The dating of the earlier Late Minoan IA period: a brief note

Sturt W. Manning & Christopher Bronk Ramsey

Introduction

Since the mid 1970s, much scholarly attention has centred on discussions about the dating of the mature to late Late Minoan (LM) IA cultural period in the Aegean – and specifically the timing of the great Minoan eruption of Santorini.[1] This focus has led to a lack of attention for related, and equally important, topics. For example: what about the dating of the earlier Late Minoan IA period? Moreover, in view of the fact that some scholars have argued that some special (but not demonstrated) factor(s) may somehow have affected the radiocarbon-based dating of the specific Santorini eruption timeframe (*e.g.* because of volcanic CO_2 on Santorini, *etc.*),[2] it seems pertinent to ask whether the dating evidence offered by material relevant to the start or early part of the Late Minoan IA period – and including material from Aegean sites other than from Santorini – might help to clarify the overall chronological scheme for the mid second millennium BC in the Aegean and east Mediterranean, and thus perhaps to resolve the on-going debates over the dating of the Santorini eruption? The present short note explores this question.

The conventional archaeological evidence for the absolute dating of the Aegean region derives from the assessment of the material culture or style links (imports, exports, associations) between the Aegean, east Mediterranean, and the Ancient Near East (and in particular Egypt), with the historical chronologies of Egypt and the Ancient Near East providing the dating framework.[3] The evidence relevant to the absolute dating of the start, or early part, of the Late Minoan IA period has been, and remains, scarce at best.[4] As a result, different scholars have reached very different opinions based on little concrete information (or interpolations based on the dating of other surrounding cultural phases), with the LM IA period beginning anywhere from about 1700/1650 BC or 1600/1550 BC in some recent assessments.[5] The problem is the poor and very limited, and therefore unclear or ambiguous, evidence-base. To recapitulate some assessments of the state of our evidence by leading scholars from the last four decades:

(i) Popham noted that "Evans' date for the beginning of Late Minoan I is generally accepted but its basis is open to question";[6]

(ii) Betancourt observed that LM IA could begin anywhere from 1650-1550 BC (*i.e.* SIP), and that "there is no evidence for the more precise 'traditional' view that it begins *c.* 1580 B.C.";[7] and

(iii) Hallager wrote that "it is important to stress

[1] See, for examples, Michael 1976; Betancourt & Weinstein 1976; Betancourt 1987; Warren 1984; 1987; 1991a; 2006; 2007; Manning 1988; 1999; 2007; Manning *et al.* 2006a; 2009; Hardy & Renfrew 1990; Wiener 2003a; 2006a; 2007a; 2009; Bietak 2003b; Bietak & Höflmayer 2007; Friedrich *et al.* 2006; 2009. The present volume largely addresses just this topic (again).

[2] Wiener 2003a; 2006a; 2007a; 2009.

[3] For example, see Furumark 1941; Hankey & Warren 1974; Cadogan 1978; Warren & Hankey 1989.

[4] For the limited evidence available, see *e.g.* Betancourt & Weinstein 1976, 336–337; Warren & Hankey 1989, 135–7.

[5] For the earlier date range, see *e.g.* Kemp & Merrillees 1980; Betancourt 1987; Manning 1988; 1995; 1999; 2001; 2007; Manning *et al.* 2006a. For the later date range, see *e.g.* Cadogan 1978; Warren & Hankey 1989; Warren 1998; 1999; 2006; Wiener 2006a.

[6] Popham 1970, 226.

[7] Betancourt 1985, 122.

that the renewed investigations of the traditional synchronisms of the MM III/LM IA material have shown the contexts – both the Egyptian/Near Eastern and Aegean – so dubious that a revised high chronology for the beginning of the LM IA is possible".[8]

No strong or decisive (etc.) archaeological evidence has been found in the last two decades to change these assessments. Some scholars have tried to argue that their interpretations of the archaeological evidence require a date for the time period of the mature-late Late Minoan IA eruption of Santorini after the beginning of the New Kingdom – so after about 1540 or 1530 BC[9] – but, *even if* one accepts these assertions (which the present authors do not, and one of us especially has argued strongly against a number of times and does not repeat here),[10] the date for the start and early part of the Late Minoan IA period remains effectively open, as noted above.

