APPENDIX 2

Dendrochronological Report

by PETER IAN KUNIHOLM, SHANA L. TARTER and CAROL B. GRIGGS

The Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology,
Department of the History of Art and Archaeology, Cornell University

ABSTRACT

Seventy-six datable fragments of severely burned oak charcoal from the over 150 collected in the destroyed gate-building on the west side of the Tille mound form a 218-year tree-ring chronology which can be crossdated with our 1503-year Bronze Age/Iron Age tree-ring chronology from Gordion and other sites. The wood of the last building phase before the destruction at Tille was probably cut shortly after 1140 BC ±37 years. Wood of what may have been an earlier phase of the building was cut not more than 70 years earlier in 1210 BC ±37 years.

INTRODUCTION

The violently burned gateway on the west side of the Tille mound whose demise marks the end of the Late Bronze Age and the transition to the Early Iron Age at Tille yielded over 150 samples of charcoal for dendrochronological analysis from 12 different units. Reference to the excavator's plan will show that the majority of the measurable samples (see catalogue below) are from Context 7458/408, namely beams (?from the roof?) of the gate passage or gate building. Other contexts include the roof or upper floor from adjoining rooms or their supports. Provenience information and stratigraphic interpretation have been kindly provided by the excavator, Geoffrey Summers. The first four samples of Tille wood were given to us at the 1989 Annual Archaeology, Research, and Archaeometry Symposium in Antalya and the remainder collected from the depot of the Adıyaman Museum, whose staff we thank for their cooperation, in the summer of 1990.

Dr. Summers's most recent interpretation, provided after we had completed our dendrochronological study, indicates that the wood (on purely archaeological grounds) is likely to be from the very end of the Bronze Age/beginning of the Iron Age and was carbonized in a burning between 1200-1000 BC. An earlier phase of the gateway was perhaps as early as the late 13th/early 12th century BC. Since we had already arrived at the same conclusion on dendrochronological grounds, it may be of interest to outline the process by which we came to our conclusions.

METHOD

All charcoal intended for dendrochronological analysis was passed to us wrapped in string in order to keep exterior rings from flaking off. The violence of the conflagration was such that no beams survived intact, and the fragments were distorted. Their analysis, therefore, was extraordinarily difficult. No traces of worked surfaces were found, and, with the exception of TIL-29 below, no direct evidence survives to give us information about the terminal ring which grew just before the wood was cut. An argument may be made on circumstantial evidence about other termini (see below). Transverse surfaces were prepared in the laboratory with fine sandpaper, and the rings were measured to the nearest 1/100mm. Samples were compared by visual inspection, by comparison of the raw and standardized ring-width graphs, and by statistical analysis of ring-width distribution.

Fragments of the measurable charcoal vary in size from 4cm. to 8cm. in diameter. The maximum ring-count on any one fragment is only 97 annual rings. Nevertheless, on the basis of curvature, comparison of absolute ring-widths, and cell morphology within individual rings, we were able to combine a number of fragments which obviously came from the same tree into individual sequences (i.e. sequences for that one tree) as long as 148 years. These, in turn, were combined into a master sequence for this phase in the life of Tille of 218 years.

SPECIES

All of the 76 datable and most of the undatable charcoal fragments at Tille are oak (*Quercus* spp.). Additional species represented at Tille, the ring sequences of which were too short for dendrochronology, however, were Poplar? (*Populus* sp.), Oriental Plane (*Platanus orientalis*), Maple (*Acer* sp.), Ash (*Fraxinus* sp.) and one or more varieties of fruit tree. A glance at the treeless hillsides around Tille today makes the notion of 148 year old oak trees seem improbable, but there in the gateway are their remains whether locally grown or floated downriver from some forest up the Euphrates.

TERMINOLOGY

In the catalogue which follows, several terms deserve explanation.

SAMPLE NUMBER: the order in which we processed the fragment (TIL-1, TIL-3, etc.); used for laboratory identification. Of greater significance is the excavator's identification number. Thus provenience information is listed in accordance with the nomenclature given to us by the excavators: site/year/grid/unit/material/batch. The meticulous reader will note that the numbers of 'samples', 'fragments', 'beams' or 'trees' do not add up with any ease whatsoever. What was collected in the field as several bags of fragments from several loci sometimes turned out to be from one tree (TH/85/7358/098/20/002 and 003 and 004). At other times a single bag turned out to be a collection of fragments from different trees, sometimes even of different species. For example, the excavator's TH/89/7458/408/20/005 includes fragments of 13 trees, all oak. On the other hand the excavator's TH/89/7660/132/20/006 includes fragments of plane, ash, and maple.

