Sturt W. Manning

WHY RADIOCARBON DATING 1200 BCE IS DIFFICULT: A SIDELIGHT ON DATING THE END OF THE LATE BRONZE AGE AND THE CONTRARIAN CONTRIBUTION

Archaeological work employing sophisticated radiocarbon dating (and sometimes other natural science approaches) has made several significant advances in the last few years in clarifying and refining, or sometimes complicating/enriching(!), aspects or problems of east Mediterranean prehistoric chronology (e.g., Cichocki et al. 2004; Levy and Higham 2005; Cessford 2005; Manning et al. 2001a; 2006). Radiocarbon has become an essential element of modern prehistoric chronologies and our consequent historical syntheses. With appropriate samples and good methodology, radiocarbon dating has the direct potential to provide independent dates for archaeological contexts, separate from long-standing cultural assumptions, debated proto-historical information, and so on. At the same time, however, this work has been the target for much contrarian attack and discussion. Critics have sought to find fault with, modify, or dismiss the radiocarbon evidence, analyses thereof, and resultant chronologies —in most (recent) cases with the aim of achieving lower dates than those indicated by either radiocarbon or conventional archaeological-historical synthesis, or (usually) both. Although this may at first sight appear to be an unproductive dialectic with at least one side effectively ignoring the other in all but straw-man terms—and there is undoubted frustration on the radiocarbon side as work is routinely misrepresented—nonetheless, this situation can in fact be healthy for the wider field. The contrarian critique can (perhaps inadvertently) usefully lead to stronger and more robust radiocarbon work, and its tighter integration with archaeological evidence. The outcome is that instead of undermining the radiocarbon work they wish to attack or dismiss, the contrarians in fact strengthen it in a rather paradoxical and Nietzschean twist.

In this paper I look at one example: the attempt to date east Mediterranean archaeological contexts of the end of the Late Bronze Age around 1200 BCE—traditionally more or less the time of the collapse of the Hittite Empire, the end of the Late Cypriot IIC period on Cyprus, towards the end of the Late Helladic IIIB period in the Aegean, the beginning of the main attested period of the 'Sea Peoples' in the eastern Mediterranean, and the ensuing 12th century BCE so-called 'crisis years' (cf. Yakar 2006; Manning et al. 2001b; Warren and Hankey 1989; Sandars 1978; Ward and Joukowsky 1992; Oren 2000; and various papers in this volume). This study is prompted by the fine example of the contrarian approach to be found in a paper by Hagens (2006). I consider this topic in order to illustrate how important an understanding of the natural history of past radiocarbon variations is to a sophisticated radiocarbon dating programme, and how *sequence* analysis in radiocarbon work (of temporally seriated archaeological data based on the excavated stratigraphy) offers a much more robust and powerful means to calendar age determinations than the simple calibration of a single radiocarbon age value (whether from a single date or an average of dates). Indeed, in many instances, selective citation of single dates or small groups can easily misrepresent the overall situation. In the case in point, Hagens achieves his purported criticism of existing work, and the suggestion of a lower chronology, by looking at sets of data in isolation, and not as part of sequences. This can be (and in this instance is) misleading. Radiocarbon analysis of archaeological sites is necessarily a holistic study. This paper employs as its example the impossibility of narrowly/successfully dating a context of 1200 BCE by single-case (or single set) radiocarbon dating. Such a context can only be successfully dated unambiguously and with precision via a sequence analysis. At the same time, the contrarian attack nicely forces clarification of the situation and so serves us well, since it makes the case it seeks to attack clearer and stronger in the long run.

Radiocarbon Calibration and Possibilities

Radiocarbon chronology, and its potential and limitations for a given calendar time interval, largely depends on the shape of the radiocarbon calibration curve. The current internationally accepted radiocarbon calibration dataset for the Holocene is IntCal04, derived for this time period from known age tree-rings mainly from Germany and Ireland (Reimer et al. 2004). The previous standard curve was IntCal98 (Stuiver et al. 1998), and was based largely on a similar database of underlying measurements, though some important additions of new data and improvements exist, for example in the 8th century BCE. The IntCal04 curve is an estimate at five-year resolution, employing a sophisticated random-walk model which smoothes the inherent noise in the raw calibration datasets on the basis of a moving five decade window. IntCal98 offered ten-year resolution and merely averaged the dates in that interval to achieve a data point for the calibration curve. It is thus more 'ragged' (or up and down) than the smoother IntCal04 curve. The two curves are compared for the period 1500–1000 BCE in Figure 1. While largely very similar, the slight smoothing of the prominent ups and downs—the 'wiggles'—in IntCal98 can be observed in IntCal04: the inset shows the curve data points with 1σ error bars in detail for a sub-period either side of 1200 BCE.

The shape of the calibration curve determines dating probabilities for individual radiocarbon ages in any given period. Radiocarbon ages which intersect with a steep slope in the radiocarbon calibration curve can thus yield single, relatively precise, calendar age ranges (for an example, see Fig. 2). In contrast, radiocarbon ages which intersect with periods with plateaux or multiple wiggles including similar radiocarbon ages, yield either multiple possible calendar age ranges or very wide—non-precise—age ranges (for an example of each, see Figs. 3 and 4). I note here that all calibration and calibration analysis in this paper has been

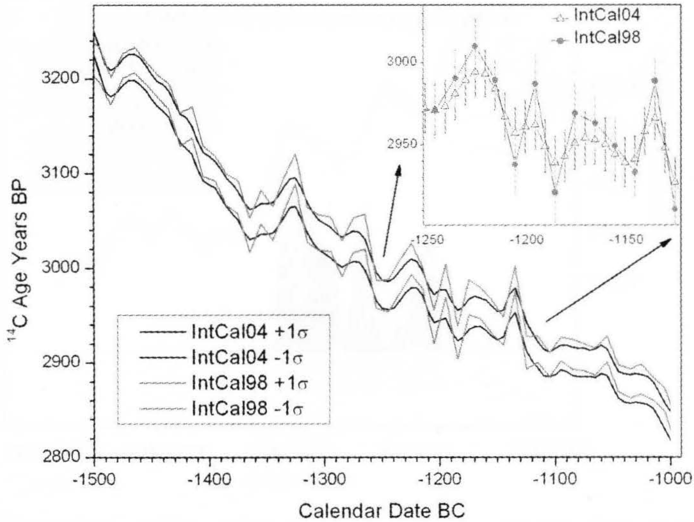

Fig 1. Comparison of the IntCal04 radiocarbon calibration curve (Reimer et al. 2004) with the IntCal98 radiocarbon calibration curve (Stuiver et al. 1998). Inset: detail of the calibration curve data points for the period either side of 1200 BCE.

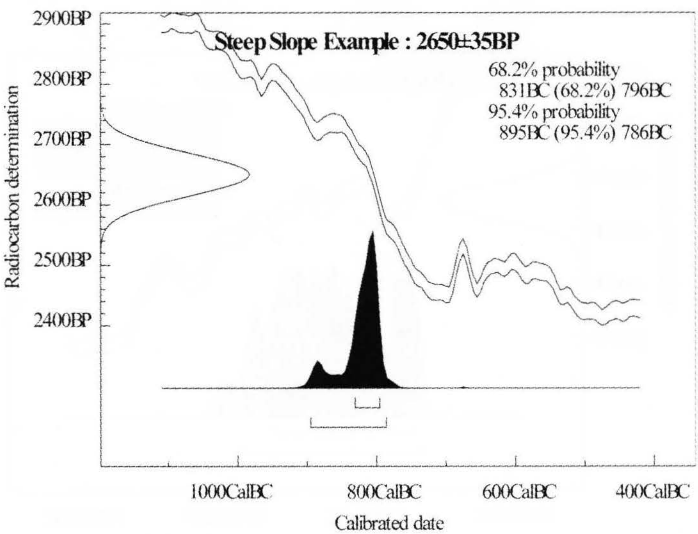

Fig. 2. Example calibration of a radiocarbon age (2650 ± 35 BP) which intersects with a steep slope (only) on the radiocarbon calibration curve, and so (with the radiocarbon timescale probability in effect condensed by the curve slope onto a narrow band on the calendar scale) yields a quite precise calendar age range: 831–796 BCE at 1σ and 895–786 BCE at 2σ. OxCal and IntCal04 with curve resolution at 5. The demarcated zones under each (overall) calibration probability distribution here and in the other figures in this paper show (upper one) the 1σ (68.2%) and (the lower one) the 2σ (95.4%) calibrated ranges.