The reason is a lack of secure or chronologically specific evidence bearing on the dating of the period ranging from Middle Minoan III through to earlier Late Minoan IA. This period falls into a "gap" *after* the reasonably secure archaeological linkages between Middle Minoan period exports and imports and Egyptian contexts of Egyptian Dyns. XII to XIII,[11] and *before* the secure late Late Minoan IB and Late Helladic IIA (and subsequent) linkages between the Aegean and Egypt from the New Kingdom and especially from the reign of Thutmose III.[12] At best, some indirect or imprecise or questionable linkages can be argued (very much depending on what a scholar wishes to achieve as an end-point).

Let us therefore examine some recent radiocarbon data for guidance, and, in particular, let us ask some new questions of these data.[13] Thus, rather than asking how all the data work in terms of trying to date the volcanic destruction level (VDL) on Santorini (as has been the primary focus of recent work), let us instead ask what the data can tell us in reverse about the parameters for the dating of the early/earlier Late Minoan IA period. That is: the time range of the Late Minoan IA period before the Santorini volcanic eruption. Here we need to note an important definitional issue. We employ Late Minoan IA Early in the sence developed at Kommos by Van de Moortel (1997) – this is because our best evidence comes from Kommos and was described in terms of this scheme. However, we note that this same material culture/time interval is also termed Middle Minoan IIIB in other recent work (Girella 2007). Thus the Late Minoan IA Early in our text could also be labelled as Middle Minoan IIIB. What we aim to do in this paper is to define the time period *after* some *terminus post quem* data sets of this Late Minoan IA Early or Middle Minoan IIIB period (depending on terminology used) and *before* the mature-late Late Minoan IA time range of the Santorini volcanic destruction horizon. This "in-between" time range, which we seek to quantify, is what we are terming as "Early-Mature/Late LM IA" (Figs 1-8).

Radiocarbon dating and the parameters for dating early or earlier Late Minoan IA (or MM IIIB to early LM IA)

The proposed strategy is to examine recent high-quality radiocarbon data on wood-charcoal sam-

[8] Hallager 1988, 12.

[9] *E.g.* Bietak 2003b; Bietak & Höflmayer 2007; Wiener 2003a; 2006a; 2007a; 2009; Warren 2006; 2007.

[10] *E.g.* Manning 1999; 2001; 2007; Manning this volume; Manning *et al.* 2002; 2006b; 2009.

[11] Kemp & Merrillees 1980; Merrillees 2003; Höflmayer 2007.

[12] Kemp & Merrillees 1980; Warren 1985; Warren & Hankey 1989, 138–46; Aston 2003, 140–5; Manning this volume.

[13] Data taken from Manning *et al.* 2006a; and Soles 2004b. For the Late Minoan IB-II evidence and dating, see further details and discussion in the paper of Manning in this volume. For data quality, see Manning *et al.* 2006a Supporting Online Material regarding the Manning *et al.* 2006a data (those run at Oxford and VERA with regard to this paper – we thank again the excavators and scholars who provided these samples and information about them, and we thank the many colleagues who worked on these samples). The Mochlos data are less easy to assess (see Manning this volume: Table 1 caption), but two were run at Oxford from samples prepared by Beta, and altogether they appear a good set usefully illustrating the Late Minoan IB Final sub-phase (see Rutter forth., and Manning this volume).

ples from some secure early or earlier Late Minoan IA (or MM IIIB to early LM IA) contexts in the Aegean (seven samples for which 21 radiocarbon dates are available) which must either set a *terminus post quem* age for these contexts or, at the latest (if outer tree-rings, or shorter-lived wood samples), date to the time period of these contexts.[14]

