Absolute Age of the Uluburun Shipwreck: A Key Late Bronze Age Time-Capsule for the East Mediterranean

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Abstract: *By integrating radiocarbon and dendrochronological investigations, we can provide a high-resolution date in the later 14th century* BC *for the time of the last voyage of the extraordinary Late Bronze Age sailing vessel found wrecked at Uluburun near Kaş off the southern coast of Turkey: approximately 1320±15* BC. *This shipwreck was in a remarkable state of preservation because it lay on a steep underwater slope at a considerable depth (42–52m, with some artefacts scattered to 61m). The ship's cargo forms one of the largest and wealthiest assemblages known from the period, including a key link to the Amarna-period Egyptian Queen, Nefertiti. Our precise absolute dating provides an important chronological marker for the Amarna period in Egypt and across the Ancient Near East, resolving a number of areas of debate or contention in the scholarly literature.*

1. Introduction

An important (and at present unique) ancient shipwreck was excavated between 1984 and 1994 in deep water at Uluburun, near Kaş, off the southern coast of Turkey, by the Institute of Nautical Archaeology (Bass 1986; 1987; Bass et al.1989; Pulak 1988; 1998; 2001; 2005a; 2005b; 2008). The original vessel was around 15 m in length and would have carried some 20 tons of cargo (for a reconstruction, see Pulak 2005: 60 fig. 11; 2008: 293 fig. 94). Underwater excavation revealed an extraordinary assemblage of over 15,000 catalogued artefacts.

Raw materials recovered include about 10 tons of copper ingots, at least a ton of tin ingots, more than half a ton of terebinth resin in approximately two-thirds of the 150 Canaanite jars aboard, 175 ingots of glass, ebony logs, ostrich eggshells, elephant tusks, hippopotamus teeth, logs of African blackwood, and various other food, craft, or medicinal items. In addition to these raw materials, manufactured goods found on the wreck include a range of ceramics (Syro-Palestinian, Cypriot, and Mycenaean Greek), faience cups, copper alloy vessels, objects in ivory and gold, jewellery, and the earliest known examples of wooden writing boards (diptychs). The origin and destination of the ship have been actively sought within the world of the east Mediterranean, in the central Levantine coast and the Aegean, respectively (Pulak 1998; 2005c; 2008). The scale of wealth present suggests that this was perhaps an elite or royal shipment of cargo and that the ship was engaged in high-level exchange (e.g. Pulak 2005b; 2008, and, to some extent, Bachhuber 2006), along the lines of those to be inferred from the 14th-century BC Amarna letters recording royal diplomatic contact in the Ancient

The famous shipwreck at Uluburun has been a noteworthy and exciting, albeit vexing, topic for the Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology for many years. Early on, Cemal Pulak submitted wood samples to Peter Kuniholm for analysis. However, the establishment of a direct tree-ring date as proposed in the 1990s (e.g. Pulak 1996; 1998: 213–214) has proved incorrect with further work (or at least unsupported and over-optimistic, and in need of more evidence: Wiener 2003: 244–246). As a result, work on an integrated radiocarbon and dendrochronological dating approach was undertaken. Initial work on dating some of the ship's timbers by such radiocarbon wiggle-matching was reported by Newton et al. (2005) and Newton and Kuniholm (2005). In this paper in honor of Peter Ian Kuniholm—friend, teacher, colleague—we are pleased to present the outcome of a robust, integrated dating program combining radiocarbon analysis and dendrochronology to best date both the ship's timbers as well as the final cargo (and hence to make an estimate of the date when the ship sank). This study replaces previous statements on the dating of the ship by dendrochronology and/or radiocarbon.

Near East between Egypt and other states and rulers (Moran 1992). Indeed, the wreck yielded a unique gold scarab bearing the cartouche of the Amarna-period Egyptian queen Nefertiti (Weinstein 1989), linking it directly to this general time period (and providing a *terminus post quem*—or date after which—for the shipwreck from during or after her reign).

The Uluburun ship represents an incredible time-capsule and has become a key source of evidence for study of numerous aspects of Bronze Age Mediterranean history, trade, interrelations at all levels, and especially for maritime interaction and technology (e.g. Bass 1986; 1987; 1991; 1998; Bass et al. 1989; Pulak 1998; 1999a; 2001; 2005; 2008; Wachsmann 1998: 303–307; Cleary and Meister 1999; Yalçın et al. 2005; Cucchi 2008; Welter-Schultes 2008). The high-resolution absolute dating of this shipwreck, and especially of its last cargo and voyage, would provide a key chronological marker-point for the synthesis of the history, archaeology, and art of the wider East Mediterranean region. In particular, given the rich international cargo, a precise date for the last voyage would have important implications for the dating of material culture across the region from Egypt to Greece, and it would provide a key test for the validity both of the long established conventional proto-historical and archaeological chronologies estimated for Egypt, Cyprus, and the Aegean, as well as various claims for radical alternatives made in recent decades.

2. Integrated tree-ring and radiocarbon dating of the Uluburun ship

This report presents a comprehensive, high-precision dating program to establish directly the approximate calendar age of the Uluburun ship, especially that of its last voyage. Previous suggestions (Kuniholm et al. 1996; Wiener 1998; Manning 1999: 344–345) of a possible direct dendrochronological date for some timbers aboard the ship have proved, with further examination and additional data and development of regional tree-ring sequences, to be without good dendrochronological support; these are hereby withdrawn (cf. Manning et al. 2001: 2535 n.38; Wiener 2003a: 244–245). A previous report of some initial radiocarbon wiggle-match work on timbers from the vessel (Newton et al. 2005; Newton and Kuniholm 2005) is much expanded here, and dates on a range of the short-lived sample material from the vessel's last voyage are incorporated into a comprehensive dating model. For this project we developed an integrated research design to date the ship combining:

(i) Radiocarbon wiggle-match dating (Bronk Ramsey et al. 2001; Galimberti et al. 2004) of several short tree-ring sequences from long-lived wood either comprising the ship's timbers (specifically, its keel; for the ship's hull construction, see Pulak 1999a; 1999b; 2003) or from aboard the ship (dunnage, or in one case perhaps an element of the ship), which set *terminus post quem* ranges for the final voyage of the ship; with

(ii) Radiocarbon dating of short- or shorter-lived materials or elements on board the ship when it sank. These materials include fittings or other functional components (wicker-work, a rope fragment made of grass from the Gramineae family) or actual cargo such as olive seeds, leaves, terebinth resin, and thorny burnet (a dense, spiny shrub native to central and eastern Mediterranean used as dunnage or bedding material between the hull and the cargo of copper ingots). These elements should set a very close *terminus post quem* for, or even in several cases theoretically date the year of, the last voyage of the ship.

The sets of radiocarbon evidence are assessed within a comprehensive Bayesian analytical model (using the approach and software of OxCal: Bronk Ramsey 1995; 2001; 2008; 2009) in order to combine the known relative time-order of the sample materials with the radiocarbon ages obtained, and to yield the best dating estimates from the simultaneous resolution of the linked multiple dating probabilities. An interesting additional issue is that we may test the validity of conventional Egyptian chronology (the date range for Queen Nefertiti) against the combined tree-ring and radiocarbon evidence from the Uluburun ship (and vice versa).

3. The samples of short-lived materials

We obtained eight radiocarbon measurements on samples of short-lived cargo materials from the final use of the ship: Figure 1 (lower), Table 1 (Hd-23129, 23132, 23162, OxA-15022, 15024, 15026, 15025, 15065). These sample material types and dates vary a little, but should all date the final use period of the ship either to the year or within a few years at most (see further discussion in section 5 (ii) below). All ages obtained are broadly similar, with quality control provided both by: (i) the comparable findings of two different laboratories (Heidelberg and Oxford); and (ii) new measurements of known age German Oak run around the same time at Heidelberg and Oxford which show generally good agreement with each other, although a little older on average compared to the IntCal98/04 average values and indicating somewhat more curve amplitude (Figures 2, 3).

The data from these eight short-lived material samples can be combined together, consistent with

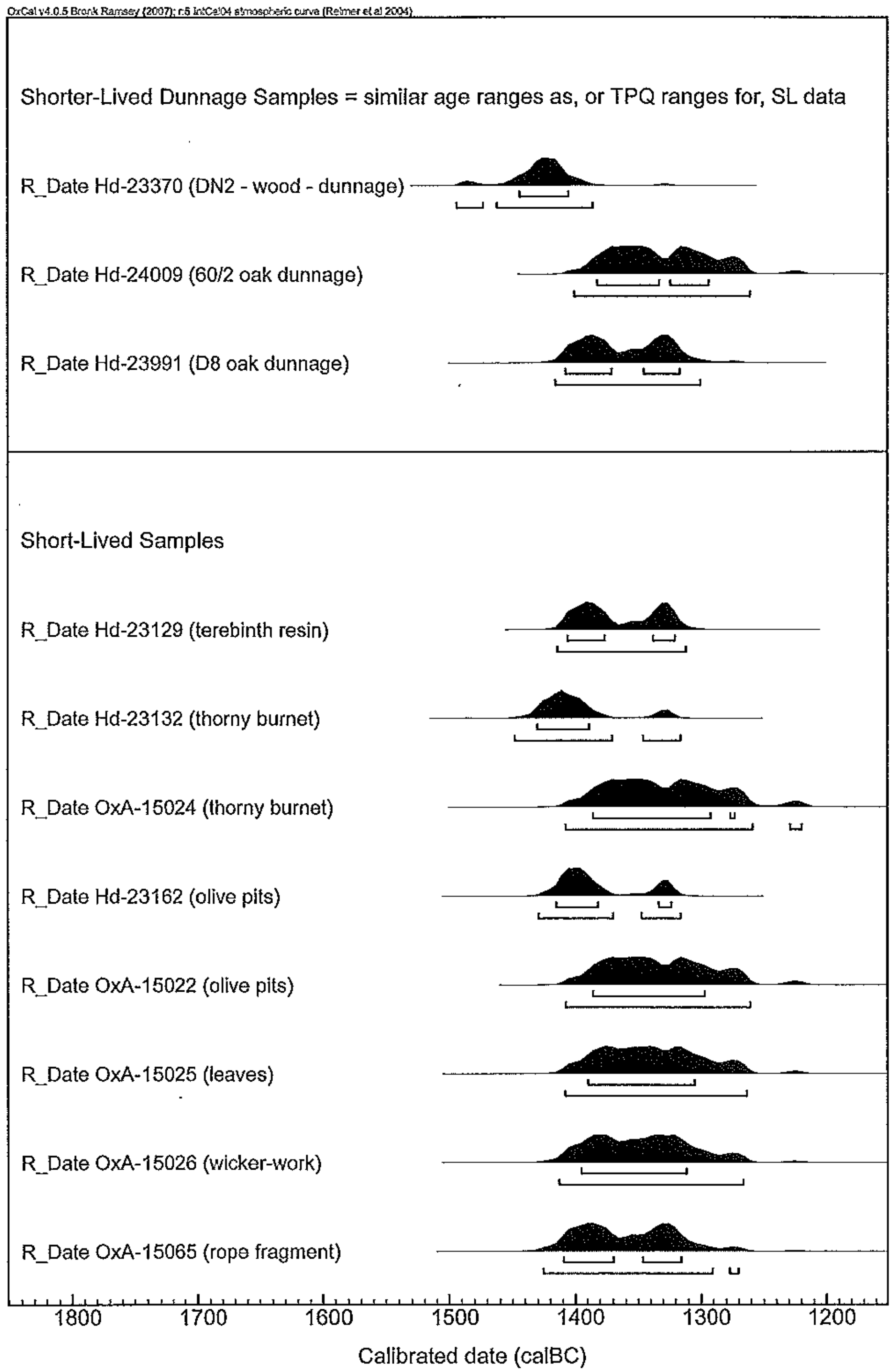

Figure 1: The individual calibrated calendar age probability distributions showing 1σ (68.2% probability) and 2σ (95.4% probability) ranges (upper and lower lines under each histogram respectively) for (i) (upper 3 histograms) 3 measurements on shorter-lived or short tree-ring sequence wood dunnage samples from the Uluburun ship, which should either be approximately the same age as, or set *terminus post quem* ranges for (perhaps very close in some cases), the ship's last voyage and the shipwreck, and (ii) (lower 8 histograms) 8 measurements on short-lived samples from the Uluburun shipwreck—these samples should closely date the final voyage time interval (the same year or next year for samples like the leaves and olive seeds, and somewhere from the same year to the next couple or few years for the other samples). Calibration to calendar years employs the IntCal04 radiocarbon calibration dataset (Reimer et al. 2004) and the OxCal software (Bronk Ramsey et al. 1995; 2001; 2008) version 4.0.5.