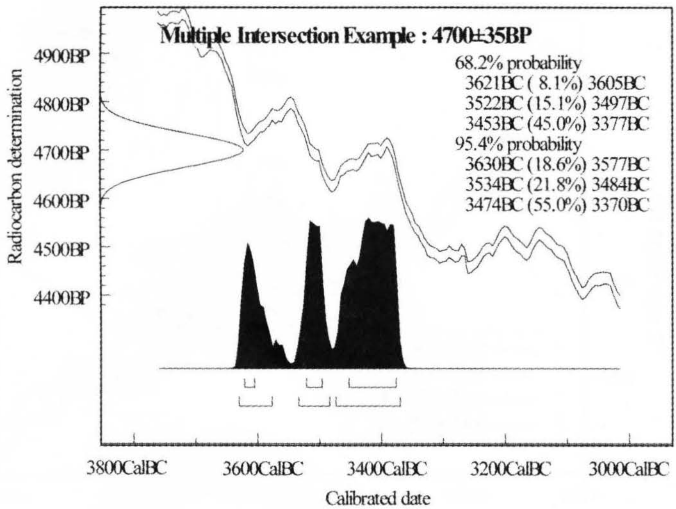

Fig. 3. Example calibration of a radiocarbon age (4700 ± 35 BP) which intersects with multiple discreet areas of the radiocarbon calibration curve because of a series of 'wiggles', and so yields three largely equally possible calendar age ranges within a wide overall 260 calendar year range (taking the 2σ limits). OxCal and IntCal04 with curve resolution at 5.

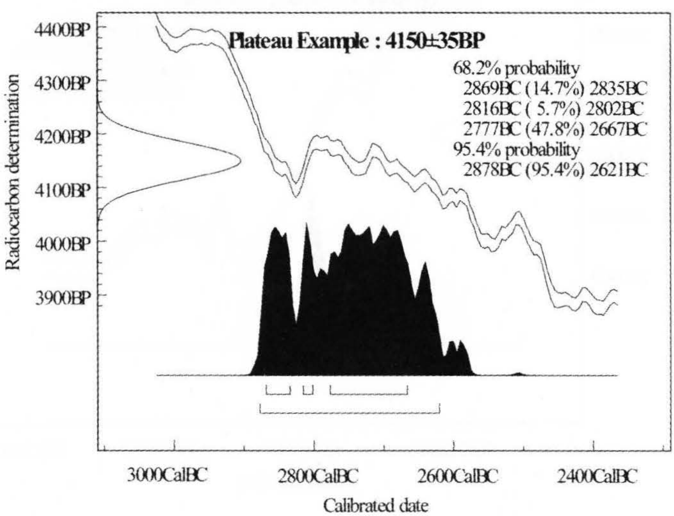

Fig. 4. Example calibration of a radiocarbon age (4150 ± 35 BP) which intersects with a plateau region of the radiocarbon calibration curve, and so yields a large spread of possible calendar age ranges. OxCal and IntCal04 with curve resolution at 5.

performed using the OxCal software (Bronk Ramsey 1995; 2001; http://c14.arch.ox.ac.uk/oxcal/), employing version 3.10 as current in 2006.[1]

Trying to Date 1200 BCE

Conventionally, the close of the Late Cypriot IIC period, or the Late Helladic IIIB period, has been placed around 1200 BCE, give or take a few decades, and the general collapse of Late Bronze Age civilizations in the region has been placed shortly thereafter in the early 12th century BCE. There is, of course, currently active debate on this point, with, on the one hand, some suggestions for earlier dates and for a more extended process with regard to Greece and Anatolia especially (e.g., Yakar 2006). On the other hand, scholars such as Hagens (2006) wish to argue for the opposite, and thus to reduce the date for the same transition from Late Helladic IIIB to IIIC, or Late Cypriot IIC to IIIA, down to around about 1125 BCE; in other words almost eight decades later. Thus, starting with the conventional view, and simplifying to the 'textbook' generalisation, a date of about 1200 BCE is a key watershed marker. Given this, and also given the recent proposals for change and/or recent criticism, it is therefore an interesting question to ask whether we can really date a horizon at 1200 BCE based on radiocarbon evidence? And, in reverse, are attempts (e.g., Hagens 2006) to claim that the radiocarbon evidence support a much later date valid?

If we consider the time range centred on a calendar date of 1200 BCE, we see that the calendar time range around it, so ca.1300–1100 BCE, given the shape and wiggles of the calibration curve, in effect acts like a plateau in the calibration curve (see Fig. 1, and inset). Thus the correct radiocarbon age for a sample dating about 1200 BCE, such as a radiocarbon measurement of 2960±35 BP, does include 1200 BCE in its calibrated range, but also offers a wide range of other possible dates: 1302–1051 BCE at 2σ confidence (see Fig. 5). In fact, we can quickly see that no radiocarbon age determination (in isolation), even at 'high precision' levels, can closely resolve a calendar date of 1200 BCE (see Figs. 6–9). It is an impossible task, if the dating is approached in isolation. And, in reverse, simulated radiocarbon ages for 1200 BCE give a wide range (Fig. 7, Table 1). Note that each run of such a simulation produces a slightly different set of values (see next section below). Even a hypothetical major focused dating programme measuring 20 good modern (as of 2006) AMS samples from a specific 'known' 1200 BCE context (let us assume short-lived seeds all from a context dated exactly to 1200 BCE), which in turn enable us to calibrate a high-precision weighted average with just a ±7 radiocarbon years standard error, nonetheless cannot narrowly resolve 1200 BCE. Instead, such a dataset finds a relatively wide date range covering quite a bit of both the 13th and 12th centuries BCE (Figs. 8–9).

[1] Since this paper was delivered and drafted, OxCal 4.0 has been made available. The new version has the advantage of making the Bayesian analyses much more fully transparent and numerically explicit.

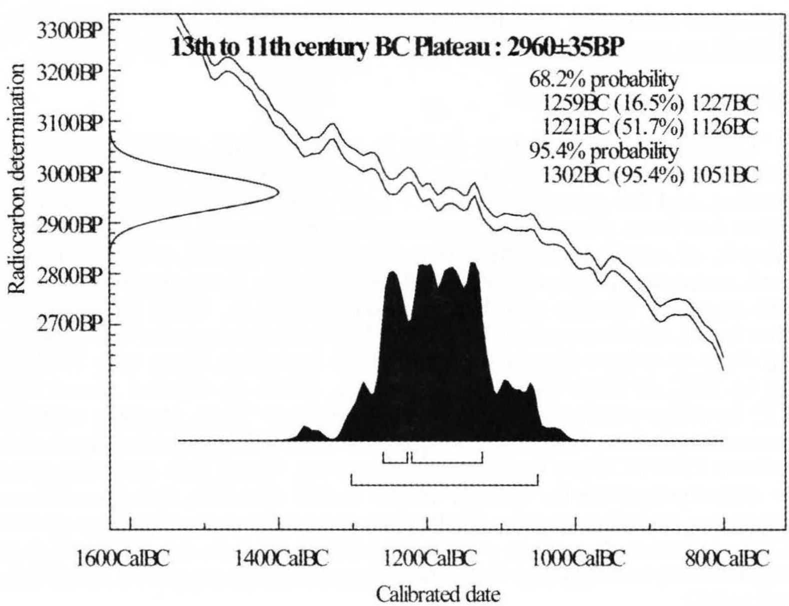

Fig. 5. Calibrated calendar age range for a radiocarbon measurement typical for a sample correctly dating around 1200 BCE. The plateau and wiggles in the calibration curve render the outcome into a wide calendar age range. OxCal and IntCal04 with curve resolution at 5.

What if the Correct Age (of the LC IIC/LC IIIA Transition) Really was 1125 BCE?

We have seen the problem of resolving 1200 BCE in isolation. Hagens (2006) discusses an 'Ultra-low chronology' (ULC), and purports to show how the radiocarbon evidence could be compatible with (and even support) this. According to the ULC, the transition from Late Helladic IIIB to IIIC is about 1145–1125 BCE, the transition for Late Cypriot IIC to IIIA is about 1125 BCE, and the transition in the Levant from Late Bronze II to the Early Iron Age is about 1100 BCE (Hagens 2006: 86, Table 2). Let us consider the case of the ULC dating for the Late Cypriot IIC to IIIA transition and a date of 1125 BCE. Can this date, if it were correct, be resolved from one of about 1200 BCE?