Thus a time-span immediately after these data could be defined as representing either a *terminus post quem* for early or earlier Late Minoan IA (or MM IIIB to early LM IA following Girella 2007) or as a date for early or earlier Late Minoan IA. Let us call this *Condition 1*. Employing the OxCal software and Bayesian analytical approach,[15] such an unknown time interval – to be quantified by the data lying before it, or after it, and so constraining it, is termed a "boundary" and values may be calculated. Further, we have some data on short or shorter-lived samples – that is samples contemporary with their find context within a year or so – from mature or late Late Minoan IA contexts. These samples offer ages which must (given the archaeological sequence known) post-date the early or earlier Late Minoan IA time period (or MM IIIB to early LM IA following Girella 2007). They set a *terminus ante quem* for the early or earlier Late Minoan IA time period.

They thus set a firm lower constraint to the above *terminus post quem* range for the early or earlier Late Minoan IA data. Let us call this *Condition 2*. Again it can be calculated in terms of a boundary in OxCal. In turn, we may state that early or earlier Late Minoan IA can therefore be tightly defined as after or equal to Condition 1 and before Condition 2. Thus our best estimate for the target time period we seek, of early/earlier Late Minoan IA to before the mature-late Late Minoan IA evidence, is the period of time *between* Condition 1 and Condition 2: we can estimate this time-span in OxCal, and we term it as a Boundary named "Early – Mature/Late LMIA". And, to constrain and reinforce Condition 2, we may also note that there are several sets of data on short-lived samples from subsequent Late Minoan IB destruction contexts at three sites on Crete.

These data must post-date Condition 2, and in reverse, set a *terminus ante quem* for it, and can further add to an overall *terminus ante quem* for the date range for the early or earlier Late Minoan IA time interval – let us term these data as *Condition 2+*. We do not have any reason to assume a specific distribution of the dated samples within their time-periods or phases. Therefore, we take the conservative approach and assume that each group of events (in each phase) is randomly sampled from a uniform distribution.

Thus our Analysis Model is: Condition 1 ≥ Target Date Range = Boundary "Early – Mature/Late LMIA" > Condition 2 > Condition 2+

We employ the Bayesian analysis software of OxCal 4.1.1 to quantify the dating of the Boundary "Early – Mature/Late LMIA" (our target in this paper), given both the archaeological sequence information (as just summarized), and the radiocarbon dates from the samples available to define Condition 1, Condition 2 and Condition 2+ above (see Table 1).

Various aspersions have been cast, or asserted, against the radiocarbon data from Santorini (and in particular those data from the period close to the time of the great volcanic eruption).[16] None of these alleged possible problems (some form of supposed contaminant leading to falsely older radiocarbon ages) have been demonstrated as relevant to the recent radiocarbon dating analyses of the time period,[17] but, nonetheless, some scholars choose to hold a sceptical position. Thus it seems relevant to consider also a Modified Analysis Model which employs *no* radiocarbon data from Santorini. The

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[14] An example is the three dates (two recent, one run some time ago) on (outer rings of) a *c.* 8cm diameter round charcoal sample from Space 25 of Building T at Kommos from an early Late Minoan IA find context: Shaw 1986, 253, figs. 6a, 6b, pls. 53a-c; Shaw & Shaw 2006, 43, 395–6, 410–1, pl.3.22 groups 5a, 5b. The Kommos phasings come from the work of the Kommos team (see Shaw & Shaw 2006) and information from Jeremy B. Rutter. Another sample which should offer a date for the early Late Minoan IA period is the charred twig fragment from K85A/66B/4: 22+23, an early LMIA context at Kommos.

[15] Bronk Ramsey 1995; 2001; 2008a; 2009; Bronk Ramsey *et al.* 2001.

[16] See in particular Wiener 2006a; 2007a; 2009.

[17] See discussions of Friedrich *et al.* 2006; 2009; Manning *et al.* 2006a; 2009.

