RADIOCARBON, Vol 51, Nr 2, 2009, p 711–720

# A REAPPRAISAL OF THE DENDROCHRONOLOGY AND DATING OF TILLE HÖYÜK (1993)

Carol B Griggs • Sturt W Manning

Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology, Cornell University, Ithaca, New York 14853-3201, USA. Email: cbg4@cornell.edu.

**ABSTRACT.** The results of a tentative oak tree-ring chronology built from charcoal samples found in Late Bronze to early Iron Age contexts (late 2nd millennium to early 1st millennium BCE) at the site of Tille Höyük in southeast Turkey, and its placement in time, was published in 1993 (Summers 1993). This represented one of the few publications about archaeological dendrochronology for this period and region. However, the dendrochronological sequence and its crossdating have been questioned, including in this journal (Keenan 2002). Here, we critically reassess and revise the dendrochronological positioning of the site's building phases and their place in time by absolutely dating 7 decadal tree-ring sequences via radiocarbon wiggle-matching.

## INTRODUCTION

Wood found at prehistoric through early historic archaeological sites in the Aegean and Near Eastern region is often problematic for dendrochronological analysis, generally due to a limited amount of small, often charred, fragmented samples. This problem is well known to many archaeologists who have sent samples for tree-ring analysis to the Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology at Cornell. The basis of dendrochronology is the presence of tree-ring growth patterns unique to a particular period on an annual timescale. Small segments with limited numbers of rings contribute exponentially to the uncertainty of tree-ring crossdating.

Sites in Turkey with successful dendrochronological results include Gordion, with many large, well-preserved, mainly uncharred timbers, including several very long-lived trees (Bannister 1970; Kuniholm 1977); Porsuk, whose samples are charred around the outside of large timbers (Kuniholm et al. 1992); and the Kültepe and Acemhöyük sites, where the samples are mainly charcoal, but include several large, intact segments (Kuniholm and Newton 1990; Newton and Kuniholm 2004). These samples, along with those from a few other sites, were invaluable for building our current near-absolutely placed Bronze to Iron Age tree-ring chronologies for the region (Manning et al. 2001, 2003; Kuniholm et al. 2005), but, unfortunately, such samples are very rare.

For sites with samples of less ring count, tree-ring crossdating is much less secure, and radiocarbon dating is of extreme importance in placing the sequences correctly in time. $^{14}$C "wiggle-matching" of decadal tree-ring segments with known ring counts between the segments can both greatly increase the precision of calendar placements and reduce the attendant dating uncertainties (Galimberti et al. 2004). While the final result is not the high-frequency annual resolution available for tree-ring values, the overall error can be reduced to the order of a few decades in many cases, depending on number of samples, length of the overall sequence, and shape of the $^{14}$C calibration curve through the relevant time interval.

Over 150 charcoal samples were collected during the excavation of the Late Bronze Age to early Iron Age contexts at the destroyed gate-building at Tille Höyük in southeastern Turkey (Summers 1993). These samples are comprised of typically small and fragmented charcoal segments (as usually found at most archaeological sites), but the sheer quantity of preserved samples, and their archaeological placement at the close of the Late Bronze Age to early Iron Age, gave this collection considerable potential. Nonetheless, the majority of the Tille samples contain less than 70 tree-rings,

*Proceedings of the 5th International $^{14}$C and Archaeology Symposium*, edited by Irka Hajdas et al.
RADIOCARBON, Vol 51, Nr 2, 2009, p 711–720

the minimum approximate count suitable for accurate dendrochronological analysis. In addition, many of the rings contained evidence of damage to the cambial layer, often more than once in the tree's lifespan, which resulted in rings that were overly wide from growth repair and could be incomplete along a measured radius. This provided an additional level of difficulty for correctly measuring the ring-widths and matching growth patterns. The Tille samples were definitely a challenge for secure tree-ring dating.

Kuniholm et al. (1993) reported on the examination and identification of all the Tille samples and stated that there were 76 "datable fragments of severely burned oak charcoal … [which] … form a 218-year tree-ring chronology which can be cross-dated with our 1503-year Bronze Age/Iron Age tree-ring chronology from Gordion and other sites" (p. 179). Here, we revisit this problematic material and offer a new assessment, using AMS $^{14}$C analysis to determine that a few of the short overlaps (~30 yr) critical to the construction of the original chronology, were based on false, but highly positive, statistical values plus good visual correlations. This often occurs in matching tree-ring patterns with short overlaps, and is a problem well-recognized in dendrochronology. The $^{14}$C dates also allowed us to place the revised sequence more securely in calendar time without comparing the Tille oak chronologies with our main current Bronze and Iron Age tree-ring chronologies, composed primarily of juniper. The new work confirms the recognition of 2 building phases by Kuniholm et al. (1993), but their relative placement in time is corrected via wiggle-match $^{14}$C dating.