To explore this, we can repeat the process in Figure 7 and Table 1, but employing 1125 BCE. One example set of 20 simulated radiocarbon ages with measurement errors of ±30 for samples from 1125 BCE is shown in Table 2 (Note again that each run of such a simulation produces a slightly different set of values; see below). The weighted average of this set is 2915±7 BP. The calibrated age range for this weighted average is shown in Figure 10 as an example. When the simulation was run again and again a further 100 times the overall average age (from 120 simulations) became slightly higher at 2924 BP. Based on a sizeable sample (120 simulations), we might reasonably regard this as a representative average value. Similarly,

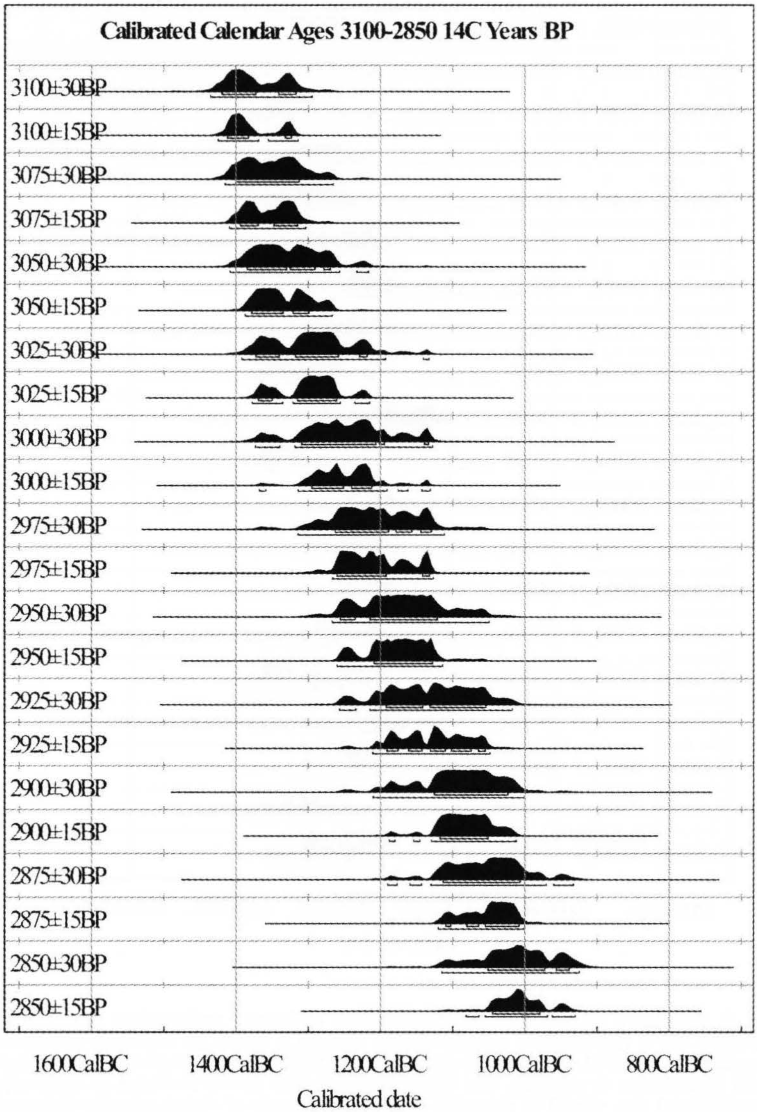

Fig. 6. Calibrated calendar age ranges which result from radiocarbon ages of 3100 BP to 2850 BP at either ±30 or ±15 radiocarbon years measurement precision by 25 radiocarbon year increments. OxCal and IntCal04 with curve resolution at 5.

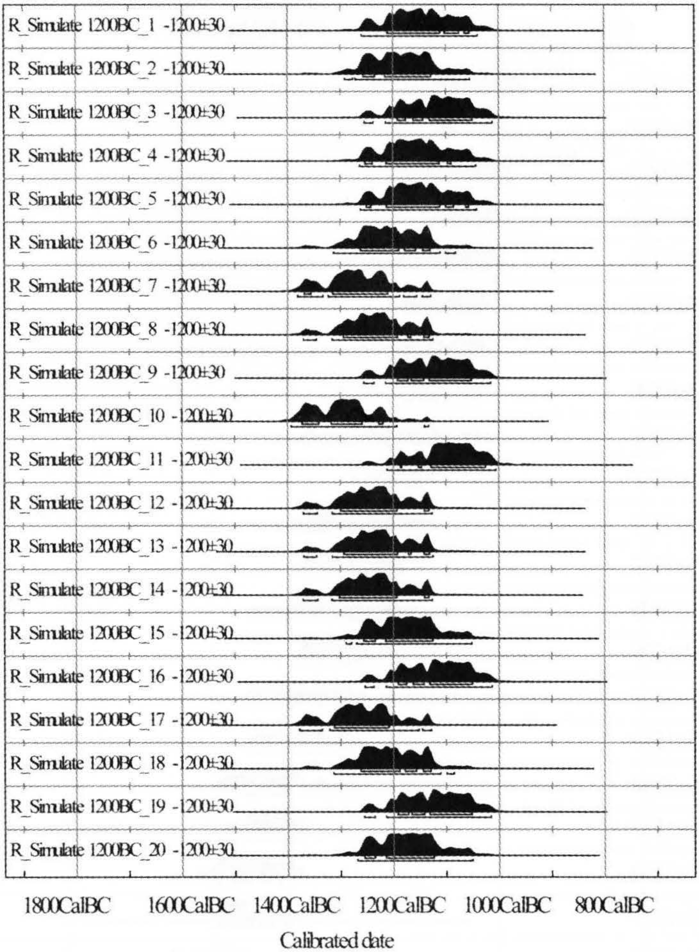

Fig. 7. Simulated (OxCal R_Simulate function) calibrated radiocarbon ranges for 20 iterations for a hypothetical sample dating 1200 BCE given an expected radiocarbon measurement error of ±30 (which is around a good level of precision possible for the better AMS laboratories at present). The R_Simulate function shows the kind of radiocarbon measurement you would be expected to get for a sample of stated calendar date and a given level of radiocarbon measurement uncertainty. In this case we see that a date of 1200 BCE can yield a very wide range of radiocarbon ages and thus calibrated calendar ages. OxCal and IntCal04 with curve resolution at 5.

Table 1. Twenty simulated radiocarbon ages (radiocarbon years BP) for a calendar date of 1200 BCE given a radiocarbon measurement uncertainty of ±30 years, as shown in Figure 7. Note the range in radiocarbon ages which could be expected in such a set even when the real age is the same year of 1200 BCE in all cases (given the measurement error of ±30 radiocarbon years, which is a good level of precision for typical measurements as of 2006). Hence we see, especially at times of marked wiggles or plateaux in the radiocarbon calibration curve (a product of the history of past natural atmospheric ^{14}C variations), the need to base analyses where possible on sets of data, which can offer representative sampling of the normal variation we can expect, and not on any single datum or selective citation of one age perhaps as preferred by a scholar as apparently supporting a particular position, since any one age (rather than a representative sample of the population of ages) could in some cases be very misleading (consider e.g., 1200BC_10 and 1200BC_11 in Figure 7 above, where the correct age of 1200 BCE only just sneaks into the edge of the 2σ calibrated range).

Calendar Date (as in Fig.7)	Simulated Radiocarbon Measurement
1200BC_1	2934±30BP
1200BC_2	2960±30BP
1200BC_3	2919±30BP
1200BC_4	2940±30BP
1200BC_5	2937±30BP
1200BC_6	2974±30BP
1200BC_7	3009±30BP
1200BC_8	2989±30BP
1200BC_9	2922±30BP
1200BC_10	3026±30BP
1200BC_11	2906±30BP
1200BC_12	2993±30BP
1200BC_13	2989±30BP
1200BC_14	2995±30BP
1200BC_15	2955±30BP
1200BC_16	2919±30BP
1200BC_17	3005±30BP
1200BC_18	2974±30BP
1200BC_19	2922±30BP
1200BC_20	2953±30BP
Average:	***2961±7BP***

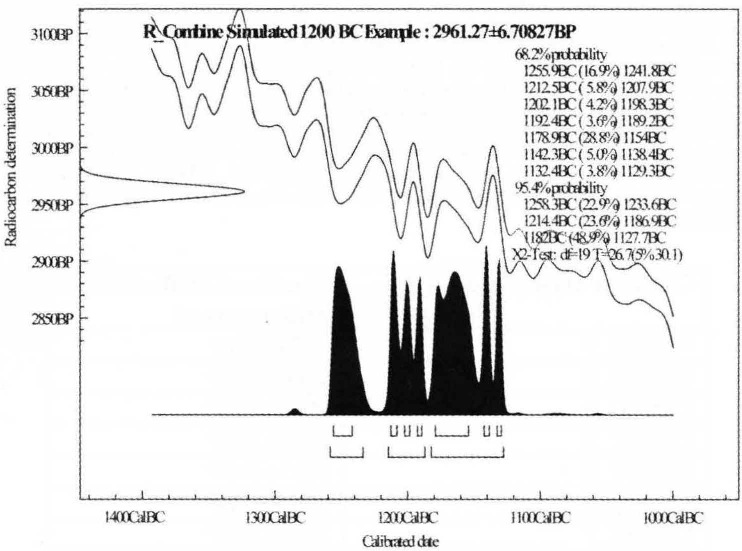

Fig. 8. Calibrated calendar age ranges for the average of the 20 simulated radiocarbon ages for 1200 BCE from Table 1 and Figure 7 (2961±7 BP). The range includes 1200 BCE (the target age), but also a large range of dates from 1258 to 1127 BCE at 2σ. The impossibility of achieving a narrow radiocarbon 'date' for 1200 BCE is thus highlighted. Even if one has, as here, 20 modern (2006 standard) high-precision AMS measurements, and can average them down to a very concise ±7 radiocarbon age BP number, one cannot avoid the plateau/wiggles in the radiocarbon calibration curve which also catch a wide range of probability in the 13th century BCE and the 12th century BCE. Even an absurdly tiny error of ±1, thus 2961±1 BP above, still leads to a similar calibration outcome: 1251–1240, or 1212–1190, or 1177–1160, or 1143–1131 BCE at 1σ, and 1258–1233, or 1215–1127 BCE at 2σ. OxCal and IntCal04 with curve resolution at 5.