Site	Submitter's reference	Material	Species	OxA
Akrotiri, Thera	M54/2/VII/60/SE>247	charcoal	*Olea europaea*	11250
Kommos, Crete	Space 25B Tr.66B	charcoal	*Cupressaceae sp.*?*	3429
Kommos, Crete				11833
Kommos, Crete				11944
Kommos, Crete	K85A/62D/9:92	charcoal	*Quercus sp.*	11251
Kommos, Crete	K85A/66B/4:22+23	charred twig		11252
Kommos, Crete	K85A/62D/8:83	charcoal	*Quercus sp.*	11253
Kommos, Crete	38/TP-KC-22	charcoal		10731
Trianda, Rhodes	34/AE1024/A rings 21-30 (bark)	charcoal	*Quercus sp.*	10728
Trianda, Rhodes	34/AE1024/B rings 11-20	charcoal	*Quercus sp.*	10729
Trianda, Rhodes	36/AE1024/C rings 1 (pith) – 10	charcoal	*Quercus sp.*	10730
Trianda, Rhodes	34/AE1024/A rings 21-30 (bark)	charcoal	*Quercus sp.*	11945
Trianda, Rhodes	34/AE1024/B rings 11-20	charcoal	*Quercus sp.*	11946
Trianda, Rhodes	36/AE1024/C rings 1 (pith) -10	charcoal	*Quercus sp.*	11948
Miletos, Turkey	AT 99.915	bone	sheep/goat	11951
Miletos, Turkey	AT 99.811	bone	sheep/goat	11954
Trianda, Rhodes	Trianda 13	charred twig	*Quercus sp.*	10643
Trianda, Rhodes	Trianda 13	charred twig	*Quercus sp.*	11884
Akrotiri, Thera	M2/76 N003	charred seed	? *Lathyrus sp.*	11817
Akrotiri, Thera	M7/68A N004	charred seed	*Hordeum sp.*	11818
Akrotiri, Thera	M10/23A N012	charred seed	*Hordeum sp.*	11820
Akrotiri, Thera	M31/43 N047	charred seed	*Hordeum sp.*	11869
Akrotiri, Thera	M2/76 N003	charred seed	? *Lathyrus sp.*	12170
Akrotiri, Thera	M7/68A N004	charred seed	*Hordeum sp.*	12171
Akrotiri, Thera	M31/43 N047	charred seed	*Hordeum sp.*	12172
Akrotiri, Thera	M10/23A N012	charred seed	*Hordeum sp.*	12175
Khania	15/TR10,Rm E	charred seed	*Pisum sativum*	2517
Khania	13/TR17,1984,Rm C	charred seed	*Vicia faba*	2518
Khania	14/TR17,1984,Rm C	charred seed	*Hordeum sp.*	2646
Khania	16/TR24,1989,L6,BA1	charred seed		2647
Khania	13/TR17,1984,Rm C	charred seed	*Vicia faba*	10320
Khania	14/TR17,1984,Rm C	charred seed	*Hordeum sp.*	10321
Khania	15/TR10,Rm E	charred seed	*Pisum sativum*	10322

VERA	Hd	BETA	^{14}C BP	±1σ	Phase
			3550	45	LMIA(early)**
	22037		3552	19	
			3350	70	LMIA(early)
			3485	33	LMIA(early)
			3435	25	LMIA(early)
			3505	40	LMIA(early)
2636			3445	25	
			3375	45	LMIA(early)
2637			3390	20	
			3397	38	LMIA(early)
2638			3600	19	
			3450	45	LMIA(early)
			3455	45	Late MB/ LMIA(early)
			3410	45	Late MB/ LMIA(early)
			3490	45	Late MB/ LMIA(early)
			3473	24	Late MB/ LMIA(early)
2740			3481	32	
			3474	24	Late MB/ LMIA(early)
2741			3485	28	
			3526	25	Late MB/ LMIA(early)
2742			3476	28	
			3423	23	LMIA
			3377	24	LMIA
			3367	39	LMIA(late)
			3344	32	LMIA(late)
			3348	31	LMIA(VDL)
			3367	33	LMIA(VDL)
			3400	31	LMIA(VDL)
			3336	34	LMIA(VDL)
			3336	28	LMIA(VDL)
2757			3315	31	
repeat			3390	32	
			3372	28	LMIA(VDL)
2758			3339	28	
repeat			3322	32	
			3321	32	LMIA(VDL)
2756			3317	28	
			3318	28	LMIA(VDL)
			3380	80	LMIB
			3340	80	LMIB
			3315	70	LMIB
			3315	70	LMIB
			3208	26	LMIB
			3268	27	LMIB
			3338	26	LMIB

