 27.9
95.4% probability
-0.5 (95.4%) 66.3
Sampled _Bound
68.2% probability
1076.9BC (68.2%) 1024.8BC
95.4% probability
1112.8BC (95.4%) 1011.9BC
Sampled D4b: 2924.08±22.1804
68.2% probability
1063.9BC (31.9%) 1044BC
1039.1BC (36.3%) 1015.7BC
95.4% probability
1090.5BC (95.4%) 1004.9BC
Agreement 70.7%
Sampled D4a: 2884.72±25.7248
68.2% probability
1053.9BC (68.2%) 1009.8BC
95.4% probability
1088.8BC (95.4%) 1000.5BC
Agreement 120.1%
Sampled _Bound
68.2% probability
1040.6BC (68.2%) 992.5BC
95.4% probability
1073.6BC (95.4%) 972.7BC
Sampled Locus 4816: 2888.87±34.7298
68.2% probability
1018.6BC (40.2%) 995BC
992.3BC (28.0%) 973.9BC
95.4% probability
1046.8BC (90.7%) 968.9BC
957.6BC (4.7%) 941.9BC
Agreement 76.4%
Sampled Locus 4830: 2807.26±15.6507
68.2% probability
999.7BC (57.5%) 979.8BC
974.9BC (10.7%) 969.6BC
95.4% probability
1003.9BC (95.4%) 938.5BC
Agreement 91.6%
Sampled L2862 GrA-16757: 2820±50
68.2% probability
1007BC (68.2%) 970BC
95.4% probability
1035.1BC (95.4%) 938.9BC
Agreement 130.2%
Sampled L4815 GrA-19033: 2835±45
68.2% probability
1008.6BC (68.2%) 971.2BC
95.4% probability
1036.5BC (95.4%) 939.7BC
Agreement 134.2%
Sampled _Bound

68.2% probability
991.8BC (68.2%) 961.3BC
95.4% probability
997.5BC (75.2%) 957.1BC
953.1BC (20.2%) 920.6BC
Sampled Locus 4426: 2772.33±11.4494
68.2% probability
970.8BC (62.4%) 958.3BC
933.6BC (5.8%) 929.2BC
95.4% probability
972.4BC (67.3%) 955.5BC
940.5BC (28.1%) 912.1BC
Agreement 86.7%
Sampled _Bound
68.2% probability
967.2BC (40.0%) 948.8BC
934.8BC (28.2%) 917BC
95.4% probability
968.6BC (95.4%) 910.7BC
Sampled Duration City V
68.2% probability
0.3 (68.2%) 26.1
95.4% probability
-0.5 (95.4%) 46.4
Sampled Locus 4218: 2786.21±22.1805
68.2% probability
941.2BC (68.2%) 910.9BC
95.4% probability
964.6BC (95.4%) 907.1BC
Agreement 116.5%
Sampled _Bound
68.2% probability
931.3BC (68.2%) 906.5BC
95.4% probability
957.9BC (95.4%) 902.1BC
Sampled Locus 2422: 2770.72±8.04333
68.2% probability
920.1BC (68.2%) 902.9BC
95.4% probability
934BC (95.4%) 896.9BC
Agreement 127.6%
Sampled Locus 2441: 2796.4±15.6174
68.2% probability
922.9BC (68.2%) 902.9BC
95.4% probability
939.4BC (95.4%) 898BC
Agreement 98.3%
Sampled Destruction City V
68.2% probability
924.2BC (68.2%) 901.6BC
95.4% probability
945BC (95.4%) 887.4BC
Sampled _Bound
68.2% probability
918.5BC (68.2%) 895.8BC
95.4% probability
931.7BC (95.4%) 873BC

Sampled Duration City IV
68.2% probability
-0.5 (68.2%) 27.7
95.4% probability
-0.5 (95.4%) 54.7
Sampled _Bound
68.2% probability
907.9BC (68.2%) 866.2BC
95.4% probability
919.2BC (95.4%) 844.1BC
Sampled Locus 5498: 2758.06±16.3079
68.2% probability
902.7BC (10.3%) 895.5BC
878.9BC (57.9%) 842.6BC
95.4% probability
911.1BC (24.5%) 886.1BC
885.1BC (70.9%) 834.9BC
Agreement 104.4%
Sampled Destruction City IV
68.2% probability
903.2BC (13.4%) 891.6BC
884.9BC (54.8%) 845.1BC
95.4% probability
917.5BC (95.4%) 823BC
Sampled _Bound
68.2% probability
899.5BC (9.0%) 889.5BC
876.7BC (59.2%) 828.3BC
95.4% probability
914.7BC (95.4%) 792.7BC
Overall agreement 115.3%
) MCMC
227094 iterations used

The Bayesian computation results for this model give an overall agreement index of 115.3%, which is well above the lower limit of 60% to meet an approximate 95% confidence level. All individual results for the various Phases and Loci also show an agreement above the 60% agreement threshold. A graphical overview of the results is shown in Figure 15.1. The solid black fill in each calibration graph shows the time-section selected by the Bayesian computation from within the full calibrated range. Thus, Bayesian statistics narrow down the width of the calibrated dates according to the stratigraphic model (stratigraphic time succession), thereby giving more precise results in historical years. Only the results related to the subject of this article are briefly discussed below, while a more extensive account will be published elsewhere.