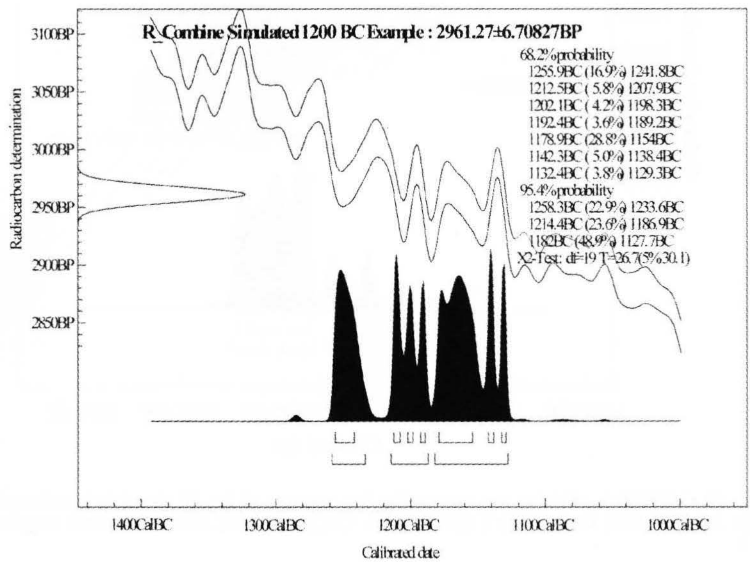

Fig. 9. As Figure 8 but using OxCal and IntCal98 and with curve resolution at 1. This use of IntCal98 and with curve resolution at 1 maximizes the ragged/wiggly record in this calibration curve, and so offers the maximum apparent difference versus the slightly smoothed IntCal04 outcome shown in Figure 8. We see that the overall 2σ range is all but identical. However, there is even more noise within the overall range. Ironically, given that 1200 BCE is the real age, and although it lies within the 1σ and 2σ ranges, it is apparently one of the less likely probabilities, because the sharp wiggles here act so as to concentrate more probability either earlier ca.1256–1242 BCE, or later ca.1179–1154 BCE! Contrast with Figure 8, where a date of 1200 BCE is in fact apparently more likely.

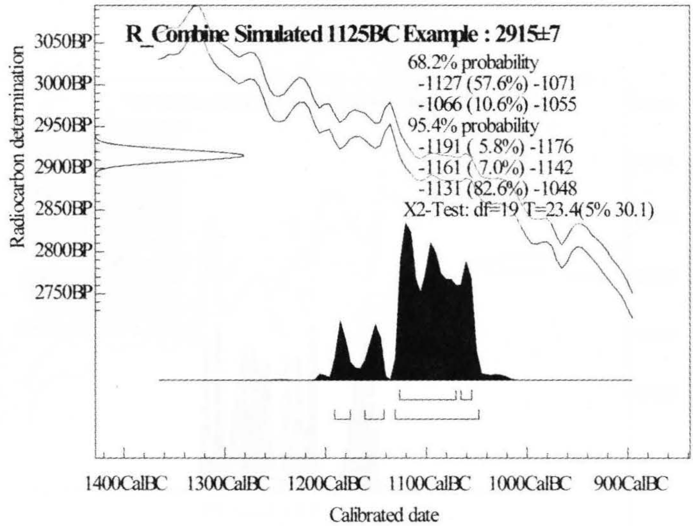

Fig. 10. Calibrated calendar age ranges for the average of the 20 simulated radiocarbon ages for 1125 BCE from Table 2 (2915±7 BP). OxCal and IntCal04 with curve resolution at 5.

returning to the 1200 BCE simulation above in Table 1, when this was run again and again another 100 times, the average over 120 simulations became 2955 BP (slightly lower than the average found in Table 1, which was based on just one set of 20 simulations); again we might treat this as a reasonable representative value. Let us use these values to investigate whether we could hope to discriminate between contexts of 1200 BCE and 1125 BCE. At first sight, the weighted averages obtained for the 120 date simulated 1200 BCE and 1125 BCE sets are not that dissimilar looking: 2955 BP versus 2924 BP (see Fig. 11). Let us assume a 'good' archaeological hypothetical scenario where 10 radiocarbon measurements on annual resolution (short-lived) samples comprise two sets dating our 1200 BCE and 1125 BCE contexts. The measurement error on the weighted average (assuming each constituent measurement at ±30) would be nine (^{14}C years). In this case, the two sets of radiocarbon data, 2955±9 BP and 2924±9 BP, could in fact be stated to be significantly different (that is they are not compatible with representing the same event at 95% confidence level), with T=5.9 > the 5% maximum level value of 3.8 (Ward and Wilson 1978). If the two contexts were dated on the basis of 20 dates each, and the weighted average error was reduced to ±7, they would be even more clearly differentiated: T=9.8 > the 5% maximum level value of 3.8. The point of differentiation in this example is with a set of seven data on each side, and so an error on each average of ≤11 (Fig. 11). Thus, in principle, given a large modern dating project, one could hope to discriminate between contexts of 1200BCE and 1125BCE, but only just, and in reasonably good, or better, circumstances.

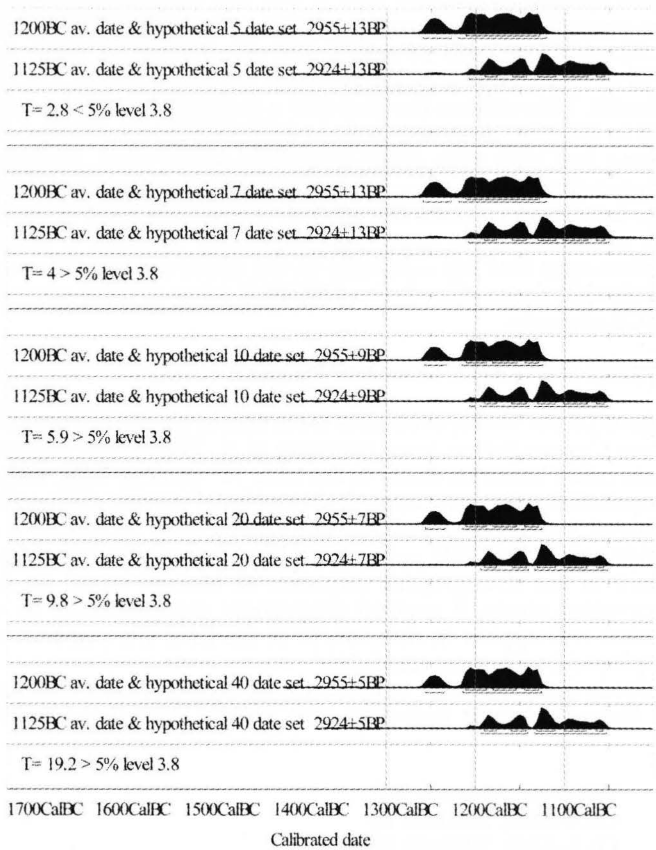

Fig. 11. Comparisons of the average radiocarbon values that might be expected, employing the average radiocarbon age from the 120 date simulations referred to in the text, for contexts of 1200 BCE and 1125 BCE for sets of 5, 7, 10, 20 and 40 dates for each context given a ±30 radiocarbon year error on each of the constituent measurements. The comparison of the two sets of 5 dates could not be distinguished at the 95% confidence level, whereas the comparisons with 7 dates, and more, all indicate a (significant) difference in ages at the 95% confidence level as represented by the two contexts (more and more clearly as the sample numbers increase). Data from OxCal and IntCal04, curve resolution set at 5.

If one compares Tables 1 and 2, one can observe (apart from the different average values) the rarity of ages greater than 2950 BP in Table 2 (2 of 20 examples, and 24 out of 120 simulations in total, or 20%), versus 12 of 20 examples in Table 1 (and 62 out of 120 simulations, or 52% overall). This reflects the fact that a radiocarbon age greater than or equal to 2952 BP does not include 1125 BCE in its calibrated range (employing IntCal04 with curve resolution set at one). Therefore, we might argue that if one were to examine a real archaeological dataset from the later Late Cypriot IIC period, if the data tend to have quite a range of radiocarbon ages, and especially include a number of radiocarbon ages that fall variously in the ≥3000 to 2950 BP range, it is more likely that they will reflect a 1200 BCE (give or take) scenario than a 1125 BCE scenario.