Our best estimate is that we have 26 datable oak *trees* at Tille plus the trees of other species. We have no way of knowing into how many architectural timbers a given tree might have been split. All of which is to say that the violence of the conflagration which destroyed the settlement, but which thereby preserved the carbonized wood for our study, makes straightforward dendrochronological interpretation less than simple.

SAPWOOD: No terminal or felling year ring is demonstrably present at Tille. Anatolian oaks, however, have a statistically calculable amount of sapwood with open vessels, in which tylosis has not yet occurred, next to and including the terminal ring, usually 26 years ±9 before the bark. Since all the Tille samples are charcoal, it is hard-to-impossible to determine the heartwood/sapwood boundary. However, in the Tille samples the greatest distortion of the wood (twisting of the rays and the rings between them) presumably has occurred at weak points or points where the wood changes character, and the heartwood/sapwood boundary is such a place. One good example of such a possible boundary is Relative Year 1354 in sample TIL-29A as shown in Pl.29. Since the Tille ring-sequence continues to Relative Year 1381, or 27 years after 1354, we think the cutting date for the latest Tille wood is not long after Relative Year 1381.

v: we think it is probable that the last preserved ring is not far from the terminal ring which grew before the tree was cut down.

vv: we can not prove how many exterior rings are missing.

+ or ++: the last ring or rings were countable but not measurable.

p: the pith ring at the center of the sample. ±p indicates that the earliest preserved ring is within a year or two of the pith.

RELATIVE DATES (RD): These are *counting years*. We began at Tille by converting all possible pieces into a common numbering system and then combining them into a single series: Tille Relative Dates 1-218. Then we found that this Tille ring-sequence crossdated with our 1503-year Bronze Age/Iron Age master dendrochronological scale which is, for these centuries, principally from the Midas Mound Tumulus at Gordion. All datable samples from Tille have thus been assigned dates (MMTRD 1164-1381) in relation to this long chronology which in turn is wiggle-matched or pinned in place by 18 radiocarbon dates of selected decades. Some day we hope to be able to say purely from dendrochronological evidence exactly what year BC is represented by Relative Year 1381. The relative dates in the catalogue are given in accordance with the Gordion numbering system. For further discussion of the absolute dates see below.

CATALOGUE

SAMPLE	PROVENIENCE	RINGS	GORDION MMT RELATIVE DATES
TIL- 1	TH/85/7358/098/20/004	A=1+54+1	
	Same timber as TIL-4 and 3L	B=1+32	
		C=1+32	
		D=43	
		E=1+29+1	
		F=1+49+1	
		G=42+1	
		A-G comb.=1+57+1	
TIL- 4	TH/85/7358/098/20/003	A=54+1	
	Same timber as TIL-1 and 3L	B=51+1	
		C=1+28	
		D=1+38	
		E=32	
		F=3+34+1	
		G=32	
		A-G comb.=54+1	
TIL- 3L	TH/85/7358/098/20/002	L=34	
	Same timber as TIL-1 and 4		
		1 A-G, 4 A-G, 3L comb.=1+57+1	1239±p - 1298+vv
TIL- 3	TH/85/7358/098/20/002	A=27	
		B=50	
		C=1+45+1	
		D=1+43	
		E=39	
		F=1+55+1	
		G=84+1	
		H=1+55+1	
		I=1+36+1	
		J=56+1	
		K=2+54+1	
		A-K comb.=148+1	1163±p - 1312+vv
TIL- 5	TH/89/7357/064/20/004	A= 22	
	Branch?	B= 23	
		AB= 24	1322p - 1345vv
TIL-19	TH/89/7660/132/20/006	A= 34	
		B= 31	
TIL-21	TH/89/7660/132/20/006	B= 37	1333 - 1369vv
		D= 28	1327 - 1351vv
TIL-23A	TH/89/7660/132/20/006	A= 73	
TIL-24	TH/89/7458/408/20/005	A= 60+8	1308 - 1375++v