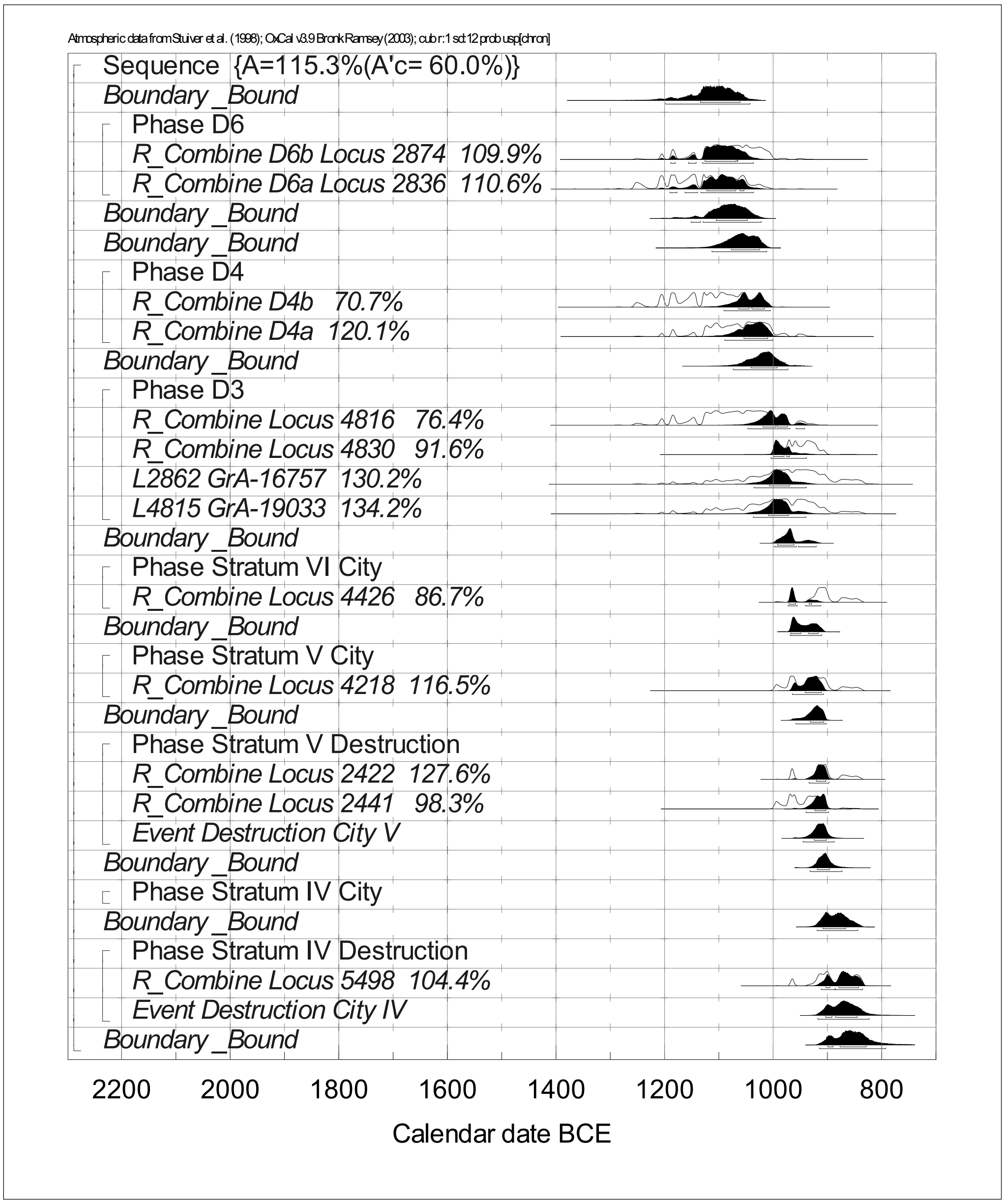

Figure 15.1. OxCal Bayesian statistical results showing the 1σ and 2σ calibrated age ranges (upper and lower horizontal black lines under each distribution, respectively), the sampled calibrated age ranges (solid black fill), as well as the sampled dates for boundaries and destruction events (solid black fill), according to the above stratigraphic model of Tel Reḥov (the two boundaries between Phase D-6 and D-4 relate to Phase D-5 in between, lacking ^{14}C dates).

The Iron Age IB–Iron Age IIA Boundary

The youngest Iron Age IB layer at Tel Reḥov in Area D is Stratum D-3, composed of refuse pits. The Bayesian statistical computation results for Locus 4815 (Fig. 15.2) are shown in more detail as an example (see also Locus 4815 within the general overview of Fig. 15.1). The 1σ sampled calibration range is 1009–971 BCE, which means that somewhere within this time period appears the highest relative sampled probability for the last stage of Iron IB, as represented at Tel Reḥov.