Site	Submitter's reference	Material	Species	OxA
Khania	16/TR24,1989,L6,BA1	charred seed		10323
Myrtos-Pyrgos	17/K5,2,1	charred seed	*Hordeum sp.*	3187
Myrtos-Pyrgos	18/K5,2,4	charred seed	*Hordeum sp.*	3188
Myrtos-Pyrgos	19/K5/K6,2,1	charred seed	*Vicia ervilia*	3189
Myrtos-Pyrgos	20/K5/L6,2,2	charred seed	*Vicia ervilia*	3225
Myrtos-Pyrgos	17/K5,2,1	charred seed	*Hordeum sp.*	10324
Myrtos-Pyrgos	19/K5/K6,2,1	charred seed	*Vicia ervilia*	10325
Myrtos-Pyrgos	20/K5/L6,2,2	charred seed	*Vicia ervilia*	10326
Myrtos-Pyrgos	18/K5,2,4	charred seed	*Hordeum sp.*	10411
Mochlos	B.kiln.2910	olive stone		
Mochlos	A.2.212	olive stone		
Mochlos	B.kiln.2801	olive stones		
Mochlos	B.9.1705	olive stone		
Mochlos	A.pit.2315N	olive stone		

Table 1. Radiocarbon data employed in this paper (Data from Manning *et al.* (2006a: Table S1) and (for the Mochlos data) Soles (2004a)). Samples employed meet one of the following three criteria: 1. Data on wood-charcoal samples from secure early or earlier Late Minoan IA (or MBA to early Late Minoan IA – hence still clearly a terminus post quem for the early LMIA time period) contexts which either set terminus post quem age ranges for these contexts or could date as recently as to this context (if a shorter-lived wood sample, or outer tree-rings) but no later than early or earlier Late Minoan IA (or MM IIIB to early LM IA following Girella 2007). These define Condition 1 – see text. 2. Data on short or shorter-lived samples from secure subsequent mature-late Late Minoan IA contexts which clearly post-date the early or earlier Late Minoan contexts, and which can thus all be held to provide a terminus ante quem range for the early to earlier Late Minoan IA time interval which is the object of the present investigation. These define Condition 2 – see text. 3. Data on short-lived sample matter from secure subsequent (again) Late Minoan IB destruction contexts on Crete – the phasings as Late Minoan IB Late (for the Myrtos-Pyrgos destruction) and Late Minoan IB Final (for the Mochlos destruction) follow the scheme of Rutter (forth.) – for more details and discussion, see also the paper of Manning, this volume. These further define Condition 2. These constrain Condition 2 and reinforce the terminus ante quem range for the early to earlier Late Minoan IA time interval. They are referred to as Condition 2+. The Condition 2 and Condition 2+ TAQ samples are shaded light grey.

*We note a correction to previous publications where the sample Space 25B Tr.66B was by mistake labeled as *chamaecyparis sp.* – false cypress. This is a species not found on pre-modern Crete – whereas we assume it should instead be labelled *cupressus sp.* (for the Cretan Cypress, see: Rackham & Moody 1996: 60), and we here use a generic description of *cupressaceae sp.* ** The Table employs LM IA (early) as used at Kommos following Van de Moortel (1997, *etc*); this period is also referred to as MM IIIB by others (Girella 2007).

data to be employed in this analysis are set out in Table 1.