SAMPLE	PROVENIENCE	RINGS	GORDION MMT RELATIVE DATES
TIL-25	TH/89/7458/408/20/005	E = 41+5	1309 - 1354++vv
TIL-26	TH/89/7458/408/20/005	A = 58	1307 - 1364vv
TIL-27	TH/89/7458/408/20/005	A = 52+5 B = 48 AB = 52+5	1324 - 1380++v
TIL-28	TH/89/7458/408/20/005	A = 25+1 B = 52+1	1255 - 1307+vv
TIL-29	TH/89/7458/408/20/005 Sapwood possibly begins at 1354	A = 52+1 E = 38 AE = 52+1	1321 - 1373+v
TIL-30	TH/89/7458/408/20/005	A = 36+1	1293 - 1329+vv
TIL-31	TH/89/7458/408/20/005	A = 44+1 B = 40+1 AB = 46+1	1331 - 1377+v
TIL-32	TH/89/7458/408/20/005	A = 42	1260 - 1301vv
TIL-33	TH/89/7458/408/20/005	A = 46+6 B = 43 AB = 46+6	1320 - 1371++vv
TIL-34	TH/89/7458/408/20/005	A = 40 B = 30+5 AB = 70	1300 - 1369vv
TIL-35	TH/89/7458/408/20/005	A = 50 C = 35 AC = 50	1321 - 1370vv
TIL-36	TH/89/7458/408/20/005	D = 38+5 E = 35+2+10 H = 18 J = 42+15 M = 31 DEJM = 52+5	1277 - 1333++vv
TIL-42	TH/89/7660/151/20/009	AB = 30	
TIL-49	TH/89/7660/150/20/010 Same tree as TIL-50	A = 45+2 B = 39+1 C = 38+1 ABC = +1p+58+1	
TIL-50	TH/89/7660/150/20/010	A = +1p+39+2	
TIL-58	TH/89/7458/408/20/009 Same tree as TIL-59	A = 33	1333p - 1365vv

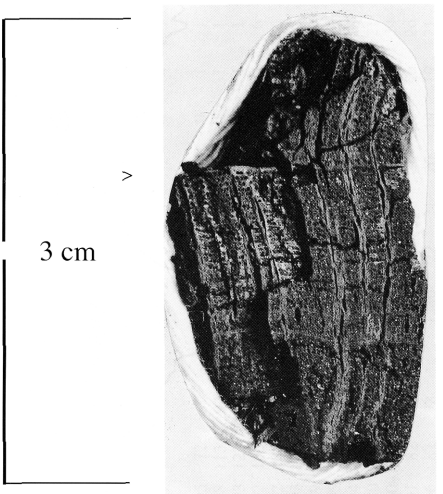
SAMPLE	PROVENIENCE	RINGS	GORDION MMT RELATIVE DATES
TIL-59	TH/89/7458/408/20/009 Same tree as TIL-58	A = 27	1333p - 1359vv
TIL-60	TH/89/7458/408/20/004	A = 20+25 B = 39 C = 55	
TIL-61	TH/89/7458/408/20/004	A = 43+1	
TIL-62	TH/89/7458/408/20/004	A = 36+5 B = 33+1	1346 - 1379+v
TIL-65	TH/89/7458/408/20/004	A = 53+1 B = 25+1 C = 45+1 BC = 45+1	1257 - 1310+vv
TIL-66	TH/89/7458/408/20/004	B = 27+1 C = 34+1 D = 42 BCD = 75+1	1294 - 1369+vv
TIL-67	TH/89/7458/408/20/004	A = 34 B = 23 C = 43+3	1327 - 1372++vv
TIL-68	TH/89/7458/408/20/004	A = 81 AB = 48+1 B = 61 erratic C = 24+22 D = 65+35 E = 40 EB = 27 F = 97+1 G = 36+8 H = 67+1 J = 46 K = 50 L = 58+1 A,AB,EB,F,H,L comb. = 117	1280 - 1381v
TIL-69	TH/89/7458/408/20/003	A = 31+1	1291 - 1322+vv
TIL-70	TH/89/7458/408/20/003	A = 57+1 B = 39+1 C = 17+1 ABC = 65+1	
TIL-71	TH/89/7458/408/20/003	A = 35+1	1285 - 1320+vv
TIL-77	TH/89/7660/150/20/010	A = 46+2	
TIL-78	TH/89/7660/150/20/010	A = 44 B = 6+19 C = 37	1268 - 1311vv