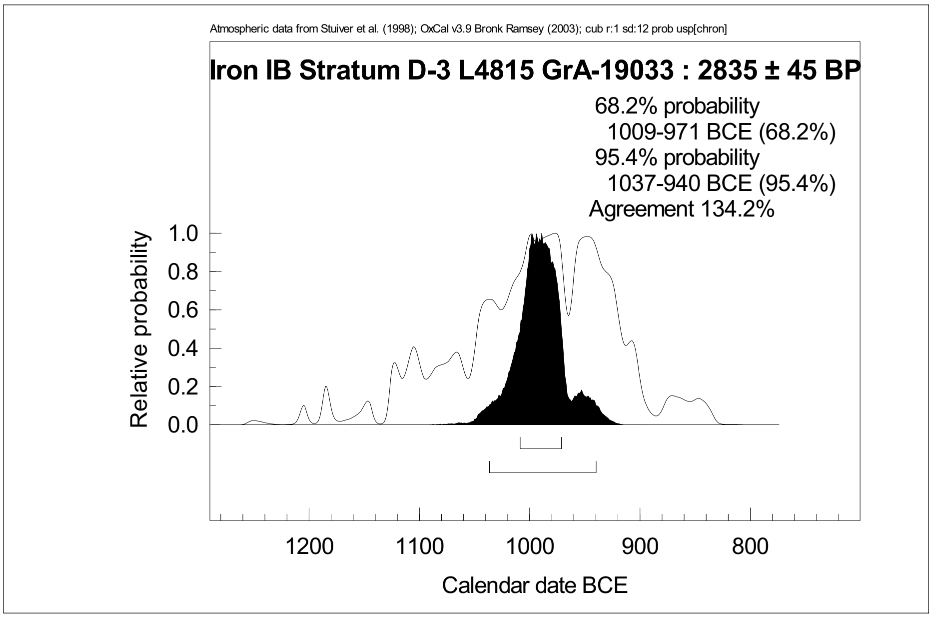

Figure 15.2. The Bayesian sampled date (solid black fill) from within the entire calibrated age range for Locus 4815 of Stratum D-3, the youngest Iron Age IB layer at Tel Reḥov. The upper and lower horizontal lines under each probability distribution indicate the 1σ and 2σ ranges, respectively.

The next youngest stratigraphic layer at Tel Reḥov is Stratum VI in Area C. The Bayesian model results from OxCal are shown in detail in Figure 15.3. The weighted average date for Stratum VI, 2772 ± 11 BP, hits the calibration curve at two places, reflected by the two peaks that reach a maximum relative probability level of 1 at the Y-axis. The Bayesian sampling computation according to the stratigraphic model selected the first peak as the most likely age range for Stratum VI, namely, 971–958 BCE. This result confirms the conclusions drawn by Bruins, van der Plicht and Mazar (2003a, 2003b), in which Bayesian statistics were not employed.

Alternative model options were also tested. Each radiocarbon date of Stratum VI was placed separately in the model, without using the R_Combine command. Thus, no weighted average was calculated and each date was separately evaluated by MCMC sampling. Another option that was also tested involved the inclusion of the three triplicate dates on fine charcoal by the R_Combine command, while the grains and bone date were included separately. Both alternative models gave essentially the same results for the Iron IB–IIA boundary and the destruction events of Strata V and IV. The model did indicate, however, that the only PGC grain date would drop just below 60% agreement (59% to 57% in different runs) with a standard deviation of 14 ^{14}C years BP. If the precision is relaxed to 20 ^{14}C years BP, the date becomes acceptable. There was no problem with the other four radiocarbon dates of Stratum VI. Moreover, the results of the above alternative models are very similar and the Bayesian computations remained remarkably stable and robust.