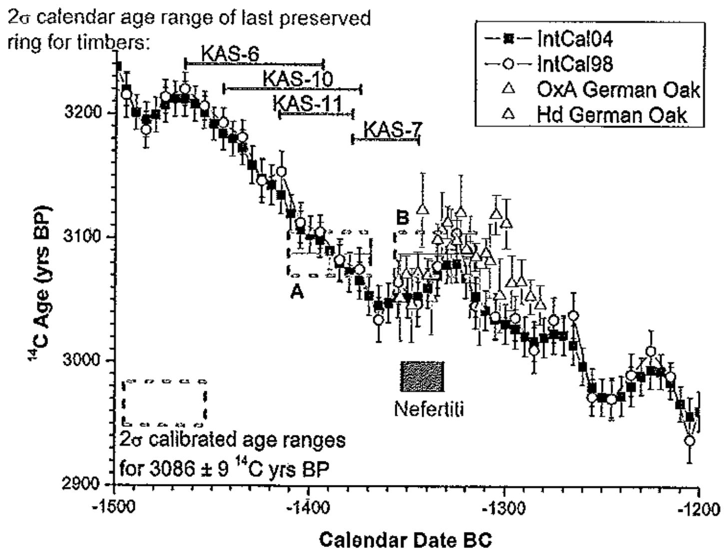

Figure 2: IntCal04 (Reimer et al. 2004), black squares, and IntCal98 (Stuiver et al. 1998), black hollow circles, radiocarbon calibration curves for the period 1500 to 1200 BC. 1σ (68.2% confidence) error bars shown. Note the inversion, or wiggle (to older radiocarbon ages), centred around 1325 BC (see further in Figure 3). The 2σ (95.4% confidence) calibrated calendar age ranges from IntCal04 for the weighted average ^{14}C age of the 8 short-lived samples found as contents from the Uluburun ship's last voyage (for the individual dates, see Figure 1, lower; for the weighted average, see Figure 4) are shown by the two cyan boxes (1411–1369 BC and 1358–1315 BC; the 1σ ranges are 1403–1377 BC and 1337–1321 BC). The ^{14}C wiggle-matched calibrated age ranges at 2σ confidence for the last preserved ring of the four dendrochronological samples from the Uluburun ship's structure or from the wood materials carried on the ship (dunnage, etc.) (see Figures 8 and 9) are shown in orange (these dendro samples from the Uluburun ship have the laboratory identification code of KAS); these set *termini post quos* for the final voyage of the ship (see text for discussion). The standard reign period of Amenhotep IV (Akhenaten) and so of Nefertiti as queen of Egypt is also indicated (Hornung et al. 2006: 492, 206–208, 477–478). A gold scarab of Nefertiti was found among the contents of the Uluburun ship (see text below); hence some part of her reign acts as a *terminus post quem* for the last voyage of the ship. See text below for discussion. (Note: a modified date range for Amenhotep IV and Nefertiti some 11 years later may become necessary given recent work—see footnote 2 and text below.)

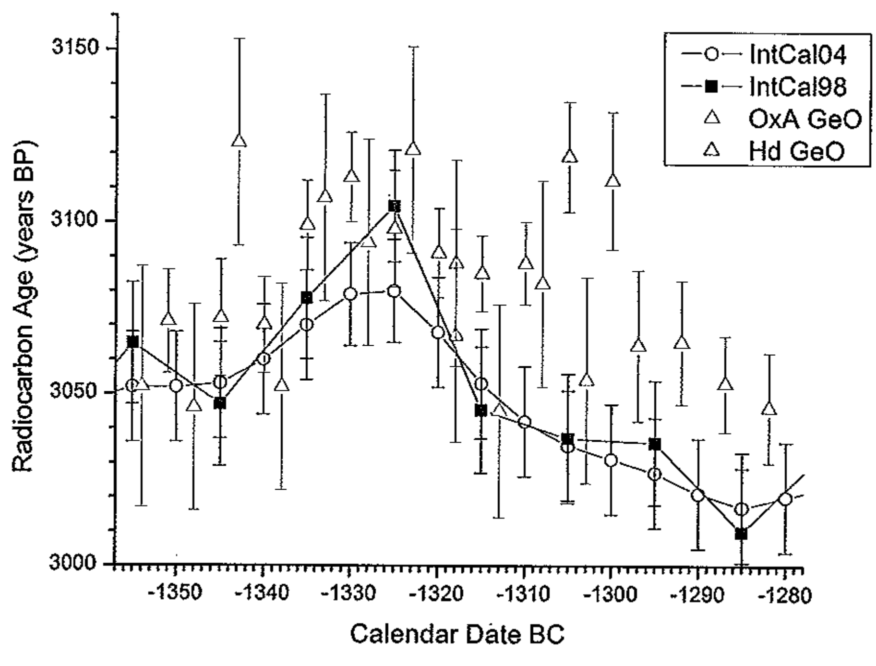

Figure 3: Detail from the plot in Figure 2 showing the region of the radiocarbon age inversion (or wiggle) in the region around 1325 BC. The new Heidelberg (part of a larger set) and Oxford measurements on German Oak use known age samples from Augsfeld supplied by Michael Friedrich. 1σ error bars shown.

Lab ID	Sample Name	Sample Material	Start Ring	End Ring	$\delta^{13}C$‰	^{14}C Age (yrs BP)	SD
Hd-22632	C-TU-KAS-3&11	Wood – *Cedrus libani*	1030	1040	-24.57	3252	25
Hd-22633	C-TUKAS-3&11	Wood – *Cedrus libani*	1050	1060	-24.38	3210	22
Hd-22642	C-TU-KAS-3&11	Wood – *Cedrus libani*	1070	1080	-24.36	3157	22
Hd-22559	C-TU-KAS 1&10	Wood – *Cedrus libani*	1009	1016	-24.4	3244	20
Hd-22591	C-TU-KAS 1&10	Wood – *Cedrus libani*	1054	1063	-24.73	3187	18
Hd-22592	C-TU-KAS-1&10	Wood – *Cedrus libani*	1064	1073	-25.13	3173	23
Hd-22593	C-TU-KAS 1&10	Wood – *Cedrus libani*	1074	1094	-25.23	3148	21
Hd-22604	C-TU-KAS-6A&C	Wood – *Cedrus libani*	1024	1034	-24.96	3276	23
Hd-22588	C-TU-KAS-6A&C	Wood – *Cedrus libani*	1035	1044	-25.04	3243	19
Hd-22580	C-TU-KAS-6A&C	Wood – *Cedrus libani*	1045	1054	-25.42	3235	25
Hd-22816	C-TU-KAS-7	Wood – *Cedrus libani*	1012	1022	-24.03	3122	23
Hd-24113	C-TU-KAS-7	Wood – *Cedrus libani*	1022	1032	-24.4	3092	25
Hd-24114	C-TU-KAS-7	Wood – *Cedrus libani*	1032	1042	-24.18	3087	20
Hd-23345	C-TU-KAS-7	Wood – *Cedrus libani*	1042	1049	-23.96	3076	22
Hd-22815	C-TU-KAS-7	Wood – *Cedrus libani*	1049	1059	-23.9	3078	15
Hd-23370	DN 2 (dunnage)	Wood – *Quercus coccifera*			-27.86	3145	23
Hd-24009	DN 60/2 (dunnage)	Wood – *Quercus coccifera*			-27.68	3050	23
Hd-23991	D 8 (dunnage)	Wood – *Quercus coccifera*			-26.79	3083	21
Hd-23129		Terebinth resin			-25.77	3087	16
Hd-23132	# 3932.01	Thorny burnet - *Sarcopoterium spinosum*			-26.51	3122	23
OxA-15024	#11268/11314/11426	Thorny burnet - *Sarcopoterium spinosum*			-25.31	3054	27
Hd-23162		Olive pits			-25.22	3104	17
OxA-15022		Olive pits			-24.37	3051	29
OxA-15026	#9387 (wicker work)	Wood - *Nerium oleander*			-26.84	3071	29
OxA-15025	# 3932.02	Leaf - *Quercus* sp.			-27.72	3061	28
OxA-15065	#11369	Rope fragment - Gramineae			-13.90	3085	28

Table 1: Samples and radiocarbon (^{14}C) data employed in this study. Source laboratories: Oxford Radiocarbon Accelerator Unit – OxA, and Heidelberg Radiocarbon Laboratory – Hd. Each timber sample is recorded in terms of an arbitrary relative sequence beginning with ring 1001.

the hypothesis that they could represent the same radiocarbon age at the 95% confidence level, to offer a more precise weighted average radiocarbon age estimate of 3086 ± 9 BP for the final cargo or last voyage (Ward and Wilson 1978) (see Figures 4 and 5). Without any other constraints, this weighted average radiocarbon age indicates a calendar date range with the current IntCal04 radiocarbon calibration curve (Reimer et al. 2004) and the OxCal calibration software v.4.0.5 (Bronk Ramsey 1995; 2001; 2008) of either about 1411–1369 Cal BC or about 1357–1315 Cal BC at 2σ (95.4% confidence): see Figure 4. The date range employing the previous IntCal98 (Stuiver et al. 1998) radiocarbon dataset is shown for comparison in Figure 5; IntCal98 employs similar underlying data for this period, but with a less sophisticated and less smoothed modelling. The bi-modal possible ranges reflect the shape of the radiocarbon calibration curve at this period (the record of past natural atmospheric radiocarbon derived for this time period from known-age tree-ring archives), in particular the pronounced short-term radiocarbon age inversion (a "wiggle") in the region around 1325 BC (see Figure 2). The wiggle is even more apparent in the previous, less-smoothed IntCal98 calibration dataset (Figures 2, 5) and is also reported in contemporary Aegean tree-rings (Manning et al. 2003; 2005). This wiggle is furthermore even more apparent in recent measurements of absolutely dated German Oak (from Augsfeld, kindly provided by Michael Friedrich) made at Heidelberg and Oxford

(Figure 3), both of which may indicate a slightly larger and somewhat longer inversion period (or plural wiggles) in the late 14th to early 13th centuries BC.

4. Wiggle-matching the tree-ring sequences and setting the *terminus post quem* for the construction of the Uluburun ship

To test and refine this age, and to resolve the bi-modal dating ambiguity noted above independently in radiocarbon terms, we analysed several long-lived *Cedrus libani* timber samples from the ship,[1] with the expectation that the last extant tree-rings on these samples would set *terminus post quem* ranges for the construction of the ship and, in turn, indicate the possible calendar ages of the short-lived samples from the ship's last voyage. Uluburun hull wood and their species identification are in Liphschitz and Pulak (2007/2008: 75).

These samples are:

- KAS-6A&C (hereafter KAS-6, with 105 years of growth represented);
- KAS-1&10 = Uluburun Lot number 6010 (hereafter KAS-10, with 108 years of growth represented);
- KAS-3 & 11 = Uluburun Lots number 6574 and 6594 (hereafter KAS-11, with 118 years of growth represented)

These three samples comprise dunnage (or chocks for wedging the cargo) from the wreck, and, in one case, KAS-6, perhaps a ship element, a frame-timber.

The final sample comes from the ship's keel:

- KAS-7, with 66 years of growth represented (the sample is also of *Cedrus libani*)

Dendrochronological sequences were measured for each timber (Figure 6). The cross-matches are not decisive or strong in either statistical or visual terms between any of these timbers (and their often erratic growth), nor between any of these timbers and other conifer chronologies from the region. It should be noted that the samples are far from perfect for dendrochronology given extensive damage by shipworm (*Teredo navalis*), which makes reading the tree-ring record challenging (Figure 7). Hence, to be conservative, we have chosen to treat each timber as independent in this study. No sapwood or bark or other features indicating outermost tree-rings are preserved. The samples' outer surfaces were worn and abraded, and thus an unknown number of tree-rings have been lost.

The critical sample is the keel (KAS-7). This is the one sample integral to the ship; it is the very foundation of its structure, given the ship's shell-based construction where the planks are joined with mortise-and-tenon to the keel (or spine of the vessel) and to each other (Pulak 1999a; 1999b; 2003). Examination of the hull remains shows that the keel is an original piece; there is no evidence for any kind of repair. For the keel to have been replaced, the mortise-and-tenon joints would have had to be cut and replaced, a radical overhaul which would leave unmistakable traces. In shell-based hull construction, the framing is secondary. Thus, even if KAS-6 is a frame-timber, it is not as integral to the ship as is the keel. The various 'dunnage' samples could be any age. In principle, the outermost tree-ring could be from the year of the last voyage of the ship (and therefore later than the date of the ship's construction); alternatively, this material could be recycled or re-used wood from years or even many decades earlier. We do not know the answer (i.e. age) as *a priori* information, and only a scientific dating can inform us.

Thus, for the wood-dendro samples, the key information is the dating of the last preserved tree-ring on the keel (KAS-7). This will set a *terminus post quem* for the construction of the ship, since there is no bark or sapwood.

Several fixed sequences of approximately 10-year increments of wood were extracted from each of these timbers for radiocarbon dating (for details, see Table 1), and the known sequences of radiocarbon dates obtained were then matched against the IntCal04 radiocarbon calibration curve (Reimer et al. 2004) to offer best age estimates for each timber (Figure 8). The last preserved tree-rings for each timber date (see Figures 8 and 9) within 2σ ranges as follows:

- KAS-6: 1465-1394 Cal BC;
- KAS-10: 1416-1379 Cal BC;
- KAS-11: 1445-1375 Cal BC; and
- KAS-7: 1379-1345 Cal BC.