## METHODS

The archaeological contexts at Tille Höyük from which the Late Bronze Age charcoal samples were recovered, and their initial study and assessment are all described in Summers (1993) and Kuniholm et al. (1993). The original analysis of the Tille Höyük samples included their initial unwrapping, species identification, an assessment of their usefulness for dendrochronology, and, if selected, their ring-width measurements. The samples are predominantly oak, *Quercus* spp., and their data were used exclusively in building the tree-ring chronologies. In this reassessment, we reexamined all the oak charcoal from the site. We checked or remeasured the rings of any fragment containing over 20 tree rings, aware that many samples could be from the same timber. The 6 samples (14 fragments) from 1 timber (TIL-27 et al.) demonstrate how scattered the remains of 1 timber can become in a destructive event. The number of measured fragments in single samples (e.g. TIL-1 with 7 fragments) shows that many samples could not be collected and/or wrapped well enough to preserve their original relationship to each other. The recognition of the relationships of the various pieces of charcoal to each other required physical examination in the laboratory plus graphing the segments' ring widths to visually match their tree-ring patterns in order to build individual tree sequences and so reassemble original associations lost through the destruction/burning of the site area and subsequent processes through excavation and recovery for study. Our practice in this reassessment was to leave out any sample with a questionable placement. In our revised chronologies, only 22 samples (52 fragments from 13 trees) are included (see Tables 3 and 4), in contrast to the 29 samples used in the original Tille chronology (Kuniholm et al. 1993). All 22 samples are from the gateway area of the site, on the western slope of the Tille Höyük (see Summers 1993:61, Figure 4).

In our reexamination, we found a basic confirmation of the 2 main tree-ring sequences in Kuniholm (1993) with slight alterations. One is Tille I (comprised of 8 trees) and the other Tille II (comprised of 2 trees), plus a tentative third chronology, Tille "Middle," comprised of 4 fragments from 3 trees (Tables 3, 4). Each chronology has good internal visual matches; however, their internal statistical values are less convincing due to short overlaps, narrow ring widths, and the individual trees' idiosyncratic ring growth, partially due to cambial damage. The ring-porous structure of oak tree rings, especially in the case of narrow ring widths, causes less variability in oak ring widths than in those of other species due to the fairly standard width of the earlywood vessels from year-to-year. This is a challenge faced in many archaeological situations, but an integration of visual study and statistics leads us to regard the 3 sequences as real (compare e.g. Billamboz 2008).

In the absence of an appropriate oak tree-ring dendrochronology for the region, we employed $^{14}$C wiggle-matching (Bronk Ramsey et al. 2001; Galimberti et al. 2004) to establish the near-absolute dating of the Tille I and II tree-ring series. Three tree-ring samples were dissected from tree 69 and two from tree 3 to place the Tille I sequence (Figure 2), and 2 samples dissected from tree 4 to place the Tille II sequence (Figure 1). The AMS $^{14}$C samples (Table 1) were run at Oxford following the procedures described in Bronk Ramsey et al. (2002, 2004a,b). The dendro-sequenced $^{14}$C data were then wiggle-match-dated employing OxCal (Bronk Ramsey 1995, 2001, 2008 version 4.05 curve resolution set at 5) and IntCal04 (Reimer et al. 2004): see Figures 1–5, Tables 1–2.

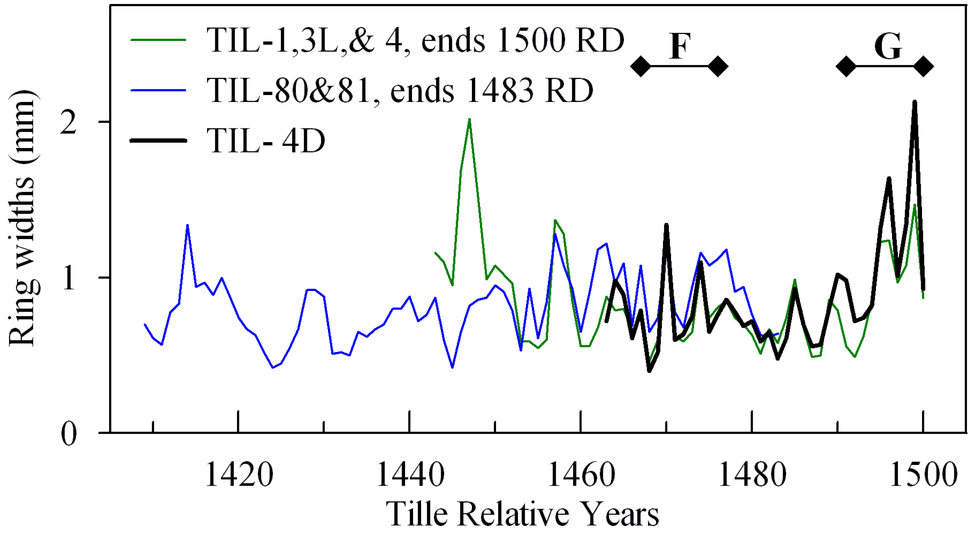

Figure 1 The constituents of the Tille II chronology, composed of 2 crossdated tree-ring sequences TIL-1, 3L, and 4 (green), and TIL-80 and 81 (blue). TIL-4D, shown separately in black, was the segment used for $^{14}$C analysis, with the 2 $^{14}$C-dated segments shown by the horizontal lines F and G.