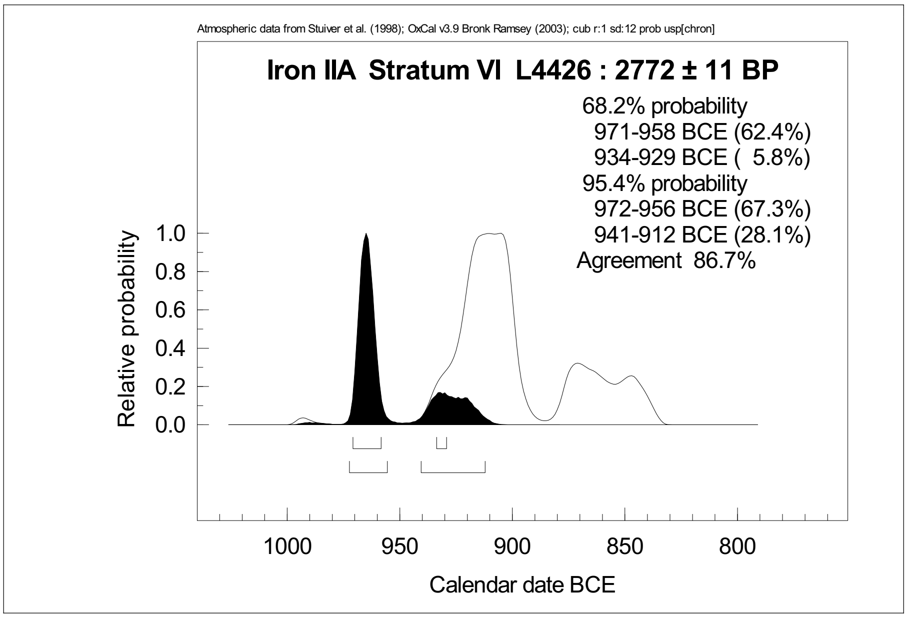

Figure 15.3. The Bayesian sampled date (solid black fill) from within the entire calibrated age range for Stratum VI, the oldest Iron Age IIA layer at Tel Reḥov.

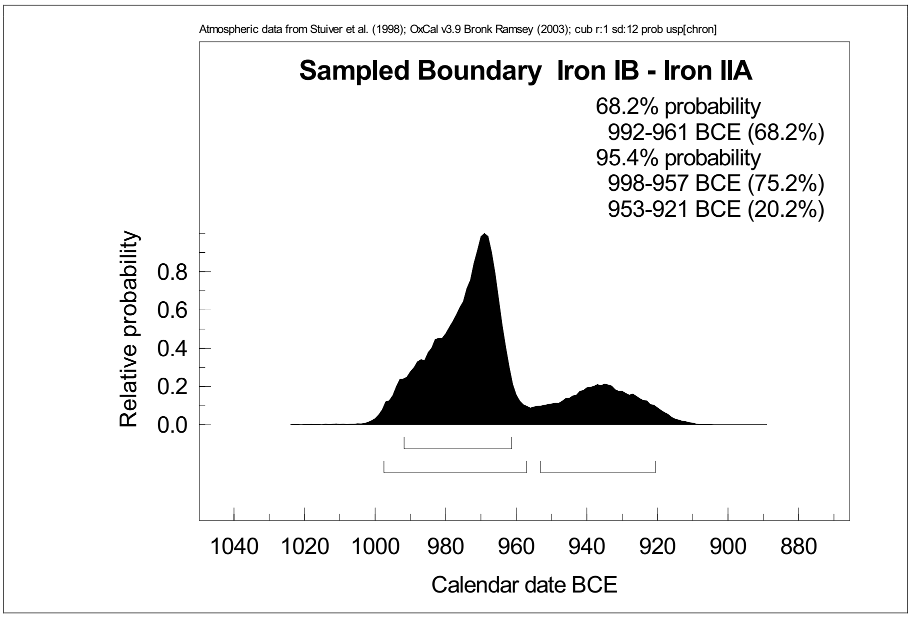

Figure 15.4. The Bayesian sampled date for the Iron IB–IIA Boundary between Stratum D-3 (youngest Iron IB) and Stratum VI (oldest Iron IIA) at Tel Reḥov.

Putting the most probable results for Stratum D-3 and Stratum VI in succession, it seems clear that the boundary between Iron IB and Iron IIA may well be placed around 980 BCE, as suggested by Mazar. On the other hand, placing this boundary around 900 or 920 BCE, as suggested by Finkelstein, seems very unlikely. Indeed, the sampled date for this boundary (Fig. 15.4) has the highest relative probability (1σ) within the period 992–961 BCE. The peak probability point is about 970 BCE (see Fig. 15.4, value of 1 on Y-axis), which is rather close to 980 BCE. The model was also tested vis-à-vis the IntCal04 calibration curve, which produced similar but slightly older results: the 1σ range is 993–961 BCE (68.2%) and the 2σ range is 1001–927 BCE (95.4%). The peak probability remains the same at ca. 970 BCE. Therefore, the Bayesian results, given the stratigraphic model, contradict the low chronology suggestions by Finkelstein and Piasetzky (2003a, 2003b) for both the IntCal98 and IntCal04 calibration curves.

The Destruction Event that Terminated the City of Stratum V

The detailed archaeological and radiocarbon date information for Stratum V are already described (Mazar *et al.* [Chapter 13, this volume]; van der Plicht and Bruins [Chapter 14, this volume]) and will not be repeated here. Concerning the destruction of City V, the Bayesian sampling result for the secure Locus 2422 is shown in detail (Fig. 15.5) as an example (see also the full sequence overview in Fig. 15.1). The highest relative probability (68.2%) for the destruction of Stratum V, in relation to Locus 2422 of Area C (Fig. 15.5), is the period 920–903 BCE. The agreement index with the stratigraphic model is 128%.