The ship's final voyage must have occurred at some point after the latest of these age ranges—that is, after somewhere between 1379–1345 BC. Perhaps surprisingly, it is the ship's keel (KAS-7) which provides the most recent *terminus post quem*. This indicates either that the other wood samples (dunnage, or possibly a frame-timber in one case) were either old or re-used material, and/or have lost a number of outer tree-rings (whether pre- or post-deposition). The keel sets the

[1] This designation covers the overall *Cedrus libani* grouping, including *Cedrus libani* var. *libani* from Lebanon and western Syria, and also *Cedrus libani* var. *stenocoma* from southern Turkey, and *Cedrus libani* var. *brevifolia* from Cyprus.

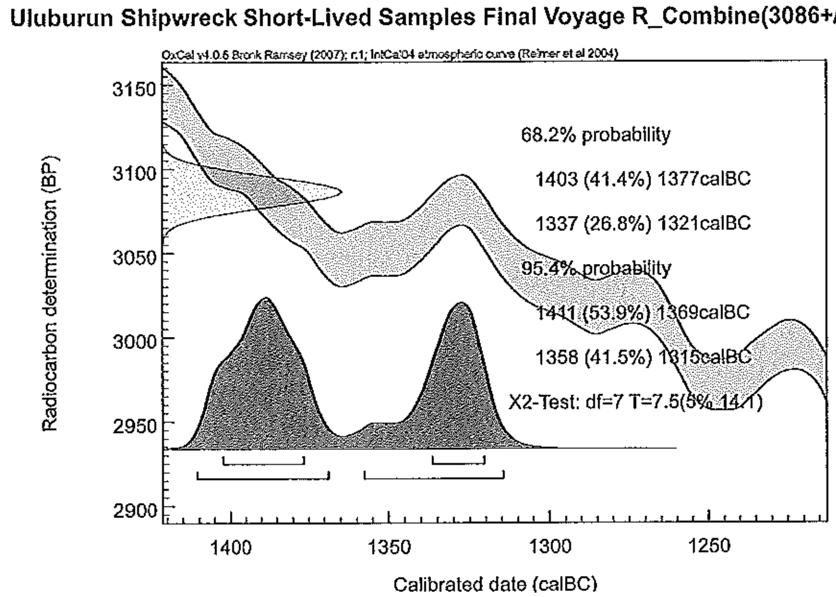

Figure 4: The calibrated calendar age ranges for the weighted average of the 8 short-lived samples in Figure 1 as an estimate of the date of the last voyage of the Uluburun ship (the last voyage was reasonably soon after this date range) (see cyan boxes in Figure 2 also). The lines under the histogram show the 1σ and 2σ ranges respectively. We see a bi-modal possibility due to the radiocarbon age inversion (wiggle) centred around 1325 BC (which is more pronounced in IntCal98). Calibration employs the IntCal04 radiocarbon calibration dataset (Reimer et al. 2004) and the OxCal software (Bronk Ramsey 1995; 2001; 2008) version 4.0.5 with curve resolution set at 1. The same radiocarbon data are shown calibrated with the previous IntCal98 (Stuiver et al. 1998) radiocarbon calibration dataset in Figure 5. For discussion of the inversion, see the caption to Figure 5.

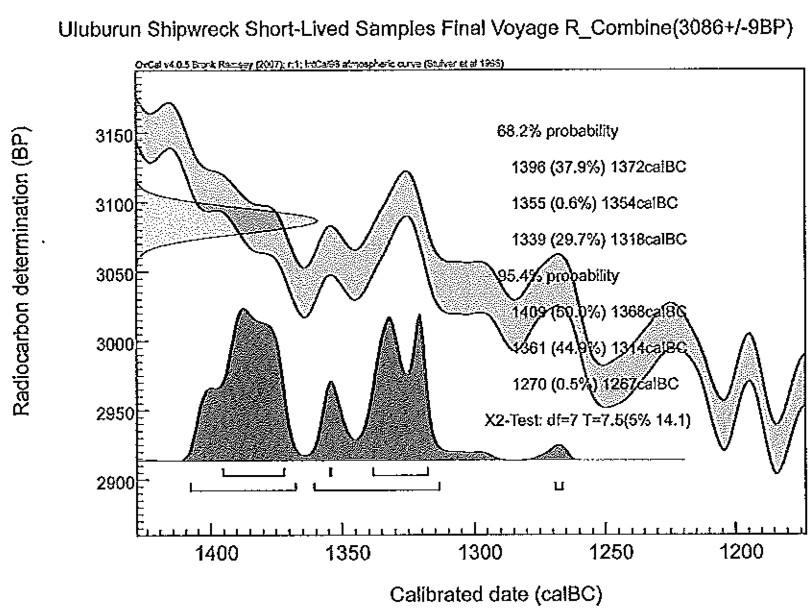

Figure 5: As Figure 4, but employing the IntCal98 (Stuiver et al. 1998) radiocarbon calibration dataset. Note especially that the age inversion (wiggle) centered around 1325 BC is more pronounced in the IntCal98 dataset (which lacks the smoothing of the IntCal04 data set). This seems noteworthy. For example, given that the final cargo/voyage of the Uluburun ship must at least post-date the accession of Nefertiti as queen (since her scarab was on the boat), and thus be after about 1353 BC (Hornung et al. 2006) or 1342 BC (see footnotes 2 and 3 and text below), the later of the calibrated dating sub-ranges (1339–1318 BC at 1σ and 1361–1314 BC at 2σ), and thus the age inversion centered around 1325 BC, would seem to be the likely date range where the short-lived samples from the last voyage of the Uluburun ship should belong. This age inversion is prominent in the Aegean record (Manning et al. 2005) and in the recent Heidelberg and Oxford data on German oak (Figure 3). This issue, and the question of how the Nefertiti date correlates with the radiocarbon information, is discussed further in the text below (section 7).

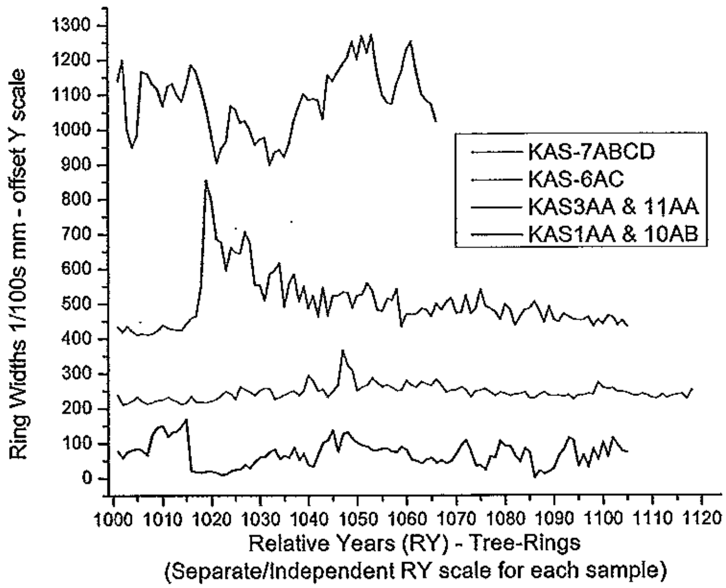

Figure 6: Dendrochronological sequences for the tree-ring samples (all *Cedrus libani*) employed in this study. Examples of erratic growth are common and samples are difficult to read or measure due to damage from shipworm (*Teredo navalis*) (see Figure 7). Each is treated as an independent sequence in this study since there are no convincing cross-dates among the samples. Details of the tree-rings radiocarbon dated from the samples for the dendro-radiocarbon wiggle-matches are given in Table 1.

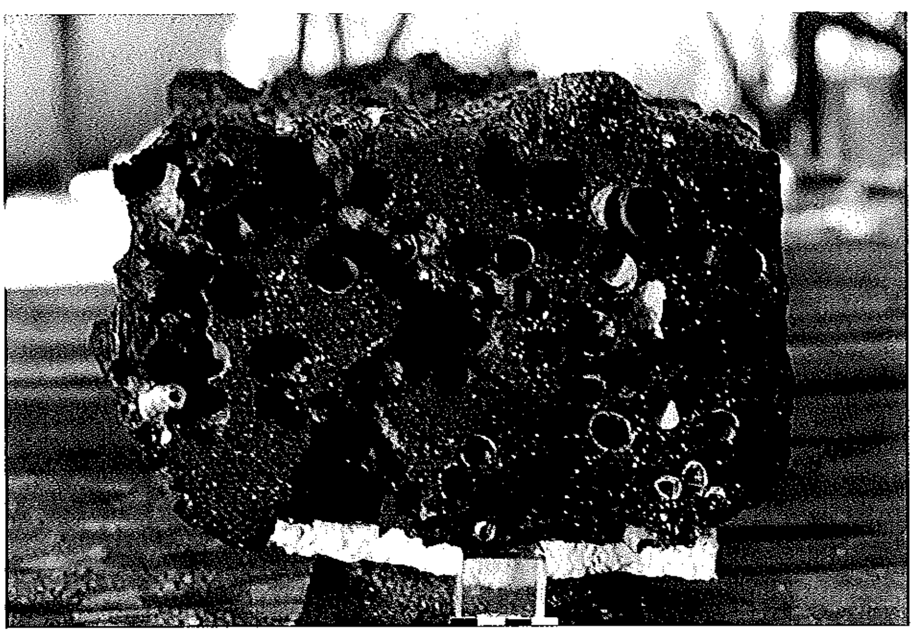

Figure 7: Section of KAS-7, from the keel of the ship, illustrating the extensive damage due to holes bored by shipworm (*Teredo navalis*), which make reading the tree-ring record a challenge (Newton et al. 2005: Abb.1).