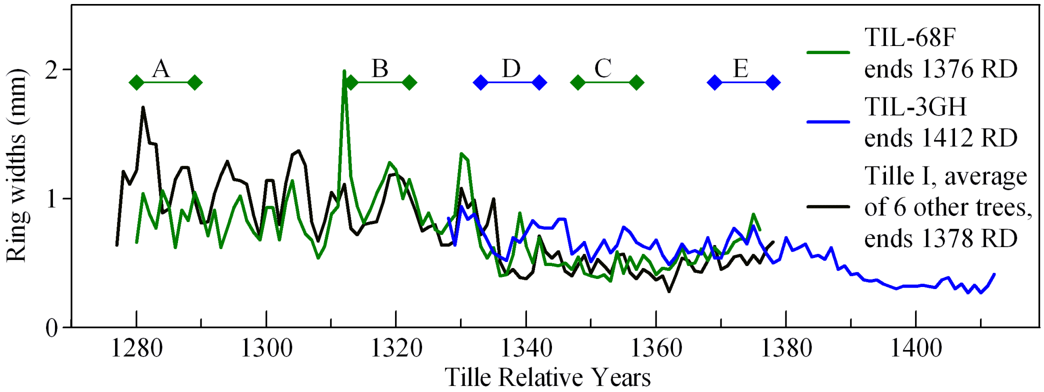

Figure 2 The Tille I chronology constituents, representing TIL-68EFH, TIL-3GH, and the average of all other samples. TIL-68 and TIL-3 are the 2 samples that had ring segments $^{14}$C dated; the segments are indicated as horizontal lines A, B, and C from TIL-68FH, and D and E from TIL-3G. See Tables 1 and 2 and Figures 3–5 for more information about the $^{14}$C ages.

Table 1 Tille Höyük wood (oak) charcoal samples and tree rings dated by $^{14}C$ accelerator mass spectrometry (AMS) at the Oxford Radiocarbon Accelerator Unit and their $^{14}C$ age results. The letters in the right column correspond to the letters above the horizontal bars, indicating the placement of the analyzed rings, in Figures 1, 2, and 3.

| Lab ID | Sample ID | $\delta^{13}C$ (‰) | $^{14}C$ age (yr BP) | Letter in Figures 1–3 |
|---|---|---|---|---|
| OxA-17428 | TIL-4D rings 1022–1031 | –25.65 | 2908 ± 30 | F |
| OxA-17429 | TIL-4D rings 1046–1055 | –25.4 | 2887 ± 31 | G |
| OxA-17430 | TIL-3G rings 1041–1050 | –25.17 | 3023 ± 31 | D |
| OxA-17431 | TIL-3G rings 1077–1086 | –25.35 | 2965 ± 31 | E |
| OxA-17432 | TIL-68F rings 1001–1010 | –24.62 | 3058 ± 31 | A |
| OxA-17433 | TIL-68H rings 1034–1043 | –24.89 | 2956 ± 31 | B |
| OxA-17434 | TIL-68H rings 1069–1078 | –24.77 | 2992 ± 32 | C |

Table 2 The modeled calendar age placements (dates BCE) for each decade (the mid-point thereof) from a Defined Sequence (dendro-sequence) analysis of the TIL-4D, TIL-68F, and H and TIL-3G samples from OxCal (Bronk Ramsey 1995, 2001, 2008 v 4.05 curve resolution set at 5) and IntCal04 (Reimer et al. 2004). The agreement index compares the final (posterior) distribution calculated (calendar age ranges stated in Table 1 above) against the original distribution (the calibrated age probability for the individual sample in isolation). If the former is unaltered, the index value is 100. The value rises above 100 where the final distribution overlaps only with the very highest part of the prior distribution. In contrast, an agreement index below 60 indicates disagreement with the model (and insufficient overlap of the distributions) at about the 5% level of a $\chi^2$ test. The overall agreement index for each tree sequence is also stated—again a score greater than the stated test statistic indicates that the model surpasses an approximate 95% confidence level.

| Sample | 1 σ (68.2% conf.) modeled placement BCE | 2 σ (95.4% conf.) modeled placement BCE | Agreement index, overall sequence | Agreement index, individual sample |
|---|---|---|---|---|
| TIL-4D rings 1022–1031 | 1126–1053 | 1187–1021 | 120.9 > 50 | 116.1 > 60 |
| TIL-4D rings 1046–1055 | 1102–1029 | 1163–997 | 120.9 > 50 | 112.7 > 60 |
| Tille I rings 1280–1289 (TIL-68F) | 1330–1317 (0.159)<br>1295–1268 (0.523) | 1344–1262 | 95.7 > 31.6 | 86.2 > 60 |
| Tille I rings 1313–1322 (TIL-68H) | 1297–1284 (0.159)<br>1262–1235 (0.523) | 1311–1229 | 95.7 > 31.6 | 73.5 > 60 |
| Tille I rings 1333–1342 (TIL-3G) | 1277–1264 (0.159)<br>1242–1215 (0.523) | 1291–1209 | 95.7 > 31.6 | 96.2 > 60 |
| Tille I rings 1348–1357 (TIL-68H) | 1262–1249 (0.159)<br>1227–1200 (0.523) | 1276–1194 | 95.7 > 31.6 | 126.8 > 60 |
| Tille I rings 1369–1378 (TIL-3G) | 1241–1228 (0.159)<br>1206–1179 (0.523) | 1227–1135 | 95.7 > 31.6 | 117.4 > 60 |