Notice that the weighted average ^{14}C date for Stratum VI and for the destruction phase of Stratum V are almost the same, 2772 ± 11 BP and 2771 ± 8 BP, respectively. Due to the wiggles in the calibration curve, it is difficult to decide whether radiocarbon dates in the range of about 2770–2750 BP, with a standard deviation (σ) of 20 or higher, belong to the 10th or 9th centuries BCE (see also Mazar *et al.* [Chapter 13, this volume]). Therefore, simple BP analysis (Finkelstein and Piasetzky 2003a, 2003b) without using the calibration curve and without wiggle-matching or Bayesian analysis cannot solve such a situation, because the radiocarbon time scale is not linear. The complex past reality of fluctuating concentrations of ^{14}C in the atmosphere and the resulting wiggles in the calibration curve *must* be taken into account through archaeological wiggle-matching (Bronk Ramsey, van der Plicht and Weninger [eds.] 2001; Bruins *et al.* 2003a; Manning and Weninger 1992) or Bayesian analysis (Bronk Ramsey 2003; Buck and Millard [eds.] 2004).

The 'Event Destruction City V' command line in the Bayesian model signalled the model to make a computation about this destruction event considering the five secure dates for the end of Stratum V (see Tables 15.1 and 15.2). The resulting sampled Bayesian date for the destruction of City V is 924–904 BCE in the 1σ range (Fig. 15.6). Previously, Bruins, van der Plicht and Mazar (2003a) had suggested a possible relationship between the destruction of Reḥov City V and the Asian campaign of Pharaoh Shoshenq I (Shishak). The date of 925 BCE has been suggested by Kitchen (1986, 2000) for this campaign based on both Egyptian and biblical chronological data. The above year would be just outside the sampled 1σ Bayesian computation of 924–904 BCE in relation to our Tel Reḥov stratigraphic model. However, the Bayesian result could fit chronologically with a novel historical dating assessment for Shoshenq I based on Egyptian texts only, in which a date around ca. 915 BCE for his campaign becomes feasible, as presented by Shortland (Chapter 4, this volume). Running our Bayesian model with the IntCal04 calibration curve yielded a slightly older date in the 1σ range: 929–906 BCE (68.2%). In fact the latter range does also now include the date 925 BCE for the Shoshenq campaign as suggested by Kitchen (1986, 2000).

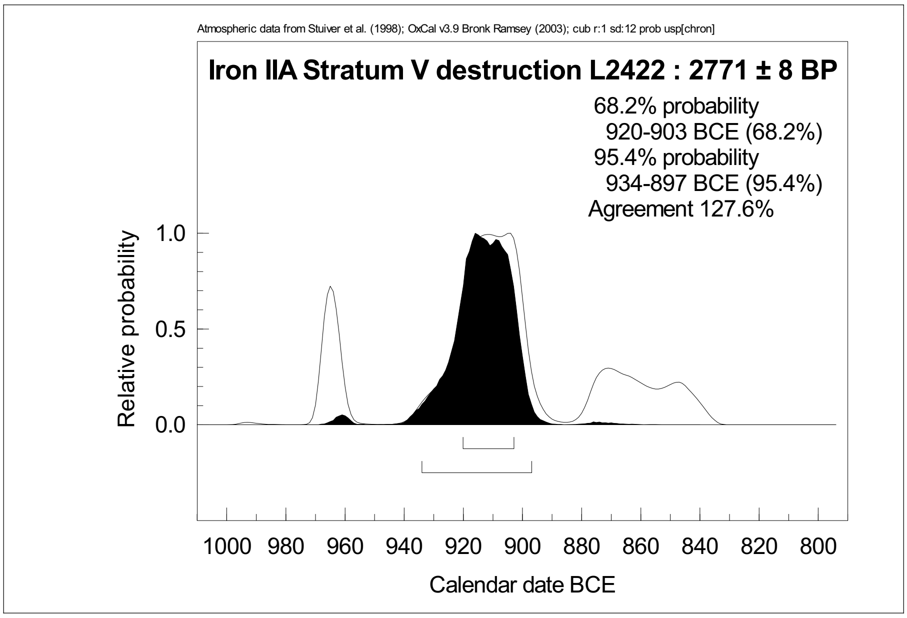

Figure 15.5. The detailed Bayesian sampled date (solid black fill) for the destruction of Iron IIA Stratum V, as shown for Locus 2422.