SAMPLE	PROVENIENCE	RINGS	GORDION MMT RELATIVE DATES
TIL-80	TH/89/7458/408/20/006 Same tree as TIL-81	A = 47 B = 17 C = 47 D = 22 E = 32 ABCDE = 50	1231 - 1280vv
TIL-81	TH/89/7458/408/20/006 Same tree as TIL-80	A = 50 B = 52 C = 48 ABC = 71	1206p - 1276vv

An additional 44 fragments were submitted but were not measured because of their short ring-counts. All were oak except for five fragments of *Platanus orientalis* (Oriental plane), one of *Fraxinus* sp. (Ash). one of *Acer* sp. (Maple), and three presumably poplar.

TILLE HÖYÜK MASTER CHRONOLOGY*	M=218	1164 - 1381v
(Includes TIL- 1, 3, 4, 5, 21BD, 24A, 25E, 26A,27AB, 28B, 29AE, 30A, 31AB, 32A, 33AB, 34AB, 35AC, 36DEJM, 58A, 59A, 62B, 65A, 67C, 68ACEFHL, 69A, 71A, 78A, 80ABCDE and 81ABC)		

* See Tables and graphic representation of Tables (pp. 186-187).



C - TU - TIL - 29A

Pl.29 Photograph of the Tille oak charcoal sample TIL-29 A. Note the severe distortion of the rings, particularly where the sapwood begins. (The half-dozen vertical lines are the rays which run from the pith towards the exterior at the top of the photograph and are not to be mistaken for the 53 rings which show as barely visible horizontal lines).

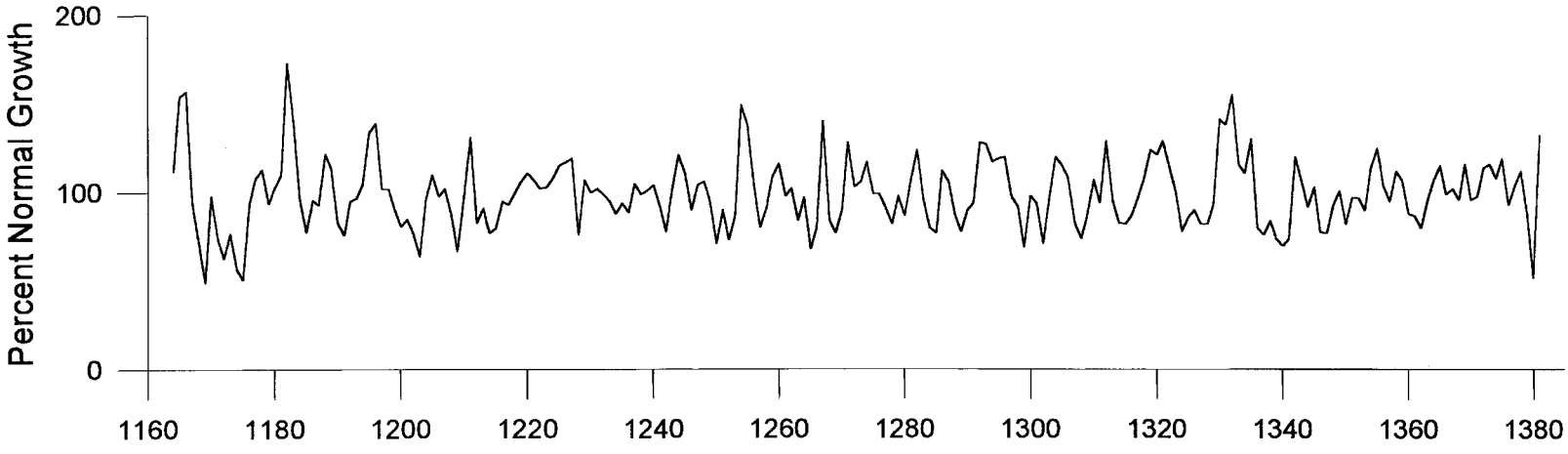


Fig.75 (a) Graphic representation of Table 1 with Gordion MMT Relative Dates.