The complete Tille chronology discussed in Kuniholm et al. (1993) was comprised of 2 subchronologies. In the revised version presented here, on the basis of reexamination of the tree-ring series and then the $^{14}C$ wiggle-match investigation (Figures 1–3, Tables 3–4), the long samples are generally in the same relative position to each other with the exception of TIL-3GH (Figures 2 and 3). The AMS $^{14}C$ analysis of the 7 decadal segments from 3 different trees indicates that the original "early" chronology (now the Tille II chronology) actually is more recent (younger) than the original "late" subchronology (now the Tille I chronology), and *vice versa* (see Figures 3–5 and Table 2). Sample TIL-3GH, the longest single sequence, belongs at the end of the Tille I chronology rather than at the

https://doi.org/10.1017/S0033822200056046

Table 3 Listing of the composite tree (oak) samples from Tille Höyük, with details on sample lengths and relative dates for each tree, and a summary of the crossdating between and among the sequences for the 2008 Tille I, II and ‘Middle’ chronologies. We note that the relatively low *t* values are the result of the relatively short overlaps involved. We nonetheless find the crossdates convincing as sets and visually, and note also the good correlation and trend coefficient values. TIL-3GH, although a relatively long tree-ring record with 84 rings, was the most difficult sample to work with because of tiny rings and large variability—these problems are reflected in the modest *t* scores (lowest in the Tille I chronology). We believe it is correctly placed, notwithstanding; this sample was employed for some of the $^{14}C$ dates because it offered the best intact sample material for the later half of the Tille I chronology.

| Chronology/ Sample | Relative dates | | Length (yr) | Statistics between each sample and average of all other samples | | | | | Average statistics between samples | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Begins | Ends | | Student’s *t* score | Correlation coefficient | Trend coefficient | Overlap | | Student’s *t* score | Correlation coefficient | Trend coefficient | Overlap |
| 2008 Tille I | | | | | | | | | | | | |
| 69A | 1291 | 1321 | 31 | 4.99 | 0.69 | 70.0 | 31 | | 4.44 | 0.64 | 75.0 | 31 |
| 25E | 1309 | 1349 | 41 | 4.03 | 0.54 | 75.0 | 41 | | 3.43 | 0.48 | 66.6 | 39 |
| 26A | 1307 | 1363 | 57 | 6.38 | 0.65 | 71.0 | 57 | | 5.04 | 0.57 | 65.4 | 50 |
| 24&33 | 1308 | 1367 | 60 | 7.02 | 0.68 | 79.0 | 60 | | 4.99 | 0.57 | 68.3 | 52 |
| 68EFH | 1280 | 1378 | 99 | 5.07 | 0.46 | 69.3 | 97 | | 3.33 | 0.43 | 64.3 | 53 |
| 27etc | 1277 | 1376 | 100 | 7.96 | 0.63 | 76.6 | 97 | | 4.95 | 0.57 | 72.9 | 53 |
| 62B | 1346 | 1378 | 33 | 5.07 | 0.67 | 84.0 | 33 | | 3.28 | 0.50 | 72.1 | 32 |
| 3GH | 1328 | 1412 | 85 | 3.41 | 0.44 | 73.5 | 50 | | 3.00 | 0.45 | 68.7 | 47 |
| Tille I chronology | 1277 | 1412 | 136 | 5.49 | 0.60 | 74.8 | 58 | Ave. | 4.06 | 0.53 | 69.2 | 45 |
| 2008 Tille Middle | | | | | | | | | | | | |
| 60C | 1405 | 1459 | 55 | 4.40 | 0.59 | 71.1 | 39 | | 3.35 | 0.52 | 64.5 | 34 |
| 70AB | 1387 | 1443 | 57 | 4.16 | 0.49 | 74.1 | 57 | | 3.48 | 0.47 | 67.5 | 43 |
| 28B | 1381 | 1433 | 53 | 3.28 | 0.44 | 64.1 | 47 | | 3.00 | 0.45 | 58.2 | 38 |
| Middle chronology | 1381 | 1459 | 79 | 3.95 | 0.51 | 69.8 | 47 | Ave. | 3.28 | 0.48 | 63.4 | 40 |
| 2008 Tille II | | | | | | | | | | | | |
| 1&3L&4 | 1445 | 1500 | 56 | 7.89 | 0.78 | 85.0 | 41 | | 7.89 | 0.78 | 85.0 | 41 |
| 80&81 | 1409 | 1469 | 61 | 7.89 | 0.78 | 85.0 | 41 | | 7.89 | 0.78 | 85.0 | 41 |
| Tille II chronology | 1409 | 1500 | 78 | 7.89 | 0.78 | 85.0 | 45 | Ave. | 7.89 | 0.78 | 85.0 | 41 |

end of the Tille II chronology. The chronologies' $^{14}$C dates indicate that the 2 sequences overlap very little, if at all. Upon examination of the samples not used in the 2 chronologies, we were able to build a third, small, "Middle" chronology, of 3 samples (4 fragments of 3 trees, Figure 3, Table 4), and found that it may tentatively connect the 2 sequences (Figure 3). The most questionable aspect of this "Middle" chronology placement is the relatively speculative crossdating between the Tille I and "Middle" chronologies, with a short overlap with low values from the statistical tests. The placement is based mainly on their visual match. Additional $^{14}$C dates would be needed on at least 1 of the "Middle" samples to validate this chronology's position between the Tille I and II chronologies. The "Middle" sequence, however, does place the 2 secure chronologies within the timeframe indicated by their respective $^{14}$C ages (Figures 3–5). In addition, the "Middle" sequence indicates a possible third building phase.