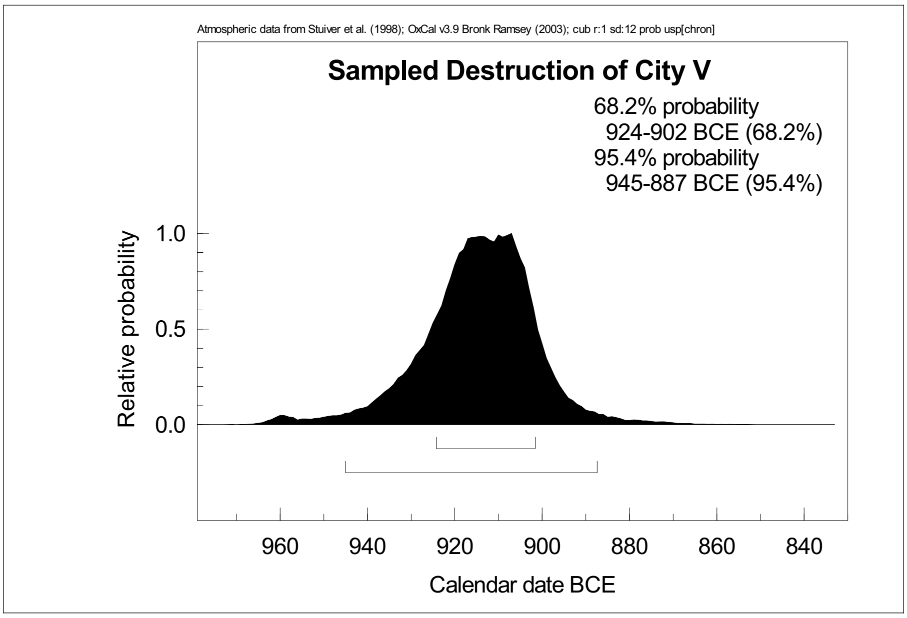

Figure 15.6. The sampled Bayesian date for the destruction of Stratum V, based on five secure radiocarbon dates from Area C.

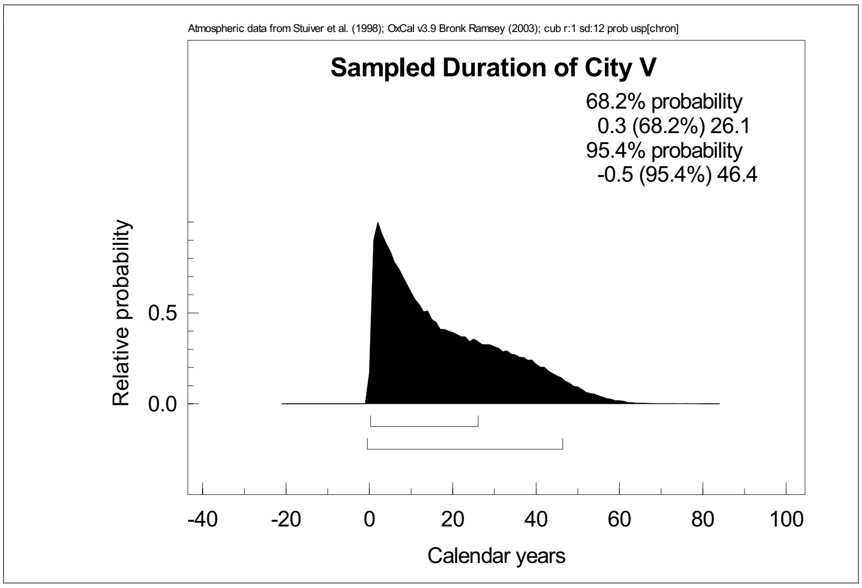

Figure 15.7. The Bayesian sampled date for the duration of City V, prior to its destruction.

Though the duration of City V is unknown, Finkelstein and Piasetzky (2003a) suggested a time-span for both City VI and City V of altogether 20 years in an attempt to squeeze the Groningen radiocarbon dates from Tel Reḥov into the young chronology theory. A duration of merely 10 years for City VI and another 10 years for City V seems very unlikely on archaeological grounds, besides ^{14}C evidence criteria (Bruins, van der Plicht and Mazar 2003b). What has Bayesian analysis to say on the subject? The line 'Interval Duration City V' signalled to the model to make a statistical computation about the duration of City V, prior to its destruction, as shown in Figure 15.7. The results suggest a time-span for City V of 26–46 years, in the 1σ and 2σ ranges, respectively.

The Destruction Event that Terminated the City of Stratum IV

The radiocarbon dates available for Stratum IV relate only to the destruction at the end of City IV's lifespan. The availability of samples for radiocarbon dating in archaeology are, unfortunately, more likely to come from fires or destruction events than from ordinary daily life. The sampled Bayesian destruction date of City IV (Fig. 15.8) has the highest probability in the 1σ range of 903–892 (13.4%), 885–845 BCE (54.8%), extended in the 2σ range to 918–823 BCE. Though it seems very unlikely that the Shishak campaign would have been responsible for the destruction of City IV, there are various other candidates later in time. As there are no younger Iron Age stratigraphic data from Tel Reḥov, the available ^{14}C data are insufficient to favour a certain decade within the above 2σ range of 920–815 BCE. The sampled Bayesian time-span for City IV is 28–55 years in the 1σ and 2σ ranges, respectively (Fig. 15.8).