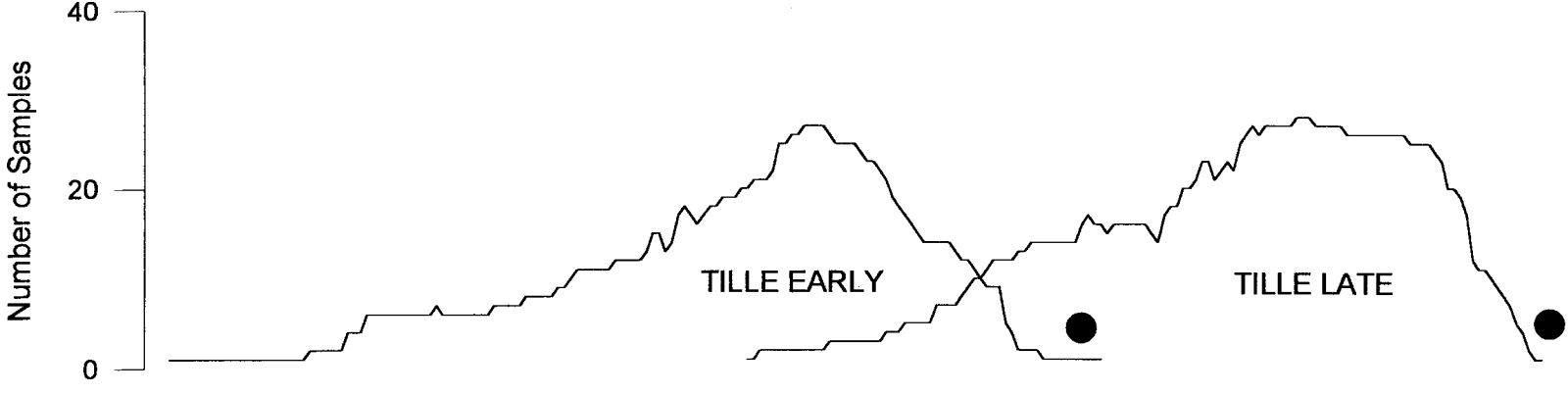


Fig.75 (b) Graphic representation of sample abundance as in Table 2 with Gordion MMT Relative Dates, showing the earlier and later groups of Tille samples. The large dots indicate the dates of the latest preserved end rings in the two series.

Composite Indices for Tille Höyük including 78 fragments from 29 samples

SUMMARY ID = 102003

TREE RING INDICES FOR TİLLE HÖYÜK, OAK

DATE	0	1	2	3	4	5	6	7	8	9
1164	0	0	0	0	112	154	157	95	72	49
1170	98	74	63	77	57	51	94	108	113	94
1180	103	110	173	139	97	78	96	93	122	114
1190	83	76	95	97	105	134	139	102	102	91
1200	81	85	77	64	96	110	98	102	88	67
1210	98	131	83	91	77	80	95	93	100	106
1220	111	107	102	103	108	115	117	119	76	107
1230	100	102	99	95	88	94	89	105	99	101
1240	104	92	78	103	121	111	90	104	106	95
1250	71	90	73	87	149	138	104	80	91	109
1260	116	98	102	84	97	68	80	140	84	77
1270	90	128	103	106	117	99	99	91	82	98
1280	87	106	124	95	80	77	112	106	87	78
1290	90	94	128	127	117	119	120	98	92	69
1300	98	94	71	98	120	115	108	83	74	87
1310	107	94	129	95	83	82	87	97	109	124
1320	121	129	114	100	78	86	90	82	82	93
1330	141	138	155	116	111	130	80	76	84	74
1340	70	74	120	106	92	103	78	77	93	101
1350	82	97	97	90	114	125	104	95	112	107
1360	88	87	80	96	107	115	99	102	96	116
1370	96	98	114	116	108	119	93	104	112	87
1380	52	132	0	0	0	0	0	0	0	0

Table 1: Annual percentages of normal ring-growth with Gordion MMT Relative Dates