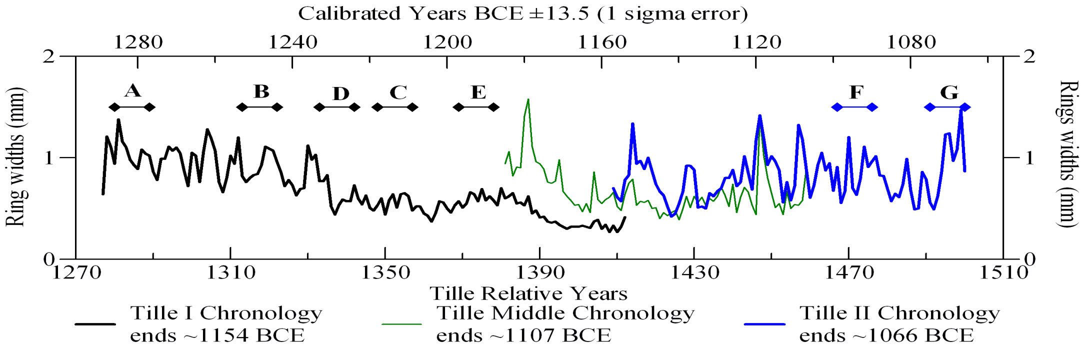

Figure 3 The approximate possible placement of the 3 chronologies, defined both by the $^{14}$C dates' placement on the IntCal04 $^{14}$C calibration curve (see Table 2 and Figure 3), and the crossdating between the 3 sequences. The most tentative issue is the crossdating between Tille I and the "middle" chronologies. For the composition and date placements of the 3 dendrochronologies (and their constituent elements), see Tables 3 and 4. The wiggle-match error range stated is for the most likely subrange of the overall 1-$\sigma$ range (see Figure 5, Table 2): this comprises the most likely 52.3% (of the total probability) fit range. Note, if this assumption (using the most likely subrange) is incorrect, then the date of the Tille I chronology would be shifted to an older calendar dating (some 42 ± 6.5 yr earlier) using the alternative 15.9% range within the overall 1-$\sigma$ range (see Figure 5, Table 2). This would also break the tentative Tille "middle" chronology bridge shown above. In reverse, since this Tille "middle" bridge can work with the most likely 52.3% placement, it perhaps forms an additional strand in the argument to make this the most likely dating choice (as shown above).

## RESULTS

The absolute dates offered in 1993 came from matching the incorrect original 218-yr oak chronology with the long, robust, Gordion area tree-ring chronologies of juniper and pine from central Anatolia (Bannister 1970; Kuniholm 1977; Kuniholm et al. 2005). Dating the chronology in this way assumed that the oaks were from either the Tille area or "floated downriver from some forest up the Euphrates," and that an oak chronology would date securely with a juniper or pine chronology. An approximate timeframe somewhere in the Late Bronze Age to early Iron Age periods was also assumed from the archaeological evidence. Our Bronze and Iron ages chronologies are nearly absolutely dated via extensive $^{14}$C wiggle-matching (Manning et al. 2001, 2003), but matching tree-ring patterns between very different species (oaks and junipers), which respond to different climate parameters, especially across ~600 km, is questionable.

The wiggle-match placements of the 7 $^{14}$C dates from the revised Tille tree-ring sequences against the current IntCal04 $^{14}$C calibration curve (Reimer et al. 2004) employing the OxCal software (Bronk Ramsey 1995, 2001, 2008; Bronk Ramsey et al. 2001) are shown in Figures 3–5 and listed

https://doi.org/10.1017/S0033822200056046

Table 4 Details on the composition of the 2008 Tille dendrochronologies.