Late Cypriot IIC to IIIA Data and Hagens' Analysis

Hagens (2006: 90–93) considers three sets of short-lived radiocarbon dates from Cyprus (taken from Manning et al. 2001b), and suggests that these data could better be dated to the later 12th century BCE, rather later than proposed by Manning et al. (2001b). Here I merely discuss the data as employed by Hagens, and not the other dates, including a couple of additions since the 2001 paper from the Maroni site, nor subsequent refinement of the stratigraphic sequence at Maroni based on detailed post-excavation study. A revised assessment incorporating all current information will appear in due course in the final site publication. The data employed by Hagens comprise:[2]

(1) Seeds from the later to late Late Cypriot IIC final occupation of Maroni *Vournes* (Ashlar Building) and Maroni *Tsaroukkas* Buildings 1 and 2:

KN-4647, 2969±44 BP
OxA-8265, 2960±35 BP
OxA-8266, 2985±35 BP
OxA-8267, 2940±35 BP
OxA-8324, 2930±40 BP

The weighted average is 2957±17 BP (for an unexplained reason Hagens uses the non-weighted average). Calibrated ranges BCE at 1σ: 1251–1243 (6.3%), 1212–1187 (22.7%), 1182–1154 (24.7%), 1145–1129 (14.6%) (IntCal04 and OxCal, curve resolution 5).

(2) A set of short-lived (0–5 years) branch samples forming a basket found in the final occupation (destruction) horizon at Apliki *Karamallos*, which is dated to the Late Cypriot IIC/IIIA transition and/or early IIIA period. This final occupation is some time *later* than the later Late Cypriot IIC as represented at Maroni (indeed the Apliki building was only constructed during LC IIC). As Hagens tries to argue, the basket *could* have been in use for a period of time before the destruction, but suggesting an interval of 'some decades' seems to be special pleading.

[2] For further references regarding these archaeological contexts, see Manning et al. (2001b).

Table 2. Twenty simulated radiocarbon ages (radiocarbon years BP) for a calendar date of 1125 BCE given a radiocarbon measurement uncertainty of ±30 years (this table derives from the same process that led to Table 1 for 1200 BCE).

Calendar Date 1125BC	Simulated Radiocarbon Measurement
1125BC_1	2872±30BP
1125BC_2	2915±30BP
1125BC_3	2934±30BP
1125BC_4	2916±30BP
1125BC_5	2842±30BP
1125BC_6	2930±30BP
1125BC_7	2945±30BP
1125BC_8	2906±30BP
1125BC_9	2947±30BP
1125BC_10	2896±30BP
1125BC_11	2922±30BP
1125BC_12	2891±30BP
1125BC_13	2883±30BP
1125BC_14	2960±30BP
1125BC_15	2914±30BP
1125BC_16	2993±30BP
1125BC_17	2912±30BP
1125BC_18	2928±30BP
1125BC_19	2913±30BP
1125BC_20	2884±30BP
Average:	***2915±7BP***

AA-33440, 2990±55 BP
AA-33441, 2960±60 BP
AA-33442, 3015±55 BP
AA-33443, 3050±55 BP
AA-33444, 2955±55 BP

(3) Seeds from inside the basket (2) from the final occupation of Apliki, and thus Late Cypriot IIC/IIIA transition or early IIIA period. These seeds should date later than (1) by some margin and later than (2) (whether by a short interval, basket not in existence for very long, to 'some decades', Hagens' special pleading).

AA-33450, 2990±45 BP
AA-33451, 2960±45 BP
AA-33452, 2930±60 BP
AA-33452A, 2945±50 BP
AA-33453, 2960±50 BP
AA-33454, 2955±65 BP

The weighted average is 2960±21 BP (for an unexplained reason Hagens uses the non-weighted average). Calibrated ranges BCE at 1σ: 1255–1237 (12.7%), 1214–1152 (42.1%), 1147–1129 (13.4%) (IntCal04 and OxCal, curve resolution 5).

We can immediately observe that none of the sets by themselves particularly wants to date in the second half of the 12th century BCE (and especially ca. 1125 BCE), contrary the suggestion of Hagens. Each set offers an average age around and/or greater than the 120 date simulated average age for 1200 BCE (see above), and not an average compatible with the 120 date simulated average age for 1125 BCE (see above).

Hagens is unhappy that (2) has a higher radiocarbon age than (1), despite coming from a culturally later context, and hence he suggests the heirloom idea for the basket. But simply glancing at the record of natural radiocarbon levels from the period around the 13th–12th centuries BCE (Fig. 1; and looking especially to the less smoothed IntCal98 data), we can also see that the situation could as easily (even better) be explained in terms of these known variations while keeping the samples in the known cultural/stratigraphic order (i.e. in their sequence).

Such a sequence analysis employing the prior archaeological order information via a Bayesian analysis is shown against IntCal04 and then IntCal98 in Figures 12 and 13, and some of the findings are detailed in Table 3.

We can see from this analysis that the Late Cypriot IIC to Late Cypriot IIC/IIIA transition (or early Late Cypriot IIIA) data can happily lie in their cultural/stratigraphic order in synchronism with the radiocarbon data. No special pleading is required. Only the final occupation/destruction seeds (3) from Apliki likely date to the mid-12th century BCE (2nd or 3rd quarters), and even then most likely (taking the 1σ ranges) before 1125 BCE. This final occupation at Apliki is contemporary with early LHIIIC in the Aegean (whether termed LC IIC/IIIA transition by Kling 1989; or early LC IIIA by Taylor 1952). The late Late Cypriot IIC samples from Maroni (1) most likely date somewhere between ca.1259–1197 BCE, or 1261–1194

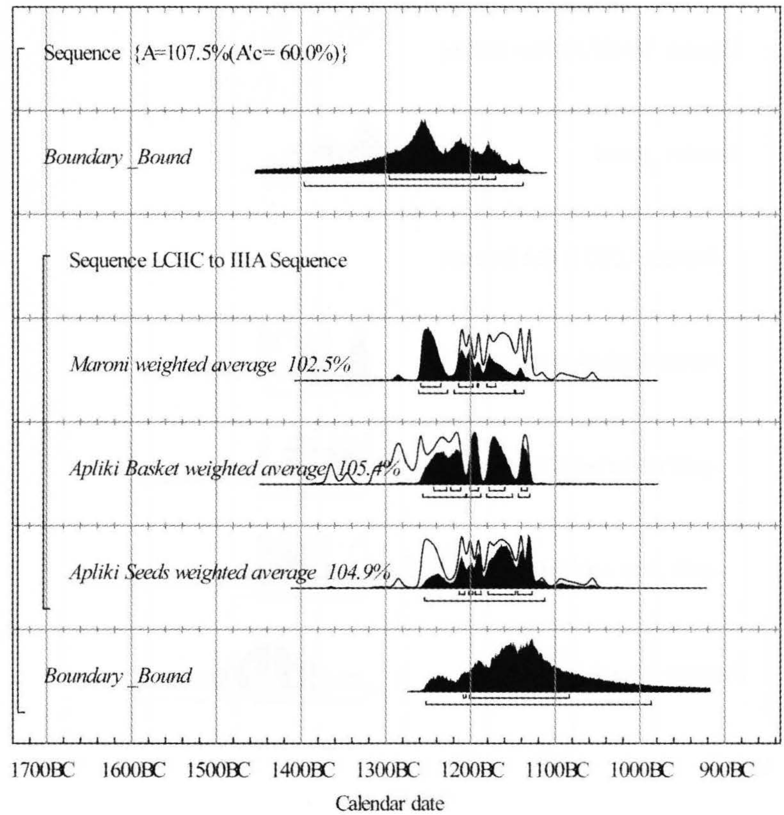

Fig. 12. Sequence analysis of the weighted average values for the three sets of short-lived samples from Maroni and Apliki discussed above in the text using OxCal and IntCal04 (curve resolution set at 5). The hollow histograms show the calibrated range for each weighted average in isolation, and the solid histograms show the modelled calendar probabilities in view of the sequence analysis. The analysis comfortably surpasses a 95% confidence threshold (overall and for each constituent element). The cultural/stratigraphic order of the samples is compatible with the radiocarbon data and the calibration curve (history of past natural radiocarbon levels). No special pleading is required.

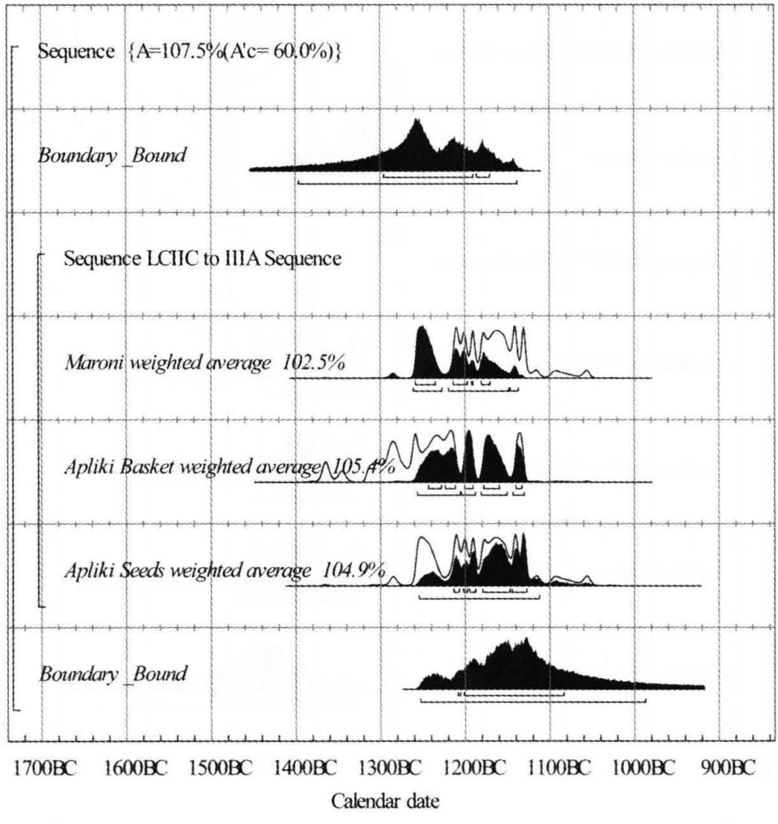

Fig. 13. Sequence analysis of the weighted average values for the three sets of short-lived samples from Maroni and Apliki discussed above in the text using OxCal and IntCal98 (curve resolution set at 1). The hollow histograms show the calibrated range for each weighted average in isolation, and the solid histograms show the modelled calendar probabilities in view of the sequence analysis. The more wiggly (un-smoothed) IntCal98 dataset offers an even better match of the observed cultural/stratigraphic ordering versus the radiocarbon record. The analysis comfortably surpasses a 95% confidence threshold (overall and for each constituent element). No special pleading is required.