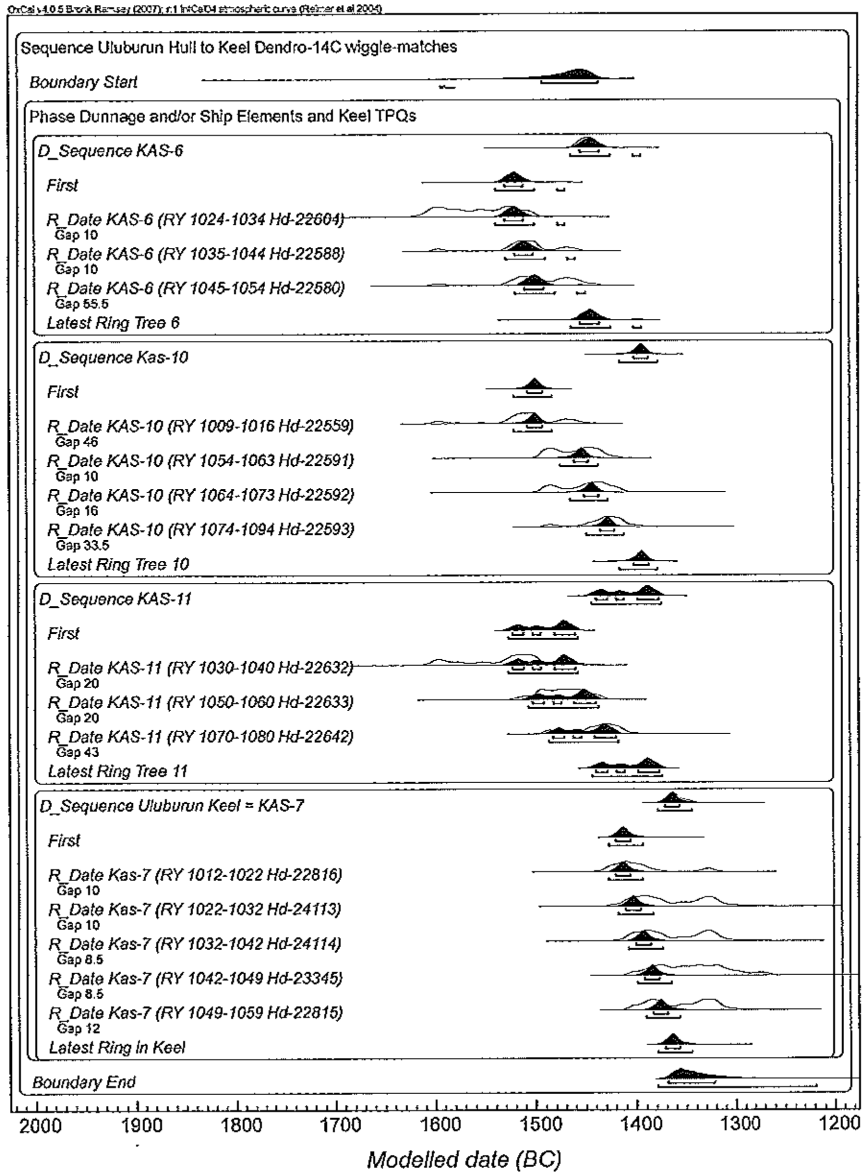

Figure 8: Bayesian fixed-Sequence (dendro-wiggle-match) analysis for the tree-ring sample sequences extracted from timbers KAS-6 (frame-timber from the Uluburun ship or dunnage), KAS-10 (dunnage), and KAS-11 (dunnage) and KAS-7 (the Uluburun ship's keel), calculating the calibrated calendar age range for the last (most recent) preserved tree-ring in each sample. The hollow (outline) distributions show the calibrated ages for each individual sample on its own; the solid black distributions within these show the calculated ranges applying the Bayesian model based on the known tree-ring (calendar year) intervals between the samples. The horizontal lines under each distribution indicate the 1σ and 2σ confidence, calibrated calendar age ranges using IntCal04 (Reimer et al. 2004) and OxCal (Bronk Ramsey 1995; 2001; 2008) version 4.0.5 with curve resolution set at 1. Each run of such an analysis produces very slightly different results; therefore, a typical outcome is shown here. To test for problems and outliers we used the OxCal agreement index. This is a calculation of the overlap of the simple calibrated distribution versus the distribution after Bayesian modelling. If the overlap falls below 60%, it is approximately equivalent to a combination of normal distributions failing a χ^2 test at the 95% confidence level. The OxCal agreement index values are indicated in parentheses, and all surpass an approximate minimum 95% confidence threshold. For the specific sequences: KAS-6 $n = 3$ yields 156.9 v. minimum threshold value at $\approx$ 95% confidence level of 40.8, KAS-10 $n = 4$ yields $=$ 153.1 v. minimum threshold value at $\approx$95% confidence level of 35.4, KAS-11 $n = 3$ yields $=$ 89.9 v. minimum threshold value at $\approx$95% confidence level of 40.8, and KAS-7 $n = 5$ yields $=$ 148.2 v. minimum threshold value at $\approx$95% confidence level of 31.6. The agreement index value for each individual sample is shown. The approximate 95% confidence threshold value is $\geq$ 60. The placement of each of the samples on the IntCal04 radiocarbon calibration curve is shown in Figure 9.

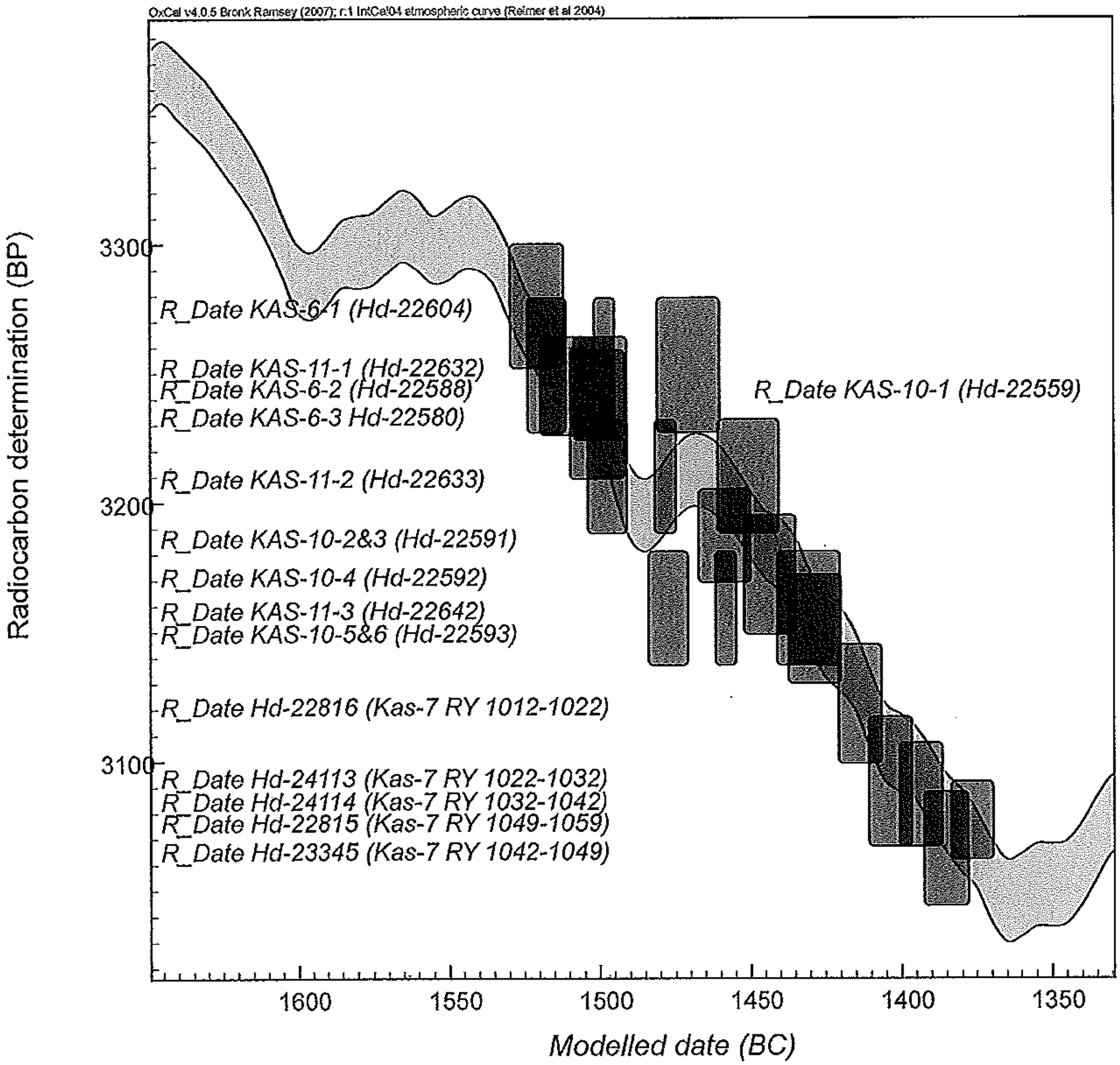

Figure 9: The modelled 1σ (68.2%) most likely calendar placements of each of the Uluburun samples in Figure 8 is shown against the IntCal04 radiocarbon calibration curve (Reimer et al. 2004). Note that the most recent tree-rings lie variously from the late 15th century through to the mid-14th century BC. In particular, the last preserved ring from the keel (KAS-7) lies at 1372–1357 Cal BC at 1σ (68.2%) confidence (1379–1345 Cal BC at 2σ 95.4% confidence). These samples thus occupy the slope of the radiocarbon calibration curve at this period (anchored here by the earlier tree-rings of each sample which must lie variously in the late 16th through later 15th centuries BC; see also Figure 8). This in turn means that the ambiguity in date for the short-lived samples (Figures 1, 2, 4, 5) is resolved: they must date later than the last preserved tree-ring of the ship itself (and thus after the last ring from the keel at 1372–1358 Cal BC at 1σ or 1379-1345 Cal BC at 2σ). Therefore, the otherwise possible date range of about 1411–1369 Cal BC (2σ) for the short-lived samples from the final voyage must be dismissed in favour of the alternative later possible date range of 1357–1315 Cal BC (2σ). Hence, the ambiguity created by the shape of the radiocarbon calibration curve and especially the late 14th-century BC age inversion (wiggle) is resolved.

relevant *terminus post quem* range for the construction of the ship: 1372–1357 Cal BC at 1σ or 1379–1345 Cal BC at 2σ. (If IntCal98, Stuiver et al. 1998, is employed, the dates for the last tree-ring of KAS-7 from typical runs of the analysis model in Figure 8 are very similar: e.g. 1370–1353 Cal BC at 1σ and 1377–1339 Cal BC at 2σ). As noted above, there was no bark or sapwood or other indication of outermost rings on this sample (and the process of its shaping likely removed outer rings); thus the *terminus post quem* provided here dates the last extant ring, and the actual date of the felling of the tree used to make the keel would be several years more recent than this.

5. Temporal relationships from the context of the last tree-ring in the keel to the dunnage samples and to the short-lived samples

(i) Dunnage samples and frame-timber(?) sample. The keel sample (KAS-7) is the only one integral to the ship and indisputably part of its primary construction (Pulak 1999a; 1999b; 2003). The possible frame-timber (KAS-6) might be as well, but this is less certain. The other "dunnage" samples, both the ones wiggle-matched above (KAS-10, KAS-11) and also the three other (shorter-lived/shorter-sequence) samples of wood dunnage material from the wreck—Hd-23370 (DN2 wood dunnage), Hd-24009 (60/2 oak dunnage), and Hd-23991 (D8 oak dunnage) (see Figure 1, upper)—have no context-based relationship with the date of the ship's construction and thus no relationship to the *terminus post-quem* date offered by the keel. They could be (1) older material that has been re-used, (2) roughly contemporary material (and when they yield older ages it could be argued that they have lost outer tree-rings), or (3) material dating as late as the year of the last voyage of the ship. We do not know from the context.

The outermost preserved tree-rings of these dunnage samples can at best be stated to provide *terminus post quem* ranges for the last voyage of the ship, with the length of the 'post' dependent on which of the three previously-noted scenarios in fact really applies. This is the assumption/model employed for the dunnage samples in Model A below.

(ii) Short-lived sample matter from the ship (from its last voyage). The short-lived sample material (Figure 1, lower; Table 1) comprises a variety of items. Some, like the olive pits, might be provisions, or could relate to cargo. In either case, they are likely to relate to the final voyage of the ship, or at most to the last few trips, and to no more than a time window of a few years. The terebinth resin was part of the ship's cargo, carried in Canaanite jars; again, it is likely to date from the final voyage, with a plausible dating window of no more than a few years. The thorny burnet dunnage again likely relates to the most recent voyage or voyages. It is hard to imagine this material surviving in usable form for many voyages, no more than a few years at most. The leaves come from young tree branches also used as dunnage, but again likely relate to the current or recent voyage and packing of cargo; they are likewise unlikely to have lain around on the ship for more than a few years in reasonable condition. The possible exceptions to this scenario of all such items belonging to the latest voyage, or at most last few voyages, or a horizon of a few years at most, are the wicker-work and the grass rope fragment samples. The growth period involved in each case is probably annual to no more than a few years (given the materials employed to make ropes at the time: Wachsmann 1998: 254, and the likely materials involved in the wicker-work/matting from the fence along the side of the boat: Pulak 1992: 11). These items were presumably used as long as they lasted in fit condition. Ropes of the available technology in the Late Bronze Age did not last long, as at least some of the finds of large numbers of Late Bronze Age stone anchors lost on the sea-bed indicate, and a lifetime of more than a few years seems unlikely. The wicker-work is more difficult to judge. Again, it seems unlikely in the taxing conditions at sea that it would have lasted for more than a few years, but perhaps this could be a time horizon of up to a decade or so, rather than of one to a few years. It is impossible to know.

A reasonable and fairly conservative assumption is that all the short-lived sample materials lie in a time horizon of no more than about 10 years (i.e. none was more than ten years old by the time of the last voyage of the ship). Thus, collectively, they should define a relatively short time-period immediately prior to the date the ship sank.

All this material should also represent constituent ages (total periods of growth) of only one to a few years at most. Thus the ages should, within one to a few years, define the last voyage.

Even if the Uluburun ship was on its maiden voyage, it is probable that the last preserved tree-ring in the keel (a *terminus post quem*, adding missing rings, sapwood and bark to the actual cutting date of the tree, and then ship construction) is older than the short-lived samples (even if only by a year or a few years on the maiden voyage scenario). The wicker-work was presumably only made of short (or shorter)-lived materials cut in the year (or year before) construction; the food, cargo and packing likewise would relate to no earlier than the year or year or two before construction (even on a maiden voyage scenario), and the ropes were likely new for the vessel and regard-less could not have been very old as they typically did not last long. In all likelihood, this was not the ship's maiden voyage. This being the case, it is all the more certain that the last tree-ring preserved on the keel sets a *terminus post quem* for all the short-lived sample materials on the ship. We assume this temporal sequence where the date for the last ring of the keel (KAS-7), and the dates for the last rings or ages of the other wood samples from the ship (whether ship elements or dunnage), act as a *terminus post quem* for the short-lived samples in Model B. We expect this model to yield the most realistic estimate of the dating of the last voyage of the ship.

Examination of Figures 1 (upper), 2, 8, and 9 reveals that the latest samples from the ship's keel (KAS-7), and several of the dunnage samples, date in the same possible calendar time range as the earlier of the two possible dating ranges found for the short-lived cargo and dunnage samples shown in Figures 2, 4, and 5 (the older possible range labelled as "A" in Figure 2). In other words, there is overlap in the later 15th through mid-14th centuries BC. However, as argued, since we may reasonably assume that the short-lived items on board the ship as contents or fittings during the last voyage of the ship were at least later than the last preserved decade of tree-rings in the keel of the ship, this situation indicates that it is the later of the two calendar date ranges possible for the short-lived cargo/packing/fittings samples which must apply. Thus the ambiguity shown in Figures 2, 4, and 5 can be approximately resolved (in favour of range "B" in Figure 2). In turn, we can best estimate the last voyage of the Uluburun ship as either effectively the same date as, or (better) immediately following, this group (a phase) of short-lived samples from the final cargo or dunnage on board. However, the majority of these short-lived contents samples should most likely be understood as closely defining this final horizon, that is, the year of, or a couple of years before and including, the last voyage, rather than being uniformly distributed throughout the preceding period.