| | Relative dates | | Length | | Numbers of: | |
|---|---|---|---|---|---|---|
| Chronology/sample | Begins | Ends | (yr) | Trees | Samples | Fragments |
| 2008 Tille I | | | | | | |
| 69A | 1291 | 1321 | 31 | 1 | 1 | 1 |
| 25E | 1309 | 1349 | 41 | 1 | 1 | 1 |
| 26A | 1307 | 1363 | 57 | 1 | 1 | 1 |
| 24&33 | 1308 | 1367 | 60 | 1 | 2 | 2 |
| 68EFH | 1280 | 1378 | 99 | 1 | 1 | 3 |
| 27AB,29AE,31AB,34AB,35AC,36DEJM | 1277 | 1376 | 100 | 1 | 6 | 14 |
| 62B | 1346 | 1378 | 33 | 1 | 1 | 1 |
| 3GH | 1328 | 1412 | 85 | 1 | 1 | 2 |
| Tille I chronology | 1277 | 1412 | 136 | 8 | 14 | 25 |
| 2008 Tille 'Middle' | | | | | | |
| 60C | 1405 | 1459 | 55 | 1 | 1 | 1 |
| 70AB | 1387 | 1443 | 57 | 1 | 1 | 2 |
| 28B | 1381 | 1433 | 53 | 1 | 1 | 1 |
| Tille 'Middle' chronology | 1381 | 1459 | 79 | 3 | 3 | 4 |
| 2008 Tille II | | | | | | |
| 1&3L&4 | 1445 | 1500 | 56 | 1 | 3 | 15 |
| 80&81 | 1409 | 1469 | 61 | 1 | 2 | 8 |
| Tille II chronology | 1409 | 1500 | 78 | 2 | 5 | 23 |
| | | | TOTALS: | 13 | 22 | 52 |

in Table 2. Their placement of the $^{14}$C ages from samples TIL-68FGH, and TIL-3GH indicates that the Tille I chronology ends around 1154 BCE. The length of 3GH, and the structure of its other fragments, indicates that it is the oldest tree represented among all the samples; its location at the site and the secure placement of TIL-3L in the Tille II chronology suggest that 3GH contains the inner rings of the same tree. All other samples in the Tille I chronology are from different locations, and the sequences of 3 trees (8 fragments) end within 4 yr of each other. That cluster of dates indicates the possible presence of heartwood/sapwood boundaries close to 1188 BCE (= around TIL Relative Date 1378, 34 yr before the end of the Tille I chronology). An addition of about 20–25 sapwood rings (typical "average" sapwood estimates for Aegean region deciduous oaks: 25.6 ± 9 rings in Kuniholm and Striker 1987:390; or 22 +9/–5 rings on the basis of a larger sample set now studied at Cornell) would place the building date of the first phase at ~1168–1163 BCE give or take a few years.

The placement of the TIL-4D $^{14}$C ages indicates that Tille II ends at ~1060 BCE. The relationship of the "Middle" chronology between the Tille I and II chronologies would put its end date at ~1100 BCE. Again, these dates are all *terminus post quem* dates. The actual felling dates of the trees, and thus the building dates, are most likely at least 20 yr beyond each end date due to rings removed during construction and by the final destruction. There was no conclusive evidence of sapwood preserved in any of the included samples. The possible demarcation between heartwood and sapwood in sample TIL-29A (a fragment included in the TIL-27 etc. group; illustrated in Kuniholm et al. 1993:185, pl.29) appears to be due more to cambial damage and repair, rather than a heartwood/sapwood boundary.

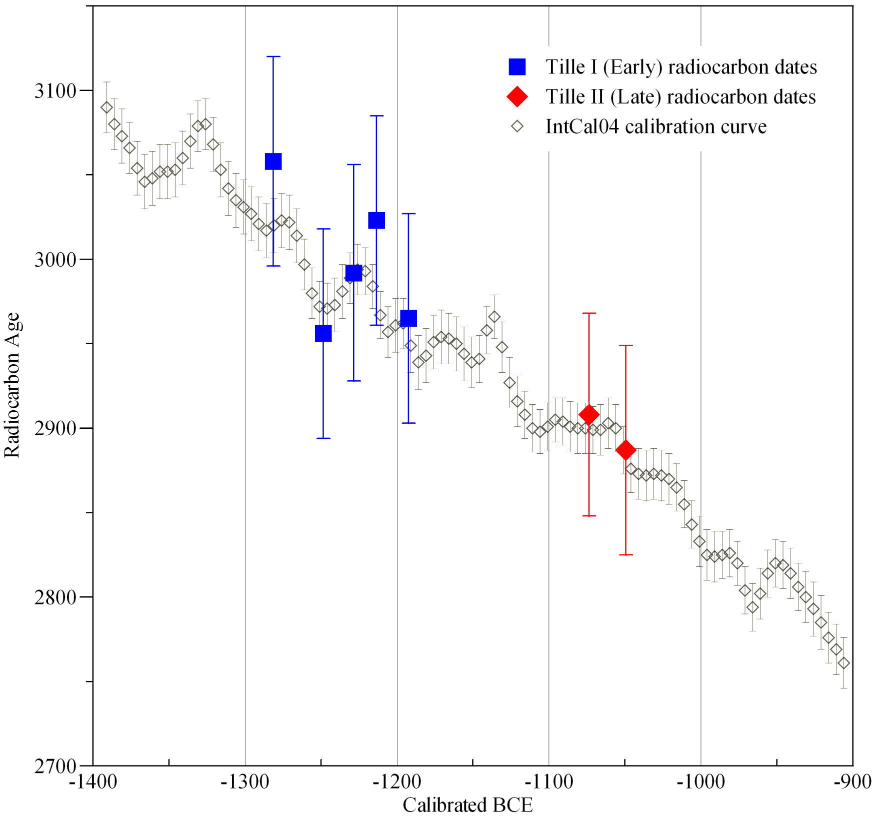

Figure 4 Placement of the 7 Tille Höyük $^{14}$C measurements against the IntCal04 $^{14}$C calibration curve and in terms of the new Tille Höyük 2008 (Tille08) I (Early) and II (Late) tree-ring chronologies. The wiggle-match fit points shown for the Tille I dates are the centers of the more likely subranges of the 1-σ ranges (the most likely 52.3% of the total probability ranges) in Table 2, with the fit error employed being the limits of this subrange. The Tille II (TIL-4D) data are fitted to the middle of their 1-σ ranges in Table 2.