BCE, and the basket from Apliki (2) likely dates somewhere in between, either 1245–1161 BCE or 1243–1160 BCE.

Table 3. The 1σ calibrated ranges found in the sequence analysis shown in Figures 12 and 13.

	IntCal98 (curve res = 1) 1σ Calibrated ranges BC	**IntCal04 (curve res = 5) 1σ Calibrated ranges BC**
1. Maroni Seeds later LCIIC	1259–1235 (40.6%), 1214–1197 (17.5%), 1192–1190 (1.2%), 1181–1170 (8.9%)	1261–1226 (47.1%), 1219–1194 (21.1%)
2. Apliki Basket LCIIC/IIIA	1243–1228 (14.0%), 1223–1211 (11.3%), 1201–1191 (13.5%), 1178–1160 (22.2%), 1140–1133 (7.1%)	1245–1191 (56.7%), 1176–1161 (11.5%)
3. Apliki Seeds LCIIC/IIIA	1213–1207 (5.2%), 1202–1197 (3.4%), 1194–1188 (6.3%), 1179–1147 (34.7%), 1144–1127 (18.7%)	1213–1187 (23.0%), 1179–1127 (45.2%)

Beyond the Single Case (or set) and Selection to Sequence Analysis

As we have seen, the problems of ambiguity are clear for trying to date single dates, or individual sets of dates, for one context in isolation in the period around 1200 BCE. This is because of the shape of the radiocarbon calibration curve (i.e. the history of past natural radiocarbon fluctuations). The only solution to such measurement constraints and ambiguity is to incorporate prior knowledge so that a sequence of data of known order can (at least partly) resolve the ambiguity by requiring partition of the otherwise wide dating ranges, as shown in Figures 12 and 13.

The perfect case for such sequence analysis is a series of data of both known order and known spacing (e.g., a tree-ring sample). This 'fixed sequence' can be directly fitted against the radiocarbon calibration curve (for discussion and further references, see Galimberti et al. 2004). A hypothetical example is shown for a set of five samples which all have a radiocarbon age of 2960±30 BP (i.e. all could seem to be 1200 BCE samples, given Table 1), but we 'know' that only the third sample is 1200 BCE, and the other ones are part of a sequence spaced apart by 20 years in each case. The raw data are shown in Figure 14: five radiocarbon determinations all with the same broad calendar age range.

The analysis incorporating the known sequence (we are assuming a tree-ring sequence situation, of samples with known spacing) is shown in Figure 15. This shows the raw calibrated age distributions (the hollow histograms; compare with Fig. 14), which are all the same and cover a wide calendar age range including 1200 BCE, and then, given the prior age model known, the calculated calendar ages applying this known information are shown as the solid histograms (employing the Bayesian

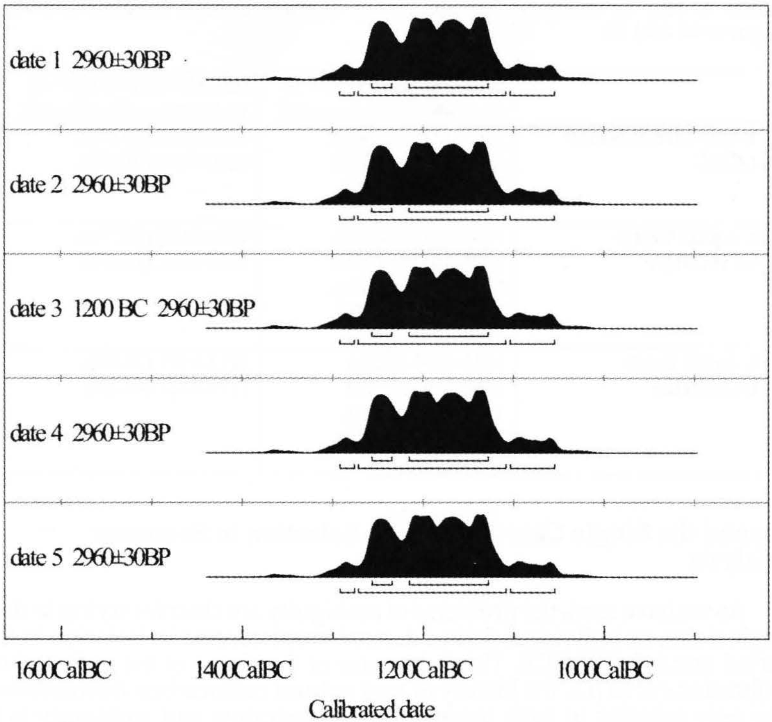

Fig. 14. Calibrated radiocarbon age ranges for 5 hypothetical radiocarbon measurements on samples of radiocarbon age 2960±30 BP. One sample in fact is 1200 BCE in calendar date (date 3 in this hypothetical example), the others are before and after, but with the same radiocarbon age found due to the effective plateau in radiocarbon ages around this time. We see the fairly large age range for each sample and the clear ambiguity problem. OxCal and IntCal04 (curve resolution set at 1).

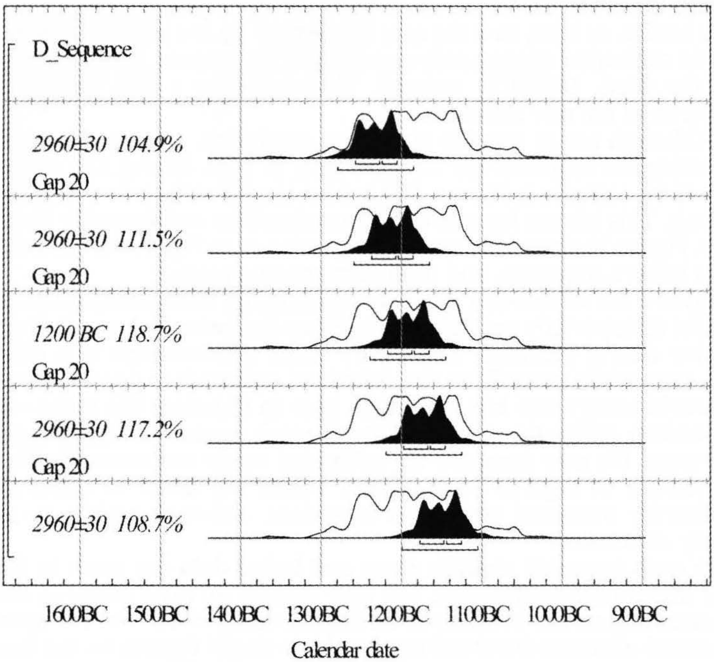

Fig. 15. Sequence analysis of the 5 data in Figure 14 applying the 'known' sequence for this hypothetical example (5 samples each 20 calendar years apart). The agreement index value is 129% versus the approximate 95% confidence threshold figure of 31.6% for the overall sequence. Each sample's individual agreement with the model also exceeds the approximate 95% confidence threshold value of 60% in OxCal. Data from OxCal and IntCal04 with 1 year calibration curve resolution. The 1σ range for the 1200 BCE sample is 1217–1187 (39.8%), or 1184–1166 BCE (28.4%) and 2σ 1239–1145 BCE.

analytical tools in OxCal). The samples in the known order and with the known spacing are accordingly spread across the possible (common) dating range, and the 1200 BCE sample is left much more clearly in this calendar time zone with the other samples more evidently tending to be either earlier, or later, as is the case (three now do not include 1200 BCE in their 1σ calibrated ranges; only one sample, the second, is still ambiguous with the third, 1200BCE, sample). Thus we have a 75% improvement compared to the raw situation.

Although not as capable of narrow resolution, we can also apply an archaeological sequence (as we have seen in Figs. 12 and 13), where the order of the samples is known, but not the length of the relevant spacings/ intervals. This too can hope to clarify an otherwise ambiguously long time range. Figure 16 shows the same information as in Figure 14, but this time with a known sequence, and unknown spacing (gaps).