NUMBER OF SAMPLES FOR TİLLE HÖYÜK, OAK

DATE	0	1	2	3	4	5	6	7	8	9
1164	0	0	0	0	1	1	1	1	1	1
1170	1	1	1	1	1	1	1	1	1	1
1180	1	1	1	1	1	1	2	2	2	2
1190	2	2	4	4	4	6	6	6	6	6
1200	6	6	6	6	6	6	7	6	6	6
1210	6	6	6	6	6	7	7	7	7	7
1220	8	8	8	8	8	9	9	10	11	11
1230	11	11	11	11	12	12	12	12	12	13
1240	15	15	13	14	17	18	17	16	17	18
1250	18	19	19	19	20	21	22	23	23	24
1260	27	27	28	28	29	29	29	29	29	28
1270	28	28	28	27	26	26	25	25	23	22
1280	22	21	20	19	19	21	21	21	20	20
1290	21	21	20	20	21	21	17	16	15	15
1300	16	16	15	15	15	15	15	15	17	18
1310	17	17	15	16	16	16	16	16	16	15
1320	14	17	18	18	20	20	21	23	23	21
1330	22	23	22	25	25	27	26	27	27	27
1340	27	27	28	28	28	27	27	27	27	27
1350	26	26	26	26	26	26	26	26	26	26
1360	25	25	25	25	24	23	20	20	19	17
1370	12	11	11	10	9	8	7	5	4	2
1380	1	1	0	0	0	0	0	0	0	0

Table 2: Sample abundance for each figure in Table 1 with Gordion MMT Relative Dates

DATING NOTES

Although these charcoal samples were distorted and hard to measure as noted above with bark and terminal rings absent, nevertheless, a number of useful conclusions may be drawn, as follows:

1. There are subjective reasons for stating that Relative Year 1381 and the bark year (= terminal year = felling year) are not far apart. In addition to the probable 26 years of sapwood that the observations above on TIL-29A imply, the end dates of 14 samples cluster within the last two decades of the master chronology. We believe that the final felling date of the Tille wood must be within 0 to 6 years of the chronology's end date, i.e., 1381-1387 MMTRD or 1140-1134 BC.

2. Since the Tille chronology is made up of oak and the Bronze Age/Iron Age chronology is comprised of pine and juniper, all these relative dates should probably be thought of as tentative until an oak dendrochronological scale extends back to this period. Although we feel that the crossdating between the Tille oaks and the Anatolian junipers is correct, we would be happier to compare oak with oak. See, however, statistical conclusions in no.7 and no.8, below.

3. Because the Gordion ring-sequence has been wiggle-matched by radiocarbon, the absolute dates of the Tille chronology are 1357 ±37 BC for the earliest innermost rings to 1140 ±37 BC for the latest outermost rings plus the allowance of 0 to 6 rings which could have been lost either at the time of construction or in the action of the fire which destroyed the structure.

4. This dendrochronological date is almost identical to the archaeological date that Dr. Summers proposes for the site, namely: the transition from Late Bronze to Early Iron Age. A look at the histogram of sample frequency (Fig.75b) shows two groupings of end dates in the form of a steep decline in the curve, approximately 100 years apart., Personal communication with Summers on 16 October 1991 confirms that there are two phases represented in this stratum from both the archaeological and the dendrochronological points of view: a late 13th/early-12th century construction, as indicated by TIL-1&4, 3, 28, 32, 65, 78, 80, and 81, which ends in 1209vv ±37 BC, and a late-12th century construction, which includes TIL-21, 24, 25, 26, 27, 29, 30, 31, 33, 34, 35, 36, 58, 59, 62, 67, 68, 69, and 71, which ends in 1140v ±37 BC.

5. A sceptical analysis of the foregoing distribution could reduce the phases from two to one. To use a simplified pottery analogy: suppose two pots, one 70 years older than the other, break into 100 fragments each. Analysis of the potsherds would show two clusters of 100 potsherds 70 years apart. We do not, as a result, have two phases of intense pottery activity 70 years apart, just the two broken pots. However, there are enough beams or beam-fragments at Tille, even though we cannot count exactly how many original trees were involved, for us to argue that there were two phases to the construction of the gateway about 70 years apart, one occurring around Relative Year 1312 (1209 BC ±37) or shortly thereafter and the second on or very soon after Relative Year 1381 (1140 BC ±37), these two dates representing the last preserved ring of their respective series: they are indicated by large dots on Fig.75b. Of the 26 datable oak trees mentioned above, 6 are in the early group and 20 are in the later group. It is possible of course that the 6 trees in the early group were reused. But we have no way of proving or disproving this. We do not know how or where the undated fragments cluster.