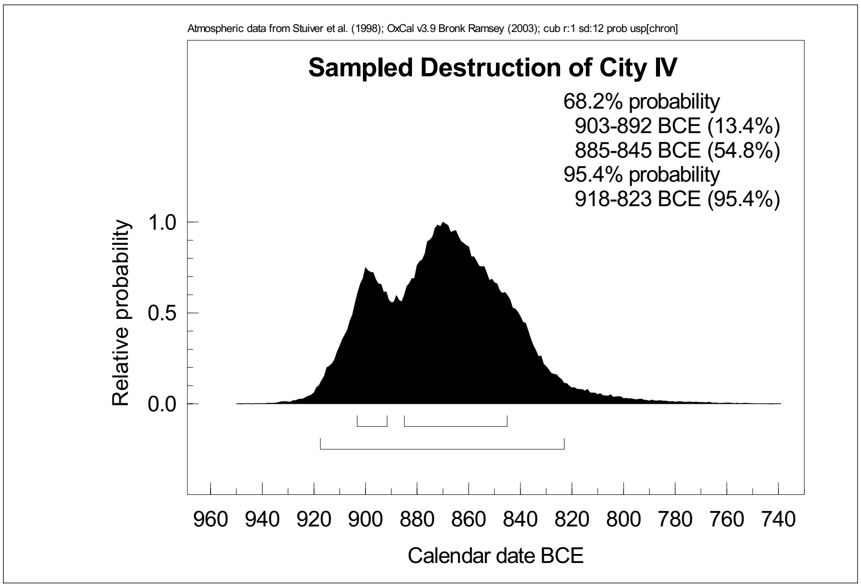

Figure 15.8. The sampled Bayesian date for the destruction of City IV, the last Iron Age settlement at Tel Reḥov.

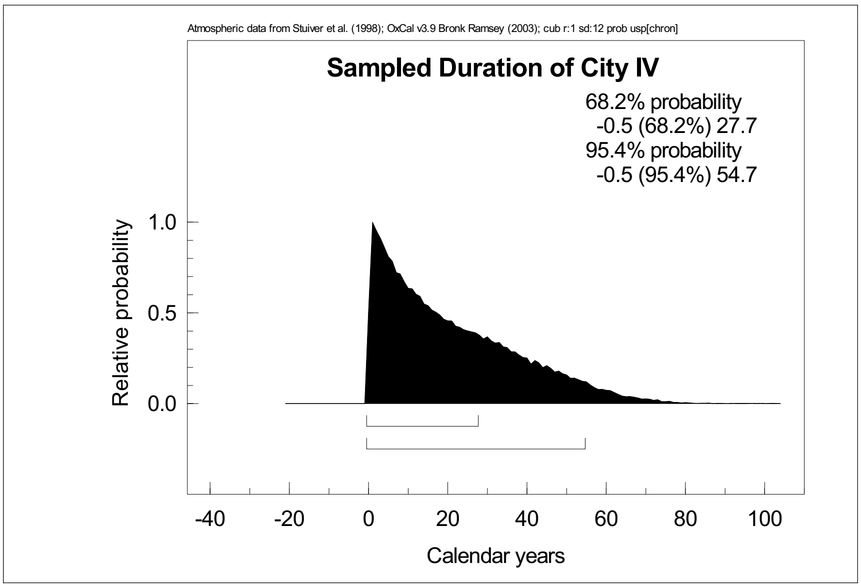

Figure 15.9. The Bayesian sampled date for the duration of City IV, prior to its destruction.

Conclusions

The Tel Reḥov excavations establish a detailed archaeological stratigraphy for the Iron Age with many finds of charred seeds in various Strata and Loci. A methodology of multiple radiocarbon measurements of single samples was used to increase precision and, very likely, also accuracy, as two independent Groningen dating systems were employed (PGC and AMS), each with independent criteria for accuracy (LeClercq, van der Plicht and Gröning 1998; van der Plicht and Bruins [Chapter 14, this volume]). The resulting dense dating basis embedded within a detailed stratigraphic sequence led to the development of a Bayesian model that proved to be remarkably stable and robust. Test runs of alternative model options gave similar results, also with respect to the IntCal98 and IntCal04 calibration curves. The latter curve resulted in slightly older dates. The above strategy considerably increased the time resolution and refinement of radiocarbon dating.

The current Bayesian stratigraphic model for Tel Reḥov gives the following most probable statistical results:

1. An early Iron Age IB–IIA transition is strongly favoured by the data, as the sampled boundary (IntCal98 calibration curve) in the 1σ range is 992–961 BCE (68.2%), and in the 2σ range 998–957 (75.2%), 953–921 BCE (20.2%). The peak probability date is ca. 970 BCE. Running the model with the IntCal04 calibration curve gives similar but slightly older results: the 1σ range is 993–961 BCE (68.2%) and the 2σ range is 1001–927 BCE (95.4%). The peak probability remains the same at ca. 970 BCE.
2. Stratum VI has its most likely 1σ position in the range 971–958 BCE (62.4%). The three model options that were tested, with or without R_Combine, all selected more or less the above time period.
3. The City of Stratum V had a possible duration of 26–46 years, in the 1σ and 2σ ranges, respectively.
4. The destruction of City V occurred most likely in the full 1σ range of 924–902 BCE (68.2%). This time range could perhaps fit with the chronological assessments for the Asian campaign of Shoshenq I (Shishak), based only on Egyptian criteria (Shortland [Chapter 4, this volume]). Running the Bayesian model with the IntCal04 calibration curve yielded a slightly older date in the 1σ range: 929–906 BCE (68.2%). The latter range does also include the date 925 BCE for the Shoshenq campaign as suggested by Kitchen (1986, 2000).
5. The City of Stratum IV had a possible duration of 28–55 years, in the 1σ and 2σ ranges, respectively.
6. The destruction of City IV occurred at some time in the 2σ range of 918–823 BCE (95.4%).