## CONCLUSIONS

We report here revised results of the dendrochronological analysis of the Tille Höyük wood samples. The samples were problematic, and although the initial results (Kuniholm et al. 1993) were valid in many ways, it was important to revisit and test the less-than-secure crossdating between sequences and their calendar date placements, with the use of $^{14}$C wiggle-matching, especially in view of criticism of the earlier chronology and its dating (e.g. Keenan 2002).

The 2 building phases indicated by the initial results have now been corroborated, but reversed in terms of placement in time, with the possible addition of another phase, or at least evidence of simple, perhaps constant, repair to the buildings over time. The ~1150 BCE date for the first building phase is consistent with the close of Late Bronze Age architectural evidence and artifacts found at the site (Summers 1993). The second chronology, samples TIL-1,3L & 4 and TIL-80 & 81, are from a significantly later building phase, with their last preserved ring dating to the mid-11th century BCE; thus, the *terminus post quem* felling dates are from the mid- to late 11th century BCE. This implies an early Iron Age date for their cutting and use, and for the final (burnt) destruction.

https://doi.org/10.1017/S0033822200056046

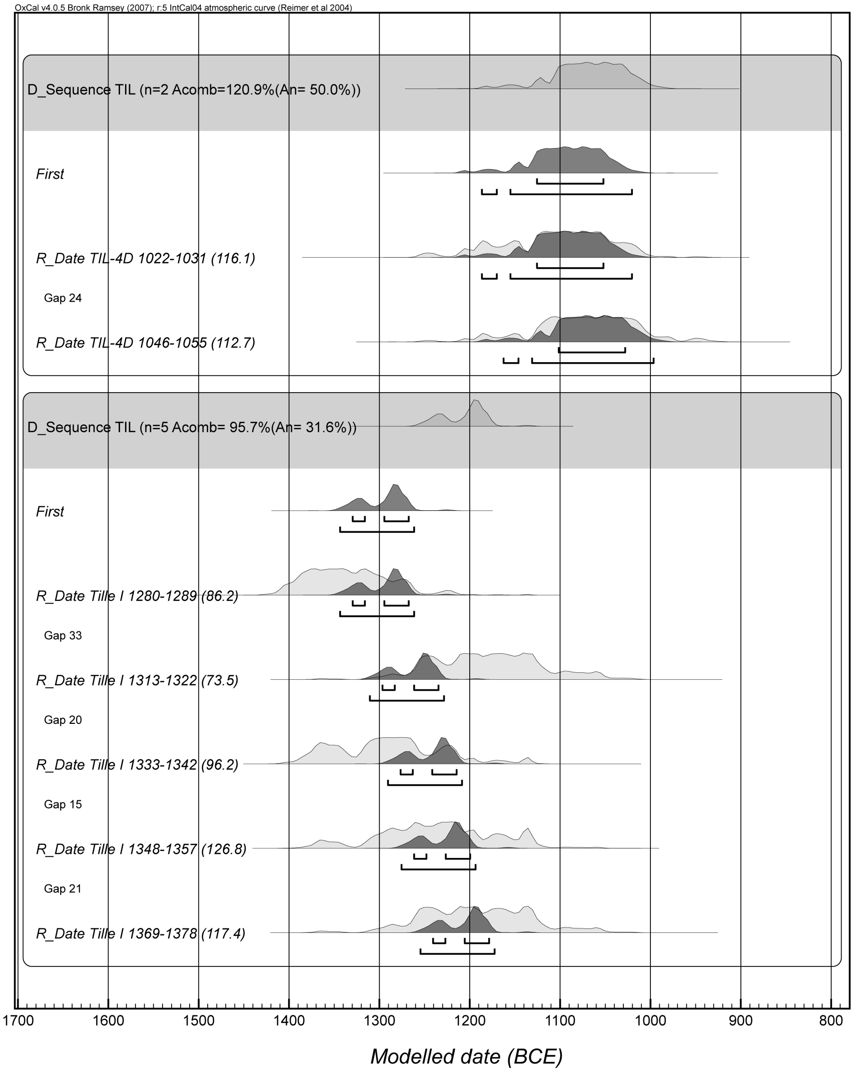

Figure 5 Modeled calendar age BCE placements of the $^{14}$C-dated samples from Tille Höyük given the known dendrochronological spacings between the samples from each of the 3 dated sequences. Data from OxCal (Bronk Ramsey 1995, 2001, 2008 v 4.05 with curve resolution set at 5) and IntCal04 (Reimer et al. 2004). The hollow distributions for each individual date show the calibrated probabilities in isolation (no model), and the solid distributions show the reduced probability distributions after applying the Defined Sequence analysis model. The upper and lower lines under each distribution show the respective 1-σ (68.2% confidence) and 2-σ (95.4% confidence) calibrated age ranges (for the modeled results): see Table 2 (which gives the 1- and 2-σ ranges).