Where radiocarbon dating was undertaken more than once on the exact same charcoal sample or sub-set of tree-rings, then these multiple measurements are combined (weighted average). Where short-lived sample material all derives from what is considered in archaeological terms to be exactly the same short temporal horizon – *e.g.* a destruction horizon – then these are combined (weighted average). A Chi-squared test allows for an assessment of whether the data are consistent with this hypothesis of all the data being potentially contemporary.[18] Otherwise the data are left un-com-

[18] Ward & Wilson 1978.

VERA	Hd	BETA	^{14}C BP	±1σ	Phase
			3253	25	LMIB
			3230	70	LMIB Late
			3200	70	LMIB Late
			3270	70	LMIB Late
			3160	80	LMIB Late
			3270	26	LMIB Late
			3228	26	LMIB Late
			3227	25	LMIB Late
			3150	40	LMIB Late
		85991	3240	50	LMIB Final
		85992	3180	40	LMIB Final
		115890	3170	60	LMIB Final
		129765	3220	40	LMIB Final
		151768	3270	40	LMIB Final

bined in a Phase (*e.g.* the data from Late Minoan IB Khania).[19]

The analyses

Figs 1 and 3 show the full Analysis Model, with the radiocarbon dates on the early to earlier Late Minoan IA period charcoal samples defining either a *terminus post quem,* or a date for, the real time period occupying the span of early or earlier Late Minoan IA (or MM IIIB to early LM IA following Girella 2007) to before mature to late Late Minoan IA (a Boundary labelled "Early – Mature/Late LM IA"). And, on the other side, the radiocarbon dates on shorter or short-lived sample matter from mature to late Late Minoan IA contexts, and then from Late Minoan IB destruction contexts, define the lower extent of this real time interval by defining a *terminus ante quem* for the target date range defined as the Boundary labelled "Early – Mature/Late LM IA". Fig. 1 shows the analysis employing the current IntCal04 radiocarbon calibration dataset;[20] for comparison, Fig. 3 shows the analysis employing the previous (similar underlying data for this period, but less smoothed) IntCal98 radiocarbon dataset.[21] Agreement for the Analysis Model overall, and for the individual elements within the model, is good.

Figs 2 and 4 show the calculated date range for the target Boundary labelled "Early – Mature/Late LM IA" in detail. The calendar age range determined with the IntCal04 calibration dataset is 1732-1702 Cal BC at 1σ (68.2% confidence) and 1742-1682 Cal BC at 2σ (95.4% confidence). The calendar age range determined with the previous IntCal98 calibration dataset is very similar: 1731-1701 Cal BC at 1σ and 1741-1678 Cal BC at 2σ.

We have noted above that some scholars have expressed concerns about whether (some or all) samples from Santorini may have somehow been affected by radiocarbon-depleted volcanic source CO_2, or similar issues (and thus be apparently too old). We see no evidence to support this case for the samples recently published and analyzed,[22] but, nonetheless, we acknowledge that the concern exists in the minds of some scholars. Therefore, let us consider also a Modified Analysis Model which employs *no data at all* from Santorini – and instead only has data from

[19] For further discussion of the analysis of these data, see Manning *et al.* 2006a; and Manning this volume.
[20] Reimer *et al.* 2004.
[21] Stuiver *et al.* 1998.
[22] Friedrich *et al.* 2006; 2009; Manning *et al.* 2006a; 2009.