Where the calibration curve is challenging, such analyses may still not offer an especially precise date, but they can nevertheless substantially improve dating precision and clarify order relationships into calendar terms even when everything else (identical radiocarbon ages—an *unlikely* real-world occurrence but employed here to illustrate the point—and a radiocarbon calibration curve plateau) work against a highly resolved date range. We may compare the calibrated range outcomes for the 1200 BCE sample in Figures 14–16. These values are listed in Table 4. The significantly increased resolution is evident, although ambiguity is not entirely eliminated.

In such sequence analysis more and better data can serve to further refine the situation—however, this only applies up to an extent as there is a diminishing return in terms of additional resolution, once the numbers of seriated elements involved reaches high single figures on the basis of known-age tree-ring examples (Galimberti et al. 2004).

The successful dating, and achievement, of a fairly high-resolution chronology for the period 1300 to 1100 BCE at a multi-strata archaeological site, or across several sites (if the strata can be tightly linked via material culture analysis), could reasonably be attempted with a seriated set of data comprising around half a dozen elements. Figures 17 and 18 give a hypothetical example for a six-phase (or sub-phase) stratigraphic sequence dating between 1300 and 1100 BCE, based on simulated radiocarbon ages for 1300 BCE, 1260 BCE, 1220 BCE, 1180 BCE, 1140 BCE and 1100 BCE. The hypothetical example assumes that each phase or sub-phase is dated by at least three modern AMS radiocarbon dates on short-lived (secure, primary context) samples. Thus the weighted average for each phase/sub-phase/context is likely going to be better than ±17 radiocarbon years BP (achieved with the weighted average of three data with ±30 year reported errors).

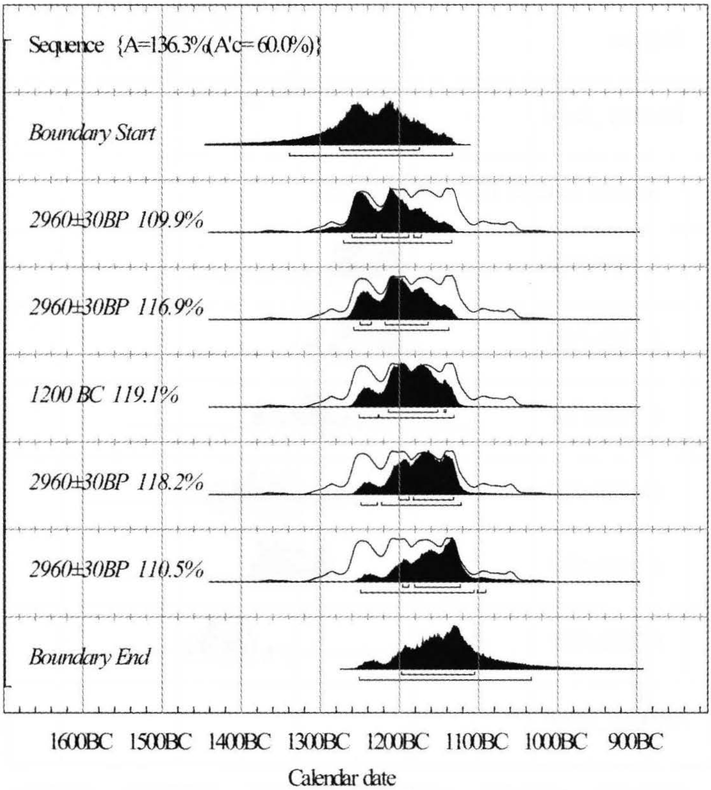

Fig. 16. Sequence analysis of the Figure 14 data with a 'known' sequence, but no information on the details of the spacings/intervals, and thus a typical archaeological stratified sequence scenario. OxCal and IntCal04 with 1 year calibration curve resolution. For the 1200 BCE sample: 1214–1151 BCE forms the main 1σ range (65.5% probability) and the 2σ range overall is 1250–1131 BCE. Note: the ranges are a little wider than for the fixed sequence analysis in Figure 15. Note also that each run of a sequence like this varies a little.

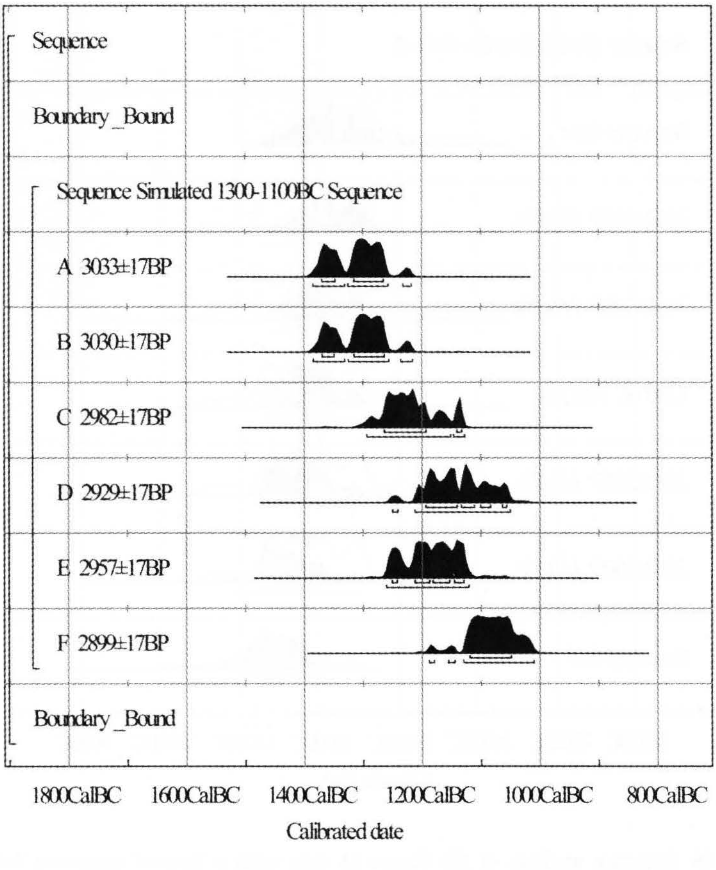

Fig. 17. The raw weighted averages for each of the six constituents of the hypothetical 1300–1100 BCE sequence in their known archaeological order. The data represent simulated data, but nicely represent the typical apparent 'problems' found by archaeologists, with some apparently overlapping data and with a radiocarbon age inversion from D to E, etc. Data from OxCal and IntCal04, curve resolution set at 5.

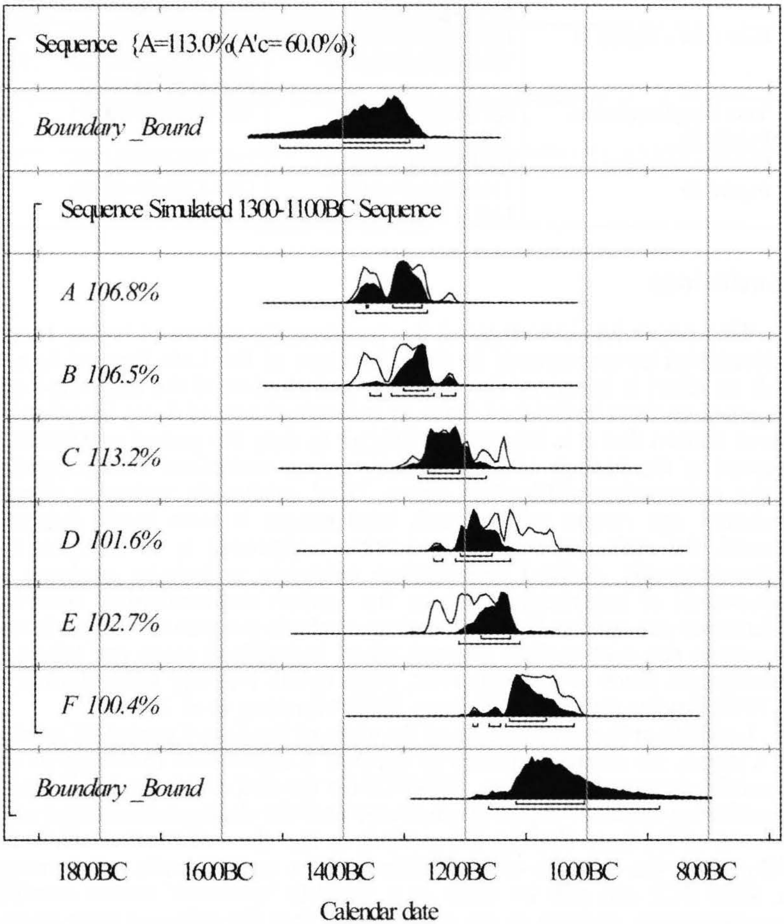

Fig. 18. Sequence analysis of the data in Figure 17 given the known archaeological sequence (but no other information). A nicely ordered and relatively well resolved chronology emerges. The minimum assumption here is six phases/sub-phases/contexts and three (modern AMS) dates per such unit on short-lived samples. Thus at least 18 radiocarbon dates are required. The hollow histograms show the calibrated probabilities for each of the constituent elements in isolation (as in Figure 17) and the solid histograms show the calculated calendar probabilities applying the sequence model incorporating the known archaeological knowledge (the order of the samples). The analysis very comfortably surpasses a 95% confidence threshold (overall and for each constituent element). Data from OxCal and IntCal04, curve resolution set at 5.