6. Bayesian analysis of all the radiocarbon evidence to best define the date of the Last Voyage (LV) of the Uluburun ship

We can quantify the observations made in the previous section through Bayesian analyses combining all the Uluburun data sets discussed. We consider two models based on the discussions in the previous section:

Model A. This employs all the data and (i) lets the dates of the last preserved tree-rings or the ages of the various dendro/wood samples (keel, frame-timber(?), dunnage) set a minimum (oldest possible age) estimate for the Last Voyage, and (ii) lets the short-lived samples do the same, but does not assume that the short-lived samples must necessarily post-date the latest tree-ring/wood dates. This model allows for the maiden voyage scenario (as one extreme) and realistically sets minimum (old as possible) parameters for the discussion.

Model B. This employs all the data in Model A for the hull timbers of the ship, or for wood found on the ship, to provide a *terminus post quem* boundary ("Ship Fitted Out") for the phase "Contents Ship Last Voyage" of short-lived sample matter from the last voyage. As the most recent key element, the wiggle-match date for the last extant tree-ring of the keel (KAS-7) in effect sets this *terminus post quem* for the contents phase. The Last Voyage of the ship is dated as the boundary (LV) immediately after the "Contents Ship Last Voyage" phase of short-lived samples. This model likely calculates a realistic estimate of the date of the Uluburun ship's last voyage.

Model A makes two further assumptions. First, rather than treat the short-lived samples as forming a uniform distribution within a last voyage phase, we more realistically assume that it is likely that the majority of these samples (everything except perhaps the wicker-work sample?) will tend to date towards the end of this phase—that is within the same year as, or one or so years before, the last voyage. Hence the date for the Last Voyage (LV) may be best estimated using the Tau_Boundary model in OxCal (Bronk Ramsey 2009), where a group of dated samples are assumed to be exponentially distributed rising to a maximum event probability at the end event—which we define as the Last Voyage, or LV, of the Uluburun ship.

Second, we have to consider the relevant time constant, that is, the average age of the samples dated within the phase. Above (section 5.ii), we proposed a time period of 10 years as a conservative range to cover all the ages of the short-lived materials. We use this 10 years model as our best estimate. With the Tau_Boundary, this means that one or two samples can be older, even substantially older, but the rest should be within 0–10 years of age—this is the nature of the exponential distribution on the Tau end which runs to infinity. However, to be cautious and to see how a longer time period estimate offsets the calculated outcome, we also consider time periods of 25 years and 50 years.

Model A, and the outcome with a 10-year time constant for the short-lived sample material, is shown employing IntCal04 (Reimer et al. 2004) in Figure 10, with the modelled age range for the LV shown in detail in Figure 11: 1333–1319 Cal BC (1σ) and 1381–1364 (10.0%), and 1341–1312 (85.4%) Cal BC (2σ). The same model is shown employing IntCal98 (Stuiver et

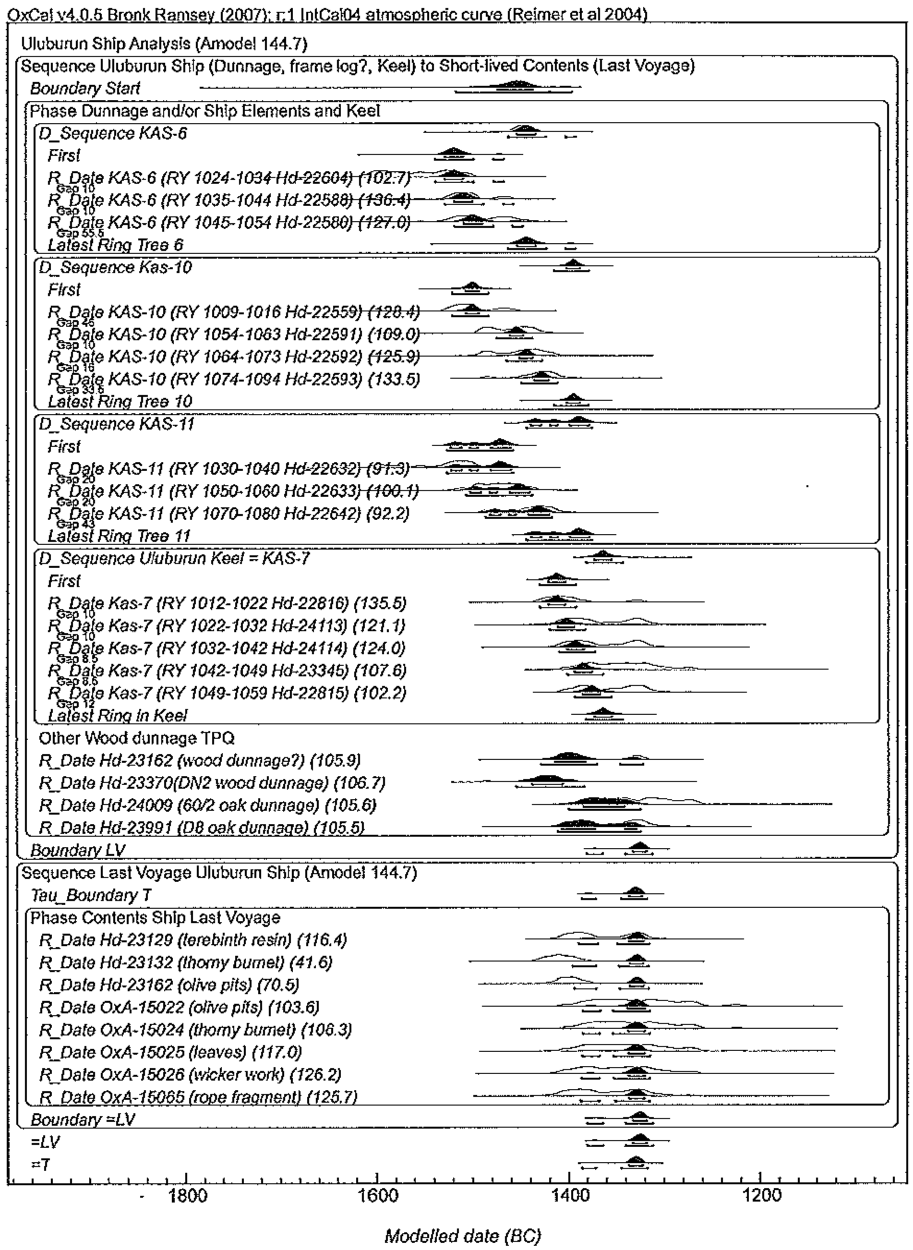

Figure 10: Model A with time constant of 10 years for the short-lived samples from the last voyage of the ship (see text) and IntCal04 (Reimer et al. 2004). Bayesian Sequence analysis using OxCal 4.0.5 and curve resolution = 1 (Bronk Ramsey 1995; 2001; 2008) for all the Uluburun data in order to best estimate the date range for the Last Voyage (LV) of the Uluburun ship (Figure 11). Model A does not assume that the short-lived samples from the ship's last voyage necessarily have to be more recent than the last tree-rings in the dunnage or ship elements (frame-timber and keel). This is in contrast to Model B, and covers, for example, the case that the ship was brand new when it sank. The time constant, that is, the assumed average (growth) age of the short-lived samples from the ship, is the main variable. Common sense would indicate that this should be a fairly short time, and the text proposes 0–10 years as plausible. The figure shows the analysis with a 10-year time period as the constraint. Outcomes when the constraint is 25 years, or 50 years, are shown in Table 2 for comparison. A Tau_Boundary model (see text, and Bronk Ramsey 2009) is applied, whereby it is assumed that the majority of the short-lived samples lie towards the date of the last voyage. The hollow (outline) distributions show the calibrated ages for each individual sample on its own; the solid black distributions within these show the calculated ranges applying the Bayesian model indicated. The horizontal lines under each distribution indicate the 1σ and 2σ confidence calibrated calendar age ranges. Note: every run of a sequence analysis achieves very slightly different results, the above being a typical example. The agreement index value for each individual sample is shown also (in parentheses). The approximate 95% confidence threshold value is $\geq$60%. Only sample Hd-23132 is slightly inconsistent, and would prefer a slightly older age; however, given the *terminus post quem* from the keel timber especially, we may instead suspect that this short-lived sample represents a near miss for the marked ^{14}C age inversion ("wiggle") region centred around 1325 BC (see Figures 2, 3); the same argument probably also informs the measured ^{14}C age for Hd-23162. The identical radiocarbon data and analysis are shown employing the previous IntCal98 radiocarbon calibration dataset (Stuiver et al. 1998) in Figure 12.

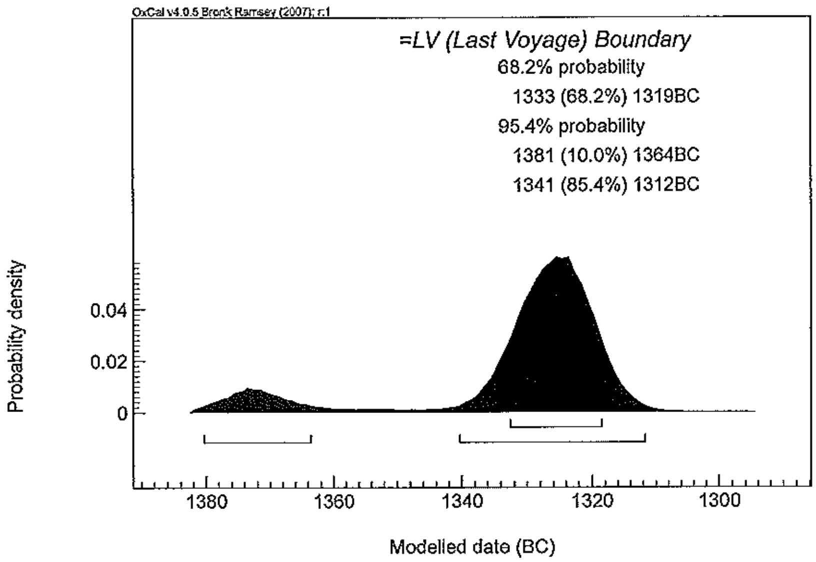

Figure 11: The modelled age estimate for the Last Voyage (LV) of the Uluburun ship from Figure 10.

al. 1998) in Figures 12 and 13, with the LV calculated as 1335–1325 (42.7%) and 1323–1316 (25.5%) Cal BC (1σ), and 1357–1348 (9.6%) and 1339–1312 (85.8%) Cal BC (2σ). Table 2 shows the modelled age ranges for the Last Voyage from Model A, given allowances of 10 year, 25 year, and 50 year time periods for the short-lived sample material from the final voyage of the ship.

Model B estimates the Last Voyage as a boundary immediately after the (uniform, and not Tau_Boundary model) phase of the short-lived material, with these placed as after the wood elements of the ship and the other wood material on board (and principally after the last ring of the keel). The overall model outcome employing IntCal04 (Reimer et al. 2004) is shown in Figure 14, with the modelled age range for the LV shown in detail in Figure 15: 1332–1311 Cal BC (1σ) and 1340–1289 Cal BC (2σ). The same model is shown employing IntCal98 (Stuiver et al. 1998) in Figures 16 and 17, with the LV calculated as 1333–1307 Cal BC (1σ) and 1343-1279 Cal BC (2σ).

With regard to Figures 10, 12, 14, and 16, we see that with IntCal04 one sample (Hd-23132) does not offer a satisfactory agreement index value (it would prefer to be a little older), whereas, with IntCal98, all the samples have satisfactory agreement index values. This may indicate that Hd-23132 is a near-miss for the marked radiocarbon age inversion (or wiggle) region around 1325 BC (see Figures 2 and 3). This wiggle is relatively smoothed away in the IntCal04 radiocarbon dataset, whereas it is more pronounced in the non-smoothed IntCal98 dataset (and in the new Oxford and Heidelberg data in Figure 3).

The striking observation is the similarity of the likely date ranges calculated for the LV across both Models A and B (Figures 11, 13, 15, 17). In Model A, if the length of the time interval for the short-lived samples is increased, then a small probability occurs in the earlier 14th century BC, but the most likely range nonetheless remains firmly in the later 14th century BC. This is clear when the time interval allowed is shorter (e.g. the 10 years of Figures 11, 13) and the most likely (1σ) ranges are 1335–1333 to 1319–1316 Cal BC. In Model B, which more likely captures the dating reality with the Last Voyage somewhat after the construction of the ship, all the analyses clearly find a later 14th-century BC range, with the most likely range about 1333–1332 to 1311–1307 Cal BC (a high-precision dating with a total range of 22–25 years) at 1σ or 1343–1340 to 1289–1274 Cal BC (with a 54–66 year range) at 2σ.