References

Bronk Ramsey, C. (1995) Radiocarbon Calibration and Analysis of Stratigraphy: The OxCal Program. *Radiocarbon* 37(2): 425-30.

—(2001) Development of the Radiocarbon Program OxCal. *Radiocarbon* 43 (2A): 355-63.

—(2003) OxCal Program v3.9, Radiocarbon Accelerator Unit, University of Oxford.

Bronk Ramsey, C., J. van der Plicht and B. Weninger (2001) 'Wiggle Matching' Radiocarbon Dates. *Radiocarbon* 43 (2A): 381-89.

Bruins, H.J., and J. van der Plicht (1995) Tell es-Sultan (Jericho): Radiocarbon Results of Short-lived Cereal and Multi-year Charcoal Samples from the End of the Middle Bronze Age. *Radiocarbon* 37: 213-20.

Bruins, H.J., J. van der Plicht, and A. Mazar (2003a) ^{14}C Dates from Tel Reḥov: Iron Age Chronology, Pharaohs, and Hebrew Kings. *Science* 300: 315-18.

—(2003b) Response to Comment on '^{14}C Dates from Tel Reḥov: Iron Age Chronology, Pharaohs and Hebrew Kings'. *Science* 302: 568c.

Bruins, H.J., A. Mazar and J. van der Plicht (in press) The End of the 2nd Millennium BCE and the Transition from Iron I to Iron IIA: Radiocarbon Dates of Tel Reḥov, Israel. In *The Synchronization of the Civilization in the Second Millennium BCE*, III, edited by M. Bietrak (Vienna: The Austrian Academy).

Buck, C.E., and A.R. Millard (eds.) (2004) *Tools for Constructing Chronologies* (London: Springer Verlag).
Gilks, W.R., S. Richardson and D.J. Speigelhalter (1996) *Markov Chain Monte Carlo in Practice* (London: Chapman & Hall).
Finkelstein, I., and E. Piasetzky (2003a) Comments on '^{14}C Dates from Tel Reḥov: Iron Age Chronology, Pharaohs and Hebrew Kings'. *Science* 302: 658b.
—(2003b) Wrong and Right, High and Low: ^{14}C Dates from Tel Reḥov and Iron Age Chronology. *Tel Aviv* 30: 283-95.
Kitchen, K.A. (1986) *The Third Intermediate Period in Egypt* (Warminster: Aris & Philips, 2nd edn).
—(2000) The Historical Chronology of Ancient Egypt: A Current Assessment. In *The Synchronization of Civilizations in the Eastern Mediterranean in the Second Millennium B.C.*, edited by M. Bietak (Vienna: Österreichische Akademie der Wissenschaften): 39-52.
Kromer, B., and K.O. Münnich (1992) CO_2 Gas Proportional Counting in Radiocarbon Dating—Review and Perspective. In *Radiocarbon After Four Decades. An Interdisciplinary Perspective*, edited by R.E. Taylor, A. Long and R.S. Kra (New York: Springer Verlag): 184-97.
LeClercq, M., J. van der Plicht and M. Gröning (1998) New ^{14}C Reference Materials with Activities of 15 and 50 pMC. *Radiocarbon* 40: 295-97.
Manning, S.W., and B. Weninger (1992) A Light in the Dark: Archaeological Wiggle Matching and the Absolute Chronology of the Close of the Aegean Late Bronze Age. *Antiquity* 66: 636-63.
Mazar, A. (1999) The 1997–1998 Excavations at Tel Reḥov: Preliminary Report. *IEJ* 49: 1-42.
—(2003) The Excavations at Tel Reḥov and their Significance for the Study of the Iron Age in Israel. *Eretz Israel* 27: 143-60.
Mook, W.G. (1983) International Comparison of Proportional Gas Counters for ^{14}C Activity Measurements. *Radiocarbon* 25: 475-84.
Mook, W.G., and H.T. Waterbolk (1985) *Handbook for Archaeologists*. III. *Radiocarbon Dating* (Strasbourg: European Science Foundation).
Reimer, P.J., *et al.* (2004) INTCAL04 Terrestrial Radiocarbon Age Calibration, 0-26 kyr BP. *Radiocarbon* 46: 1029-58.
Stuiver, M., and J.van der Plicht (eds.) (1998) Calibration Issue. *Radiocarbon* 40(3).
Stuiver, M., *et al.* (1998) INTCAL98 Radiocarbon Age Calibration, 24000-0 cal BP. *Radiocarbon* 40(3): 1041-83.
Van der Plicht, J., and H.J. Bruins (2001) Radiocarbon Dating in Near-Eastern Contexts: Confusion and Quality Control. *Radiocarbon* 43: 1155-66.
Van der Plicht, J., H.J. Streurman and G.R. Schreuder (1992) A New Data Acquisition System for the Groningen Counters. *Radiocarbon* 34: 500-505.