The $^{14}$C dates, plus the possible inclusion of 1 more building phase (the "Middle" phase), suggest a more complicated history for the gateway area at Tille Höyük, and perhaps a continuity of occupation from the later 13th through to the 11th century BCE (compare with discussions of Summers 1993). The revised Tille dates and the other evidence from the site in turn imply strong regional differences in the exact timings and nature of the close of the Late Bronze Age across Anatolia and southwest Asia.[1]

[1] Note: the tree-ring data for the 13 tree samples employed in this paper—see Table 4—will be submitted to the ITRDB on publication of this paper.

## ACKNOWLEDGMENTS

We thank Geoff Summers very much for his encouragement to reexamine the Tille material, and his comments. We thank the Oxford Radiocarbon Accelerator Unit for the $^{14}$C data.

## REFERENCES

Bannister B. 1970. Dendrochronology in the Near East: current research and future potentialities. *Proceedings of the Seventh International Congress of Anthropological and Ethnological Sciences* 5:336–40.

Billamboz A. 2008. Dealing with heteroconnections and short tree-ring series at different levels of dating in the dendrochronology of the Southwest German pile-dwellings. *Dendrochronologia* 26(3):145–55.

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon* 37(2):425–30.

Bronk Ramsey C. 2001. Development of the radiocarbon calibration program. *Radiocarbon* 43(2A):355–63.

Bronk Ramsey C. 2008. Deposition models for chronological records. *Quaternary Science Reviews* 27(1–2): 42–60.

Bronk Ramsey C, van der Plicht J, Weninger B. 2001. 'Wiggle matching' radiocarbon dates. *Radiocarbon* 43(2A):381–9.

Bronk Ramsey C, Higham TFG, Owen DC, Pike AWG, Hedges REM. 2002. Radiocarbon dates from the Oxford AMS system: Datelist 31. *Archaeometry* 44(3) Supplement 1:1–149.

Bronk Ramsey C, Higham TFG, Leach P. 2004a. Towards high-precision AMS: progress and limitations. *Radiocarbon* 46(1):17–24.

Bronk Ramsey C, Higham TFG, Bowles A, Hedges REM. 2004b. Improvements to the pretreatment of bone at Oxford. *Radiocarbon* 46(1):155–63.

Galimberti M, Bronk Ramsey C, Manning SW. 2004. Wiggle-match dating of tree-ring sequences. *Radiocarbon* 46(2):917–24.

Keenan DJ. 2002. Why early-historical radiocarbon dates downwind from the Mediterranean are too early. *Radiocarbon* 44(1):225–37.

Kuniholm PI. 1977. Dendrochronology at Gordion and on the Anatolian Plateau [PhD dissertation]. Philadelphia: University of Pennsylvania.

Kuniholm PI, Newton MW. 1990. A 677 year long tree-ring chronology for the Middle Bronze Age. In: *Anatolia and the Ancient Near East: Studies in Honor of Tahsin Özgüç*. Ankara: Türk Tarih Kurumu Basimevi. p 279–93.

Kuniholm PI, Striker CL. 1987. Dendrochronological investigations in the Aegean and neighbouring regions, 1983–1986. *Journal of Field Archaeology* 14:385–8.

Kuniholm PI, Tarter SL, Newton MW, Griggs CB. 1992. Dendrochronological investigations at Porsuk/Ulukışla, Turkey 1987–1989. *Syria* 69:379–89.

Kuniholm PI, Tarter SL, Griggs CB. 1993. Dendrochronological report. In: Summers GD. *Tille Höyük 4: The Late Bronze Age and the Iron Age Transition*. Ankara: The British Institute of Archaeology at Ankara. p 179–90.

Kuniholm PI, Newton MW, Griggs CB, Sullivan PJ. 2005. Dendrochronological dating in Anatolia: the second millennium B.C.: significance for early metallurgy. In: *Anatolia III, Der Anschnitt, Beiheft* 18. Bochum: Deutsches Bergbau-Museum. p 41–7.

Manning SW, Kromer B, Kuniholm PI, Newton MW. 2001. Anatolian tree-rings and a new chronology for the east Mediterranean Bronze-Iron Ages. *Science* 294(5551):2532–5.

Manning SW, Kromer B, Kuniholm PI, Newton MW. 2003. Confirmation of near-absolute dating of east Mediterranean Bronze-Iron dendrochronology. *Antiquity* 77(295): http://antiquity.ac.uk/ProjGall/Manning/manning.html

Newton MW, Kuniholm PI. 2004. A dendrochronological framework for the Assyrian colony period in Asia Minor. *Türkiye Bilimler Akademisi Arkeoloji Dergisi* (TÜBA-AR) 7:165–76.

Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Hogg AG, Hughen KA, Kromer B, McCormac G, Manning S, Bronk Ramsey C, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46(3):1029–58.

Summers GD. 1993. *Tille Höyük 4: The Late Bronze Age and the Iron Age Transition*. Ankara: The British Institute of Archaeology at Ankara. 203 p.