These ranges provide a likely good, close, and highly resolved dating for the LV of the Uluburun ship.

This late 14th-century BC date for the last voyage of the Uluburun ship is independently obtained solely from the radiocarbon, tree-ring, and context-based knowledge of the necessary sequence of the samples. Conveniently, and offering a strong independent reinforcing of its likely approximate validity, this late 14th century BC date range is also very compatible with the artefact/archaeological date assessments of the final voyage based on the material culture items recovered from the wreck (e.g. Wiener 2003a: 245–246; Bass et al. 1989; Pulak 2008).

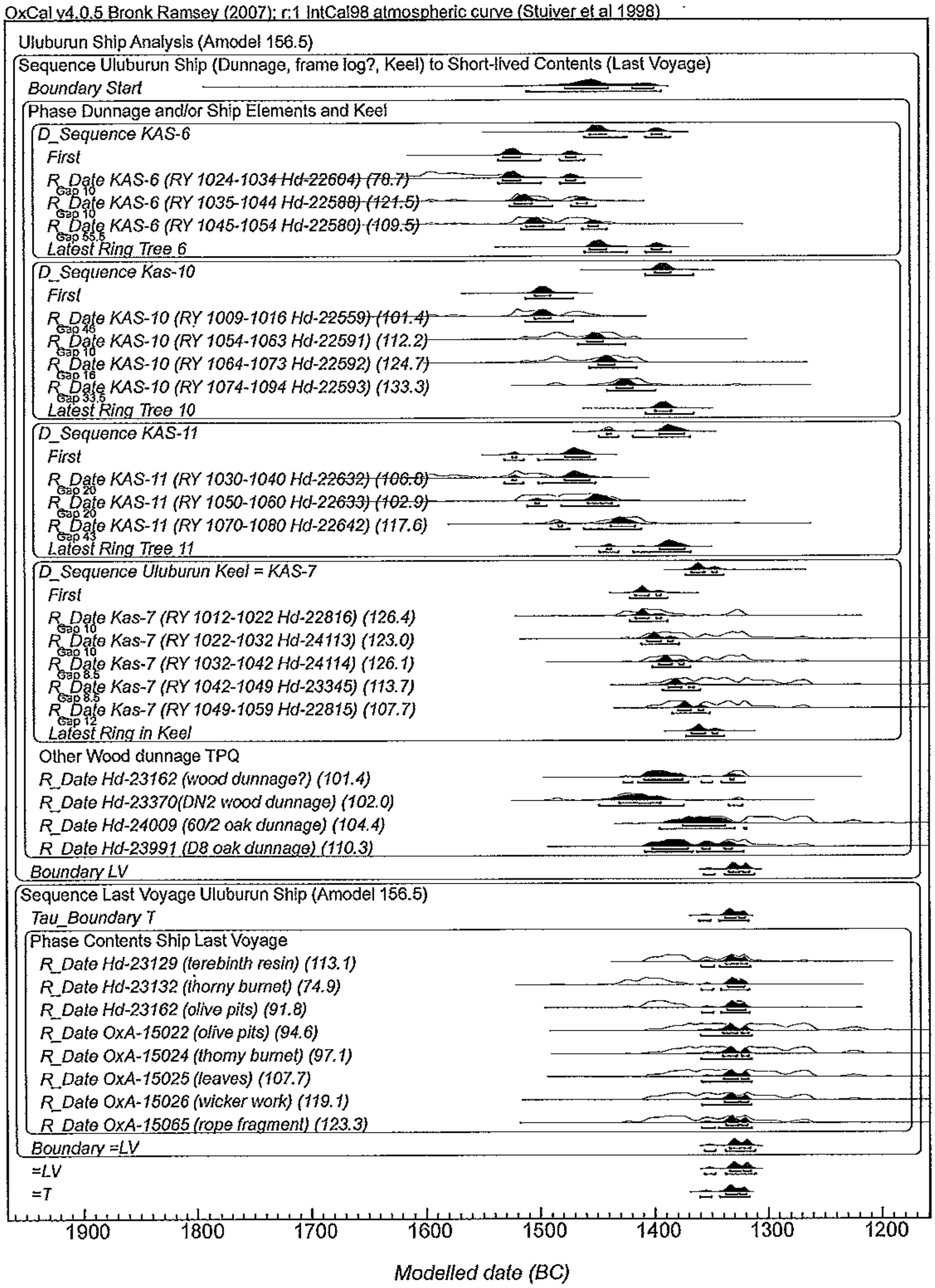

Figure 12: As Figure 10, but with the calibration analysis employing the IntCal98 radiocarbon calibration dataset (Stuiver et al. 1998). A very similar set of outcomes results. For other details, see the caption to Figure 10.

Tau Boundary Interval	IntCal04 1σ Cal BC	IntCal04 2σ Cal BC	IntCal98 1σ Cal BC	IntCal98 2σ Cal BC
10 years	1333-1319	1381-1364 (10.0%) 1341-1312 (85.4%)	1335-1325 (42.7%) 1323-1316 (25.5%)	1357-1348 (9.6%) 1339-1312 (85.8%)
25 years	1371-1365 (6.1%) 1335-1315 (62.1%)	1377-1347 (25.8%) 1341-1310 (69.6%)	1373-1366 (11.0%) 1354-1352 (2.5%) 1335-1314 (54.8%)	1378-1344 (35.2%) 1339-1309 (60.2%)
50 years	1371-1359 (16.6%) 1335-1314 (51.6%)	1376-1309	1372-1365 (9.1%) 1357-1349 (10.4%) 1335-1313 (48.6%)	1376-1308

Table 2: Modelled calendar age ranges for the Last Voyage (LV) of the Uluburun ship from Model A (see text and Figures 10–13). Where there is more than one sub-range, if there is a clearly much more likely sub-range, then it is underlined. Each run of such analyses produces very slightly different outcomes; typical results are shown. Model A does not assume that the short-lived samples from the ship's last voyage necessarily have to be more recent than the last tree-rings in the dunnage or ship elements (frame-timber and keel*); this is in contrast to Model B and covers, for example, the case that the ship was newly built when it sank. The time constant allocated to the last-voyage samples, that is, the average age of the short-lived samples from the ship, is the main variable. These materials are all likely less than 10-years old and are in fact likely to range from a single year's growth to a maximum of a few years' growth in total. Thus, a time constant of 10 years seems plausible and realistic. However, to be conservative, we have also considered longer intervals of 25 and 50 years. This 10-year time constant is different than the issue of time duration (i.e, cutting/use/production) of the various short-lived samples; that is, how long is the time window of the Last Voyage, and where within this time window (the Phase) might the majority of the samples belong? Common sense would indicate that this time period should be a fairly short time. Short-lived materials and cargo/use items would likely represent the current voyage, or at most be leftovers or re-use from the previous few voyages. The wicker-work and the rope fragment might be a little longer duration in use, but given maritime conditions of the time (see text), it seems likely that these would have had to be renewed or replaced within a few years. The thorny burnet, on board as packing, again likely reflects the last voyage, but could be re-used; it is nevertheless unlikely to have survived for such re-use for more than a few trips or a few years in total. A total time window for the short-lived material on the ship's last voyage of less than about 10 calendar years is probably quite realistic and even generous, and most of the samples likely fall into an even tighter time window of just the last one or few years. It thus appears realistic to consider a Tau_Boundary model where it is assumed that the majority of the samples lie close to the end of the Phase (i.e. the time of the Last Voyage). This is the suggested likely scenario as shown in Figures 10–13. The most likely dating range or sub-range is consistent across all the models (1335/33 to 1325/19/16/15/14/13 Cal BC at 1σ), but as the time constant is increased, the modelled range widens a little. * Note: the keel (KAS-7) does require at least a very short *terminus post quem* factor in reality (ignored in Model A). Even if the ship was newly built, the keel is missing bark or sapwood, and thus at least a few (or more) years must lie between the last extant tree-ring in the keel and when the tree was actually cut (bark). There would then be additional time before the wood was used for the keel and before the ship sailed (even if this was its maiden voyage). This short *terminus post quem* is likely longer than the time period in which the short-lived sample matter was lying around or stored, but clearly could be almost the same time period (as Model A allows for; contrast this with Model B).

7. Uluburun dating, Nefertiti, and Egyptian and Near Eastern chronology

Although small, one of the most notable finds from the Uluburun ship is of a unique gold scarab of Nefertiti, wife of Amenhotep IV (Akhenaten) (Weinstein 1989; 2008; Bass 1987: 731–732). This object can now offer an important test for the relationship between the Uluburun last voyage radiocarbon-based dating (above) and the standard historical chronology for Egypt. The earliest date for the production of this scarab is from early in the reign of her husband Amenhotep IV. Weinstein (1989: 27) argues for an earliest date (or *terminus post quem* for the item) from about years 2 or 3 to certainly year 5 of Amenhotep IV's reign. Amenhotep IV's accession is conventionally dated to about 1353 BC (Hornung et al. 2006: 492, 477), with the lowest recent "mainstream" published scholarly date at 1340 BC (Helck 1987). The last date for its production is around the time Amarna was abandoned (and when the worship of the Aten was abandoned), which is about three years after the death of Amenhotep IV. (There are wine vintages attested at Amarna for 13 years under Amenhotep IV/Akhenaten, equating to years 5 through 17 of his reign, and then for a further three vintages: Hornung et al. 2006: 207). A date around 1332–1331 BC results, likely more or less when the child Tutankhamun becomes ruler; there is an absence of explicit evidence for the date of his accession (for a summary of the evidence, see Hornung et al. 2006: 208, 477). By this time Nefertiti was either dead, or, with the abandonment of the worship of the Aten and move of the capital, a scarab naming Nefertiti and the Aten would no longer have been produced (Weinstein 1989: 27). New work may, however, change the "conventional" position, and instead suggests an accession date for Amenhotep IV at 1342 BC and for Tutankhamun at 1321–1320 BC.[2] The scarab could not have existed

[2]Recent work on evidence of Horemheb's last attested year appears to indicate that the length of his reign may have to be re-assessed downwards from the usual 28 years of reign to perhaps a reign of no more than about 14 or 15 years (David Warburton and Rolf Krauss, pers. comms. 2008, 2009; contrast this with comments in Hornung et al 2006: 476–477). Taking

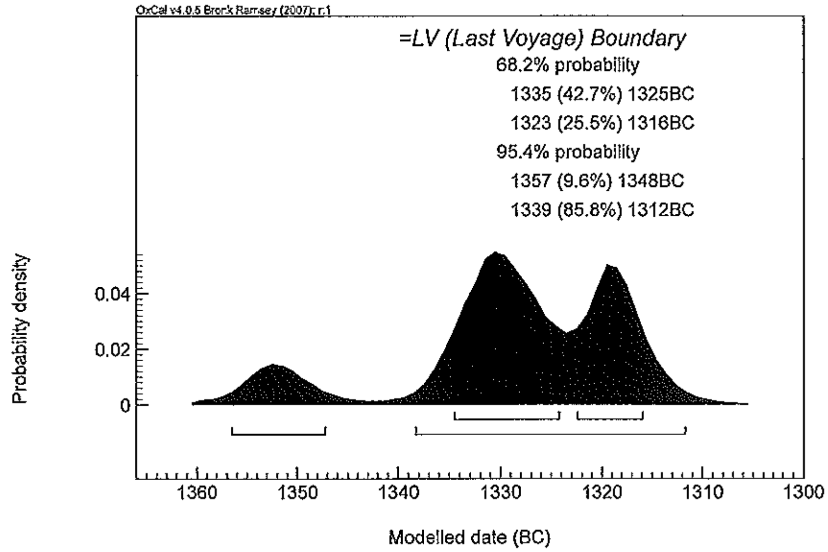

Figure 13: The modelled age estimate for the Last Voyage (LV) of the Uluburun ship from Figure 12.

before this Amarna period, so, according to the latest work, not before about 1340 BC, previously not before about 1350 BC. However, the scarab could, of course, have been in circulation at any time after her death. Weinstein (1989: 27–29) further speculates that the form of the writing and the title used may indicate a more specific date late in the reign of Amenhotep IV, or in the year or two immediately after his death (if and/or when Nefertiti perhaps became co-regent in Amenhotep IV/Akhenaten years 15–16 and/or perhaps was ruler/king subsequently, although these are all contentious points).[3] In this case, a date around the mid-1330s BC (or mid-later 1320s BC on the new chronological position noted in footnote 2) would be called for. The scarab was found quite worn in places, especially on the back, but still retained traces of lines representing wing ribbing (so the extent and use-time of the "wear" is open to interpretation). This being the case, the scarab may have been around for some years or decades before this last voyage and have been "bric-a-brac" by this time (Weinstein 1989: 23). Equally, however, this worn state could be explained in other ways, and the scarab might have only been a few years, to a few decades, old at the time of the shipwreck. Weinstein argued that the scarab probably belonged to an Egyptian official or a member of his family, and was disposed of after the end of the Amarna period, after which it ended up with a merchant, and on the ship, some years or even a couple of decades later in the post-Amarna period. This is clearly a plausible scenario, and the combination of tree-ring and radiocarbon evidence would suggest that the scarab reached the seabed with the ship either during the later Amarna period or in one of the next few decades following it, with either the conventional Egyptian dates or the revised dates (see footnote 2).