Table 4. Comparison of the calibrated ranges found from the raw data (Figure 14) and then the different analyses shown in Figures 15–16. P=Probability (out of a total of 1.0).

	1σ range(s) BC	2σ range(s) BC
Raw data – Figure 14	1257–1235 (P=0.133) 1215–1128 (P=0.549)	1292–1276 (P=0.023) 1272–1109 (P=0.861) 1104–1055 (P=0.07)
Tree Ring Sequence – Figure 15	1217–1187 (P=0.398) 1184–1166 (P=0.284)	1239–1145 (P=0.954)
Flexible Sequence – Figure 16	1214–1151 (P=0.661) 1145–1144 (P=0.012) 1141–1140 (P=0.009)	1251–1228 (P=0.103) 1226–1131 (P=0.851)

Conclusions

This paper has investigated the problematic nature of trying to use radiocarbon measurements to date the close of the Late Bronze Age, if such an effort is based on the selection and citation of the calibrated age ranges of various individual dates or individual sets of dates in isolation. I have shown that it is inherently difficult to date the period ca.1200 BCE because of the history of natural radiocarbon variations as represented in the radiocarbon calibration curve. Thus, arbitrarily trying to choose preferred age ranges within such total ranges is even more dubious. Instead, the only appropriate and robust approach is to consider the archaeologically derived radiocarbon evidence in holistic analyses of sequence(s) of information, where the known archaeological ordering of contexts can inform the radiocarbon analysis (sequence analysis), and overcome the ambiguities created when individual cases are taken in isolation (cf. Buck et al. 1991; 1992; 1999; Bronk Ramsey 1995; Zeidler et al. 1998; Bayliss and Bronk Ramsey 2004; Manning et al. 2006).

Looking at the specific case of the close of the Late Cypriot IIC period on Cyprus, no evidence exists to support a significant lowering of the generally accepted date of ca. 1200 BCE for the end of this period. In turn, considering the Sea Peoples phenomena and the changes associated with the end of the Late Cypriot IIC period, or the close of the Late Helladic IIIB period, the collapse of the Hittite Empire, and so forth, a date range ca. 1200 BCE can still be used as a suitable 'textbook' round number approximation, so long as we are mindful that the relevant time period might in fact have been a few decades earlier or later (and need not have been contemporary across the relevant cultures/areas), and that the processes involved covered periods of time rather than point events.

Cornell University

Acknowledgements

I wish to thank Tim Harrison for organizing a splendid meeting in Toronto, and for his patience with respect to this paper. I thank Mary Jaye Bruce for her assistance with this manuscript.

Works Cited

Bayliss, A. and C. Bronk Ramsey
2004 Pragmatic Bayesians: A Decade of Integrating Radiocarbon Dates into Chronological Models. Pp. 25–42 in *Tools for Constructing Chronologies: Crossing Disciplinary Boundaries*, eds. C.E. Buck and A.R. Millard. London: Springer Verlag.

Bronk Ramsey, C.
1995 Radiocarbon Calibration and Analysis of Stratigraphy: The OxCal Program. *Radiocarbon* 37: 425–430.
2001 Development of the Radiocarbon Calibration Program. OxCal. *Radiocarbon* 43: 355–363.

Buck, C.E., J.B. Kenworthy, C.D. Litton, and A.F.M. Smith
1991 Combining Archaeological and Radiocarbon Information: A Bayesian Approach to Calibration. *Antiquity* 65: 808–821.

Buck, C.E., C.D. Litton, and A.F.M. Smith
1992 Calibration of Radiocarbon Results Pertaining to Related Archaeological Events. *JAS* 19: 497–512.

Buck, C.E., J.A. Christen, and G.N. James
1999 BCal: An On-line Bayesian Radiocarbon Calibration Tool. *Internet Archaeology* 7: http://intarch.ac.uk/journal/issue7/buck index. html.

Cessford, C.
2005 Absolute Dating at Çatalhöyük. Pp. 65–99 in *Changing Materialities at Çatalhöyük: Reports from the 1995–99 Seasons*, ed. I. Hodder. London: British Institute at Ankara and McDonald Institute for Archaeological Research.

Cichocki, O., M. Bichler, G. Firneis, W. Kutschera, W. Müller, and P. Stadler
2004 The Sychronization of Civilization in the Eastern Mediterranean in the Second Millennium BCE: Natural Science Dating Attempts. Pp. 83–110 in *Tools for Constructing Chronologies: Crossing Disciplinary Boundaries*, eds. C.E. Buck and A.R. Millard. London: Springer Verlag.

Galimberti, M., C.B. Ramsey, and S.W. Manning
2004 Wiggle-Match Dating of Tree-Ring Sequences. *Radiocarbon* 46: 917–924.

Hagens, G.
2006 Testing the Limits: Radiocarbon Dating and the End of the Late Bronze Age. *Radiocarbon* 48: 83–100.

Kling, B.
1989 *Mycenaean IIIC:1b and Related Pottery in Cyprus.* SIMA 87. Göteborg: Paul Åströms Förlag.

Levy, T.E. and T. Higham, eds.
2005 *The Bible and Radiocarbon Dating Archaeology, Text and Science.* London: Equinox.

Manning, S.W., C. Bronk Ramsey, W. Kutschera, T. Higham, B. Kromer, P. Steier, and E. Wild
2006 Chronology for the Aegean Late Bronze Age. *Science* 312:565–569.

Manning, S.W., B. Kromer, P.I. Kuniholm, and M.W. Newton
2001 Anatolian Tree-rings and a New Chronology for the East Mediterranean Bronze-Iron Ages. *Science* 294:2532–2535.

Manning, S.W., B. Weninger, A.K. South, B. Kling, P.I. Kuniholm, J.D. Muhly, S. Hadjisavvas, D.A. Sewell, and G. Cadogan

2001b Absolute Age Range of the Late Cypriot IIC Period on Cyprus. *Antiquity* 75: 328–340.

Oren, E.D. (ed.).

2000 *The Sea Peoples and their World: A Reassessment*. Philadelphia: University Museum.

Reimer, P.J., M.G.L. Baillie, E. Bard, A. Bayliss, J.W. Beck, C.J.H. Bertrand, P.G. Blackwell, C.E. Buck, G.S. Burr, K.B. Cutler, P.E. Damon, R.L. Edwards, R.G. Fairbanks, M. Friedrich, T.P. Guilderson, A.G. Hogg, K.A. Hughen, B. Kromer, G. McCormac, S. Manning, C.B. Ramsey, R.W. Reimer, S. Remmele, J.R. Southon, M. Stuiver, S. Talamo, F.W. Taylor, J. van der Plicht, and C.E. Weyhenmeyer

2004. IntCal04 Terrestrial Radiocarbon Age Calibration, 0–26 Cal Kyr BP. *Radiocarbon* 46: 1029–1058.

Sandars, N.K.

1978 *The Sea Peoples: Warriors of the Ancient Mediterranean, 1250–1150 B.C.* London: Thames and Hudson.

Stuiver, M., P.J. Reimer, E. Bard, J.W. Beck, G.S. Burr, K.A. Hughen, B. Kromer, G. McCormac, J. van der Plicht, and M. Spurk

1998 INTCAL98 Radiocarbon Age Calibration, 24,000–0 cal BP. *Radiocarbon* 40: 1041–1083.

Taylor, J. du Plat.

1952 A Late Bronze Age Settlement at Apliki, Cyprus. *The Antiquaries Journal* 32:133–167.

Ward G.K. and S.R. Wilson

1978 Procedures for Combining Radiocarbon Age Determinations: A Critique. *Archaeometry* 20: 19–31

Ward, W.A. and M.S. Joukowsky (eds.).

1992 *The Crisis Years: The 12th Century B.C.: From Beyond the Danube to the Tigris*. Dubuque: Kendall/Hunt Publishing Company.

Warren, P. and V. Hankey

1989 *Aegean Bronze Age Chronology*. Bristol: Bristol Classical Press.

Yakar, Y.

2006 Dating the Sequence of the Final Destruction/Abandonment of LBA Settlements: Towards a Better Understanding of Events that Led to the Collapse of the Hittite Kingdom. Pp. 33–51 in *Strukturierung und Datierung in der hethitischen Archäologie/ Structure and Dating in Hittite Archaeology*, eds. D.P. Mielke, U-D. Schoop, and J. Seeher. BYZAS 4. Istanbul: Deutsches Archäologisches Institut Istanbul.

Zeidler, J.A., C.E. Buck, and C.D. Litton

1998. The Interpretation of Archaeological Phase Information and Radiocarbon Results from the Jama River Valley, Ecuador: A Bayesian Approach. *Latin American Antiquity* 9:135–159.