6. Then, after the wood was cut and the construction finished, the gate building at Tille had a lifetime of ?? years before it burned. For this, dendrochronology cannot provide an answer, and we turn to the excavator for any observations he may have been able to make on the spot.

7. Following are the supporting statistics for the end date of the 218 year Tille chronology matched against the Gordion chronology at 1381 GOR MMTRD (= 1140 ±37 BC).

	DISTANCE	t-SCORE	OVERLAP	TREND	D SCORE
BRONZE & IRON AGE (GORDION) MASTER	610km.	4.46	n=218	67.3%	79.2

A quantitative measurement of the way in which the Tille ring-sequence matches that of our Bronze Age and Iron Age Master Chronology at MMTRD 1381 is the trend coefficient or year-to-year changes in growth expressed as a percentage (a random fit would be 55±5%.) The trend coefficient at 1381 is 67.3%, well above the 99.9% confidence level. The mean t-distribution at 1381 is 4.46, also well above the 99.9% confidence level, and the mean D-score (t-score * (trend-coefficient - 50%)) at 1381 is 79.2. Two other relative dates, 1540 and 1263, respectively 159 years later and 118 years earlier than 1381 also yield significant scores, but we have concluded that they are random rather than representative of the real fit. Note: all fits were checked visually by sliding the graphs against each other.

Trend coefficient:

trend coeff.	number	%	
0.0 - 50.0	808	53.4	
50.0 - 52.0	271	17.9	
52.0 - 54.0	275	18.2	
54.0 - 56.0	106	7.0	
56.0 - 58.0	35	2.3	< trend =56.7 at 1263 (random)
58.0 - 60.0	16	1.1	< trend =58.5 at 1540 (random)
60.0 - 62.0	0	0.0	
62.0 - 64.0	2	0.1	
64.0 - 66.0	0	0.0	
66.0 - 68.0	1	0.1	< trend =67.3 at RD 1381 or 1140 BC +37

Calculation of Student's t:

t-score	number	%	
0.0 - 0.5	997	65.9	
0.5 - 1.0	200	13.2	
1.0 - 1.5	151	10.0	
1.5 - 2.0	82	5.4	
2.0 - 2.5	52	3.4	
2.5 - 3.0	23	1.5	
3.0 - 3.5	6	0.4	
3.5 - 4.0	0	0.0	
4.0 - 4.5	2	0.1	< t= 4.01 at 1263 (random); t= 4.46 at RD 1381 or 1140 BC +37
4.5 - 5.0	0	0.0	
5.0 - 5.5	1	0.1	< t= 5.06 at 1540 (random)

D-score (=t * (trend% - 50%))

All fits under 100 years are omitted.

D-score	number	%	
0.0 - 10.0	1465	96.8	
10.0 - 20.0	41	2.7	
20.0 - 30.0	6	0.4	< D = 26.8 at 1263 (random)
30.0 - 40.0	0	0.0	
40.0 - 50.0	1	0.1	< D = 44.5 at 1540 (random)
50.0 - 60.0	0	0.0	
60.0 - 70.0	0	0.0	
70.0 - 80.0	1	0.1	< D = 79.2 at RD 1381 or 1140 BC +37

8. Comment on the supporting statistics (immediately above), especially the D-score: out of over 1500 possible dendrochronological fits (minimum acceptable fit = 100 years of overlap between the two chronologies), Relative Date 1381 has scores that put it in a class by itself. Even though we are crossdating oaks with junipers from a site 610 kilometers away, we think that Relative Date 1381 must be the correct placement for the final ring at Tille. We also note that tests of growth profiles of modern (living) Anatolian oaks against those of living junipers (both of whose absolute dates are known) show similarly high correlations: trend coefficient = 59.8%, overlap (n) = 362 years, $\underline{t}$ = 6.05, D-score = 59.5.

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