The accession of Amenhotep IV thus sets a clear *terminus post quem* for the shipwreck. We can therefore test the compatibility of the conventional protohistorical date estimates for Nefertiti against the above radiocarbon-based chronology from the Uluburun ship. To be potentially valid, the proto-historical dates must be older, and not more recent, than the age range found above for the shipwreck. We find exactly this situation: the conventional dates, or recently modified conventional dates (e.g. Weinstein 1989: 17–29; Hornung et al. 2006; Helck 1987; Kitchen 1996; 2007; von Beckerath 1997; Krauss and Warburton, personal communications—see footnote 2), are either a little older than, or contemporary with, the age range determined by radiocarbon. For example:

the other evidence for the New Kingdom (e.g. lunar information) into account, this would mean reducing the "conventional" date for Amenhotep IV to about 1342 BC (i.e., to more or less where Helck 1987 placed it). A similar reduction would apply for Tutankhamun (to 1321–1320 BC). A study on this new chronology ("The basis for the Egyptian dates") by Krauss and Warburton will appear in a forthcoming volume edited by D. Warburton entitled *Time's Up! Dating the Minoan Eruption of Santorini* (Monographs of the Danish Institute at Athens 10.)

[3] Various as yet unproven claims have been made, for example, for Nefertiti to be identified with the kings named Ankhetkheprure, Nefernefruaten or Smenkhkare, and especially the woman ruler Ankhetkheprure Nefernefruaten (Hornung et al. 2006: 207). But she may well have died (as queen—that is king's wife), and the woman ruler during a short period between Amenhotep IV/Akhenaten and Tutankhamun could instead be one of Akhenaten's other wives or daughters: e.g. Kiya or Merytaten. For a good discussion of the poorly understood period of the few years around and following the death of Akhenaten, see Allen 2009. An online version of this volume is available at: http://history.memphis.edu/murnane/.

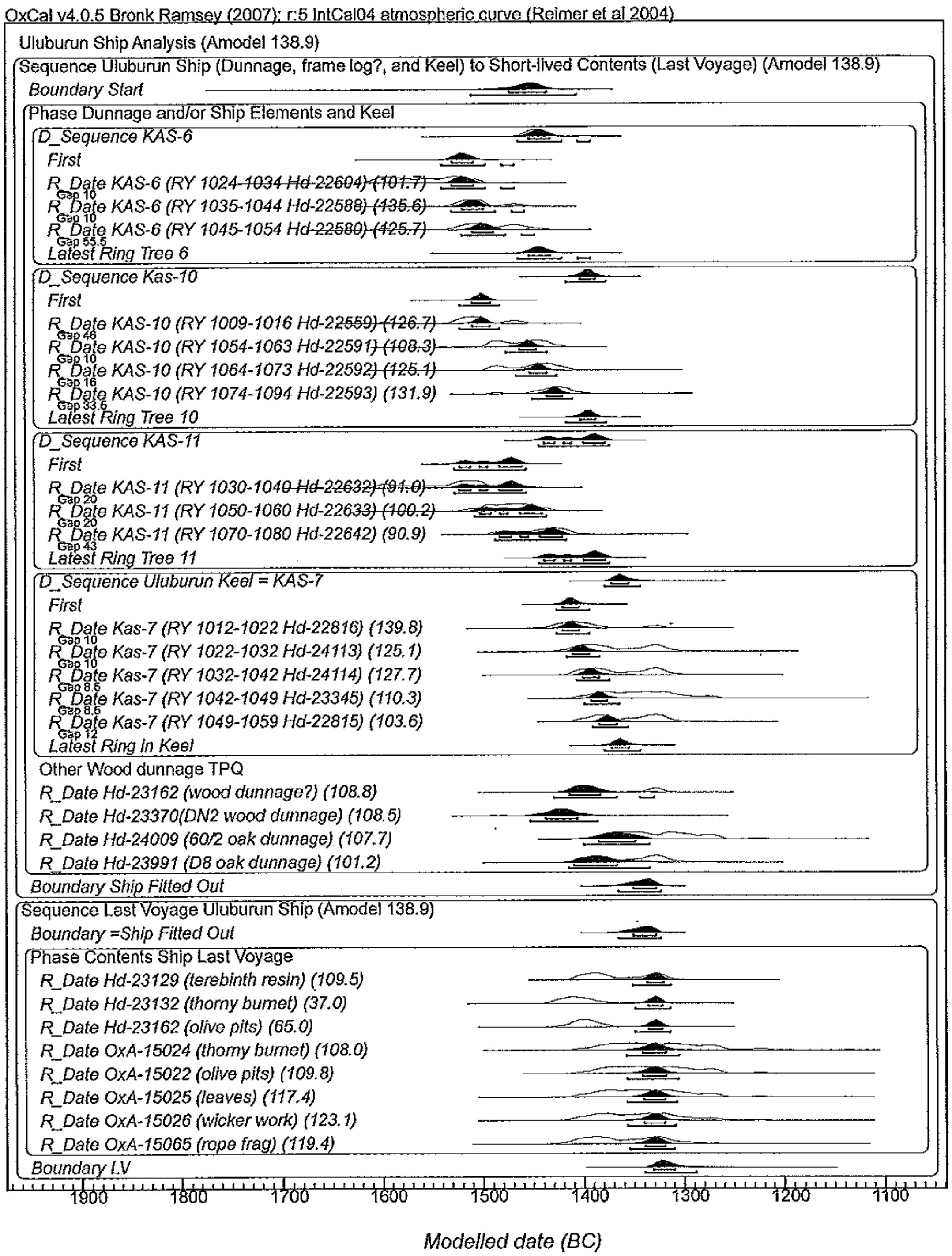

Figure 14: Model B and IntCal04 (Reimer et al. 2004). Bayesian Sequence analysis using OxCal 4.0.5 and curve resolution = 1 (Bronk Ramsey 1995; 2001; 2008) for a sequence where the wood elements of the ship (the keel: KAS-7) and other wood items on the ship act to define when the ship was built/fitted out, and set a *terminus post quem* for the short-lived items from the ship from its last voyage (Phase Contents Ship Last Voyage). The Last Voyage (LV) is calculated as a boundary immediately subsequent to this phase (see Figure 15). For other details on how to read the figure, see the caption to Figure 10.

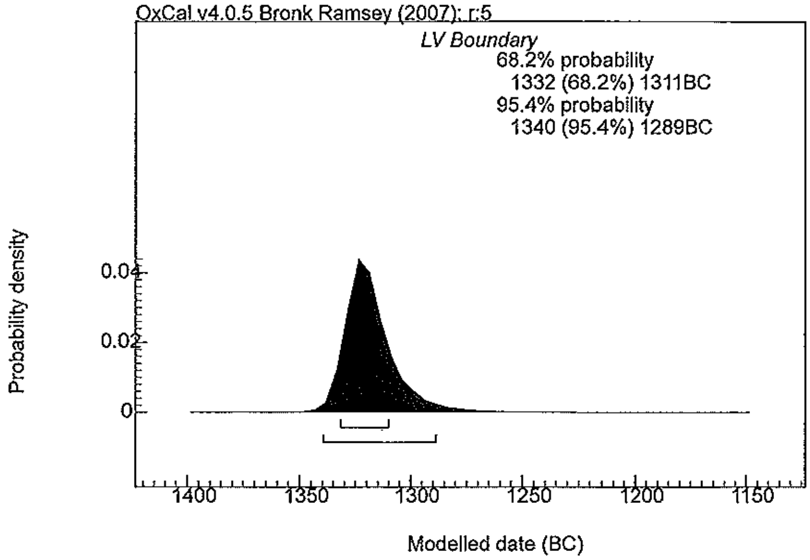

Figure 15: The modelled age estimate for the Last Voyage (LV) of the Uluburun ship from Figure 14

(i) Conventional TPQ/production range 1353–1332/1 BC, earlier than or equal to the most likely radiocarbon 1σ ranges (see previous section) of Model A: 1335/33–1319/16 Cal BC, or Model B: 1333/32–1311/07 Cal BC (or, referring to the 2σ or most likely sub-range of the overall 2σ ranges, Model A: 1341/39–1312 Cal BC, and Model B: 1343/40–1289/74 Cal BC); or

(ii) Revised conventional TPQ/production range 1342–1321/20 BC, earlier than or equal to the most likely radiocarbon 1σ range of Model A: 1335/33–1319/16 Cal BC, or Model B: 1333/32–1311/07 Cal BC (or, referring to the 2σ or most likely sub-range of the overall 2σ ranges, Model A: 1341/39–1312 Cal BC, and Model B: 1343/40–1289/74 Cal BC).

In reverse, proposed chronologies for Egypt which posit dates for the accession of Amenhotep IV substantially later than the conventional dates, and, in particular, later than about 1311–1307 BC (the most likely 1σ range from Model B), or, at the extreme dates of variously about 1309 BC, 1308 BC, 1289 BC or 1274 BC (the latest date in any of the 2σ ranges from either models A or B), appear incompatible with the robust radiocarbon-based chronology summarised in Figures 10–17 and Table 2, and so may be rejected. (These include, for example, chronologies which are some 70 years later than the conventional dates, as in Hagens 2006, and certainly those radical ultra-low chronologies which suggest dates a couple of centuries later again: James et al. 1991; Rohl 1995.) In turn, because of the inter-linked correspondence recorded in the Amarna archive between the Egyptian kings and contemporary rulers of Babylonia (especially) and Assyria, the Hittites, the Mitanni, Alashiya (usually regarded as Cyprus), and various other Levantine entities (Moran 1992), the above finding, which requires at least the conventional range of dates for Nefertiti and Amenhotep IV (Akhenaten), also provides a similar requirement for the chronologies of Babylonia and Assyria (summaries in von Beckerath 1994: 23–24; Klinger 2006: 313–319). Radically later (more recent) dates for the civilizations of second to first millennium BC Egypt, and the linked ancient Near East in general, are thus incompatible with the substantive and independent integrated dendro-radiocarbon wiggle-match evidence presented here for the Uluburun ship.

8. Discussion and Conclusions

The high-resolution integrated dendro-radiocarbon methods produce a date between about 1335–1332 to 1319–1307 BC (1σ) or 1343–1339 to 1312–1274 BC (2σ) (overall range of options from the analyses above, with the most likely range 1335/1333–1319/1316 BC on Model A and 1333/1332–1311/1307 BC on Model B at 1σ for the last voyage of the Uluburun ship. With its rich cargo, the ship now provides a key independent chronological marker for the east Mediterranean region. It independently confirms the approximate absolute dating of the well-documented Amarna period in Egypt and its contemporaries in the ancient Near East, in the mid-later 14th century BC. In the Aegean, it dates the Late Helladic IIIA2

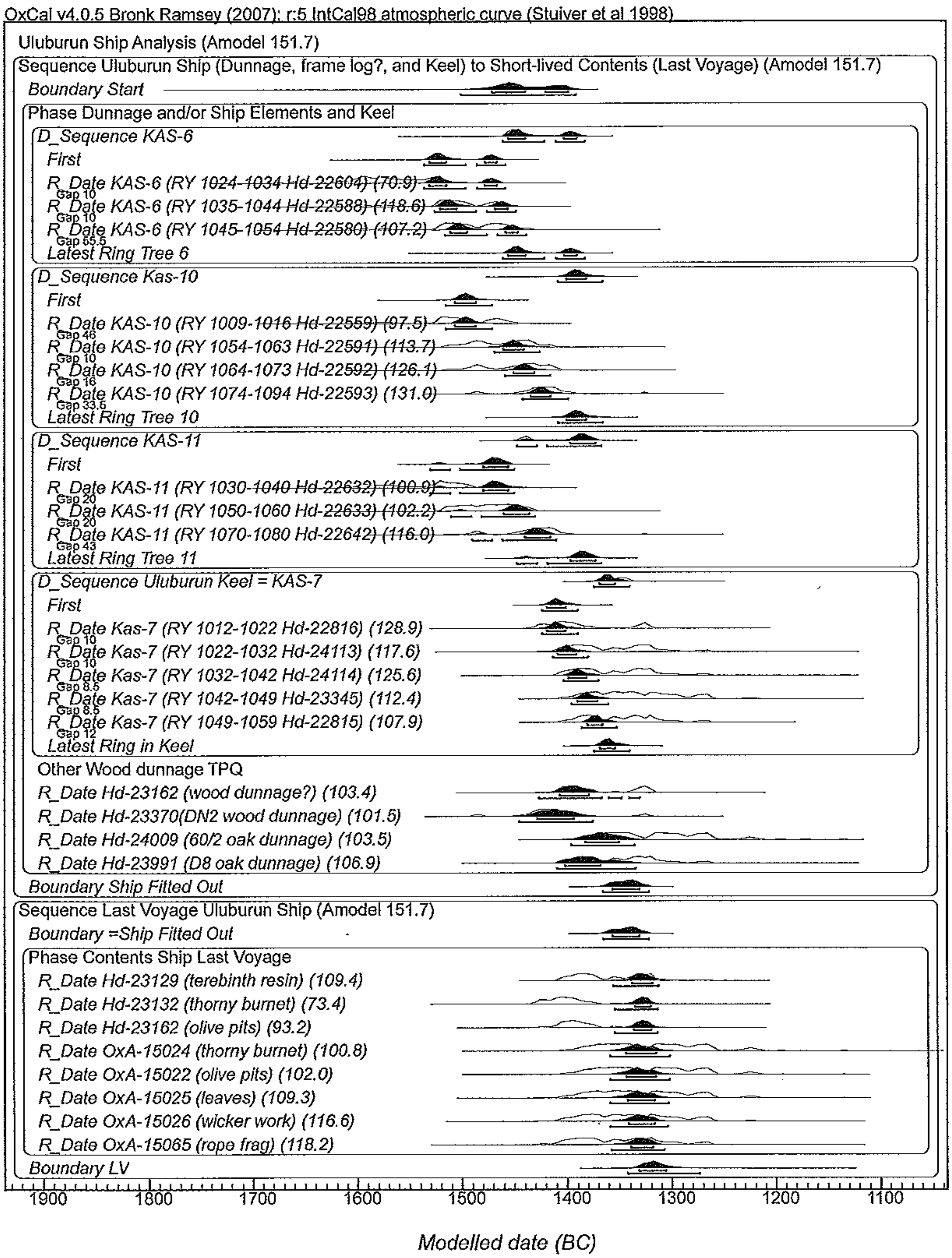

Figure 16: As Figure 14, but with the calibration analysis employing the IntCal98 radiocarbon calibration dataset (Stuiver et al. 1998). A very similar set of outcomes results. For other details of how to read the figure, see the caption to Figure 10.

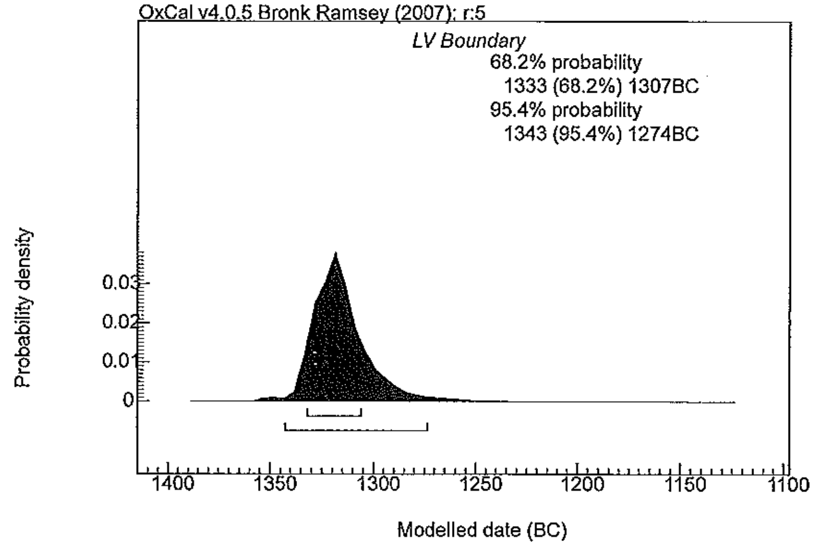

Figure 17: The modelled age estimate for the Last Voyage (LV) of the Uluburun ship from Figure 16.

period (Bass et al. 1989; Warren and Hankey 1989: 148–154; Wiener 1998; 2003a).

The ability of radiocarbon to resolve this Amarna-period time-capsule precisely, and in good agreement with standard recent assessments of the historical information regarding the ancient chronologies of Egypt and the Ancient Near East, is important. The Amarna period is the best documented (e.g. Moran 1992; Murnane 1995) and most securely cross-dated short time horizon in the Near East from the whole of the Bronze Age, where, critically, documents at Amarna combined with those known from Mesopotamia attest that Amenhotep IV and his father Amenhotep III were contemporaries of Burnaburiash of Babylonia and (thence) also of Ashshur-Uballit I of Assyria (Klinger 2006: 313–319; von Beckerath 1994: 23–24). This nexus of links therefore ties the Amarna period dating (above) to the Babylonian and Assyrian chronological traditions. The Amarna letters also permit direct links to other rulers such as the Hittite king Shuppiluliuma I; hence the dendro-radiocarbon dating of the Uluburun ship confirms his mid-later 14th century BC date, and those for others linked to the Amarna time-frame. There is also a very secure tie to Aegean chronology through the large number of Aegean ceramics found at Amarna itself, or in contexts closely associated to this short time-period (Hankey 1997; Wiener 1998; 2003a). The fact that an integrated radiocarbon and dendrochronological analysis can resolve a precise date in accord with the archaeology and history when there is good, extensive, and replicated archaeological and historical information, suggests that the former is a good guide to dating the latter (and radiocarbon dates from Amarna itself are also compatible with the historical dating: Manning 2006: 335–338). Where we then have archaeological or historical evidence that is much less secure, unclear, sparse, or non-replicated, we might even venture to suspect that large-scale integrated dendrochronological and radiocarbon analyses might offer the best guide to absolute dates.

It is of course noticeable that the good agreement of the integrated dendrochronological and radiocarbon analysis for the Uluburun ship with the dating of the Amarna period in Egypt and the Ancient Near East stands in stark contrast with the situation in the Aegean and east Mediterranean in the 17th to early 15th centuries BC. For the 17th to early 15th centuries BC, scholarship has for some years noted an apparent disagreement between the radiocarbon-based chronology versus conventional archaeological-historical assessments and estimates for dates in the Aegean and on Cyprus (Betancourt 1987; Manning 1988; 1999; Friedrich et al. 2006 and this volume; Manning et al. 2006 and this volume; Bietak 2003; Bietak and Höflmayer 2007; Wiener 2003b and this volume).

What is going on? There is no apparent difference on the radiocarbon side—and indeed the same two (of three) radiocarbon laboratories and their quality controls (see Manning et al. 2006: Supporting Online Material) have provided the data in both the Uluburun case (above) and the most recent major studies of the 17th to 15th century BC case (Manning et al. 2006; Friedrich et al. 2006). Some have suggested or asserted that perhaps volcanic CO_2 or another mechanism somehow affected the dates on samples from Santorini, but the data seem in fact to indicate the contrary, and no actual positive evidence has been produced to support these claims (see the contrasting discussions of Friedrich et al. 2006, and this volume, Manning et al. 2006, and this volume, and Wiener, this volume). Even a supposed Santorini-specific problem cannot explain away the evidence from elsewhere in the Aegean. As Manning (et al. 2006, see also this volume) observed, even excluding all the evidence from Santorini, the other Aegean radiocarbon data indicate a similar chronology (and one at odds with the conventional archaeological-historical dates for the 17th to earlier 15th centuries BC). Keenan (2002) claimed that upwelling of stagnant radiocarbon-depleted deep water in the Mediterranean caused radiocarbon dates to be too old before about year 0 in the Mediterranean. The case lacks any evidential support (Manning et al. 2002) and is clearly disproved back to the 14th century BC by the Uluburun data (above); it is also noticeable that east Mediterranean radiocarbon dates from earlier in the second millennium BC (e.g. Marcus 2003; or Voutsaki et al., this volume), or from the third millennium BC (e.g. Manning 1995; 2008), do not seem too old in any systematic or significant way. The "problem" seems to lie in the 17th to early 15th centuries BC.

If we look to the archaeology, the notable difference is the quality and quantity of data at issue for the interpretation of the material culture correlations between the Aegean and Cyprus, and Egypt and its historical chronology in the 17th and 16th centuries BC. (By the time we reach the 15th century BC, things come together, and can even agree well: Manning n.d.) For the Amarna period there is a multi-strand, secure, Egyptian historical chronology linking with Babylonia and Assyria (and their independent chronological traditions). There is furthermore a vast web of material culture linkages (including a large cache of direct Aegean-Egyptian linkages from Tell el-Amarna itself, and other associated linkages: Hankey 1981; 1997; Wiener 1998; 2003a). In contrast, for the Late Bronze I to II periods, there are far fewer, or no (for the Late Minoan IA period) clear and direct linkages, and thus there is much more flexibility or ambiguity in the conventional interpretations of cultural associations, especially for the earlier LBI stage (Kemp and Merrillees 1980; Betancourt 1987; Manning 1988; 1999; 2007; Manning et al. 2006). Since the present study demonstrates that sophisticated integrated dendrochronological and radiocarbon analysis offers a precise chronology compatible with secure and well-based archaeological-historical data and assessment for the east Mediterranean region, we may have to consider the possibility that a similar integrated analysis on appropriate samples (e.g. Manning et al. 2006; Friedrich et al. 2006) could offer better guidance for other periods in the Aegean-east Mediterranean where the archaeological-historical linkages are less secure.

In the meantime, we approach a near-fixed point for the archaeology of the east Mediterranean, agreed by science and archaeology: a date for the last voyage of the Uluburun ship, and for its extraordinary contents, in about 1335–1332 to 1319–1307 BC (1σ) or about 1343–1339 to 1312–1274 BC (2σ) (overall range of options from the analyses above, with the most likely range 1335/1333–1319/1316 BC on Model A and 1333/1332–1311/1307 on Model B at 1σ). If we then generalise these various date estimates and slightly different approaches, and the use of the two calibration datasets, we can offer an approximate round numbers estimate for the last voyage of the Uluburun ship of about 1320 ±15 BC (covering all the 1σ ranges).

Acknowledgments

We thank the NSF, NEH, NSERC, NERC, the Institute of Nautical Archaeology (INA) and Texas A & M University, the Institute for Aegean Prehistory, the Malcolm H. Wiener Foundation, and other patrons of the Aegean Dendrochronology Project for their funding and support of this work. We thank and acknowledge especially the honorand of this volume, Peter Ian Kuniholm, and also Maryanne Newton, for their fundamental work on the Uluburun samples over many years (e.g. Newton et al. 2005), and we thank Laura Steele for her substantial laboratory work on the Uluburun samples. We thank N. Liphschitz for plant and tree species identification. We thank Michael Friedrich for supplying samples of known-age German Oak. We thank Peter Kuniholm for comments on the text.

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[Note added in Proof: This paper has employed the current standard IntCal04 radiocarbon calibration curve (and considered the previous IntCal98 curve). However, Figure 3 shows that some recent Heidelberg measurements, especially, on known-age German oak, provide radiocarbon ages somewhat older than IntCal04 in the period 1360–1260 BC (see further in Kromer, B., Manning, S., Friedrich, M., Talamo, S., and Trano, N. n.d. ^{14}C calibration in the 2nd and 1st millennia BC—Eastern Mediterranean Radiocarbon Comparison Project (EMRCP). *Radiocarbon*, in press). When these data are included in a future IntCal modelling exercise (with the other available data), they may slightly raise the radiocarbon ages for IntCal in this interval. If so, this may allow the date for the Last Voyage to become slightly more recent. Hence, if there is room for movement on the date of 1320 ± 15 BC stated above, it is toward a slightly more recent date (i.e., toward c. 1300 BC).]

Article submitted April 2009

Published by

Oxbow Books, Oxford, UK

Library of Congress Cataloging-in-Publication Data

Tree-rings, kings, and Old World archaeology and environment: papers presented in honor of Peter Ian Kuniholm / edited by Sturt W. Manning & Mary Jaye Bruce.
p. cm.
Papers from a conference held Nov. 3–5, 2006, at Cornell University.
Includes bibliographical references.
ISBN 978-1-84217-386-2
1. Mediterranean Region—Antiquities—Congresses. 2. Mediterranean Region—Civilization—Chronology—Congresses. 3. Mediterranean Region—Environmental conditions—Congresses. 4. Dendrochronology—Mediterranean Region—Congresses. 5. Archaeology and history—Mediterranean Region—Congresses. 6. Climatic changes—Mediterranean Region—History—Congresses. 7. Human ecology—Mediterranean Region—History—Congresses. 8. Social archaeology—Mediterranean Region—History—Congresses. 9. Kuniholm, Peter Ian—Congresses. I. Manning, Sturt W. II. Bruce, Mary Jaye. III. Title: Tree-rings, kings, and Old World archaeology and environment.
DE60.T74 2009
930—dc22 2009038639

ISBN 978-1-84217-386-2

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Printed in Malta at
Gutenberg Press

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