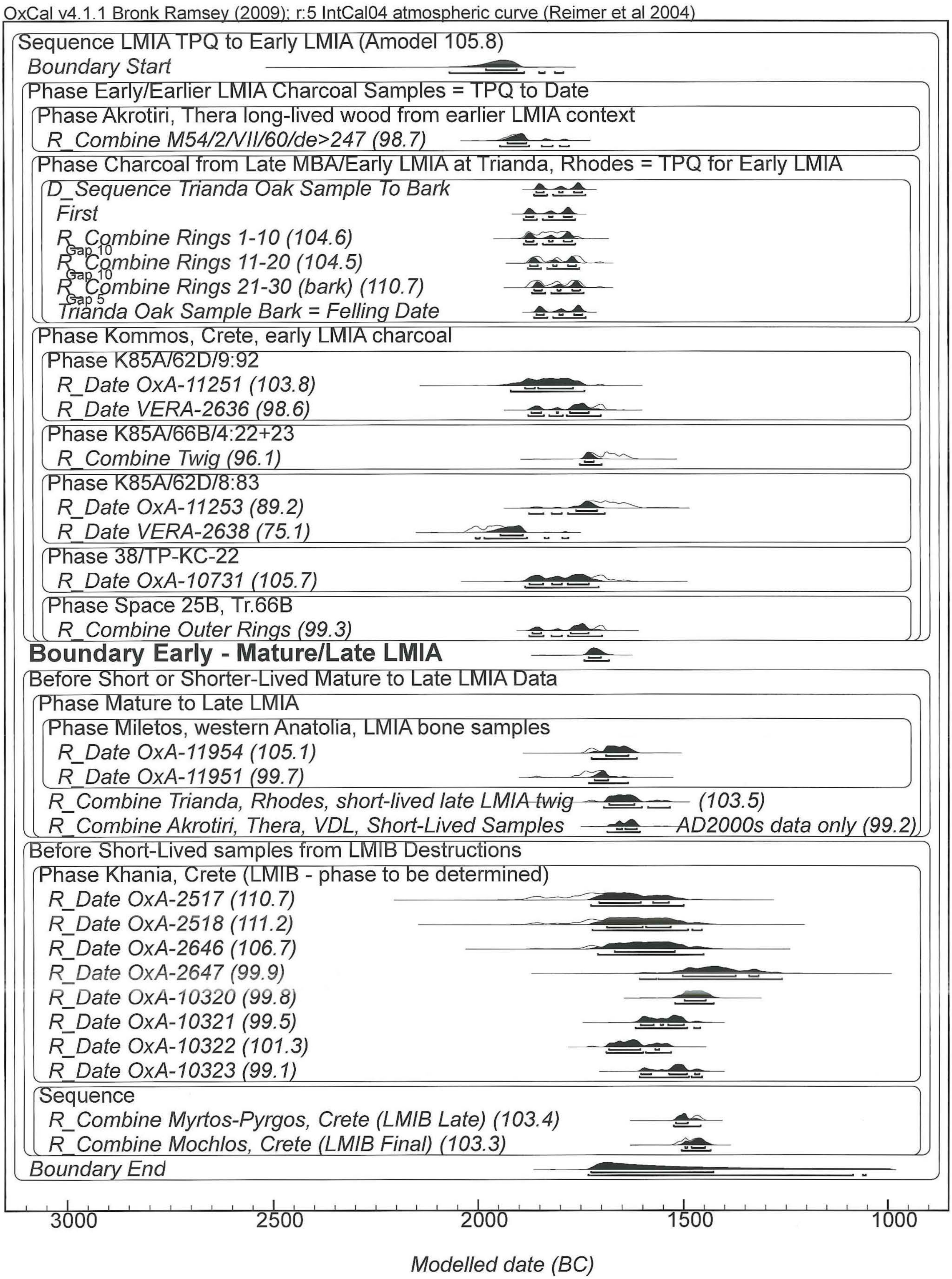

OxCal v4.1.1 Bronk Ramsey (2009); r:5 IntCal04 atmospheric curve (Reimer et al 2004)
Sequence LMIA TPQ to Early LMIA (Amodel 105.8)
Boundary Start
Phase Early/Earlier LMIA Charcoal Samples = TPQ to Date
Phase Akrotiri, Thera long-lived wood from earlier LMIA context
R_Combine M54/2/VII/60/de>247 (98.7)
Phase Charcoal from Late MBA/Early LMIA at Trianda, Rhodes = TPQ for Early LMIA
D_Sequence Trianda Oak Sample To Bark
First
R_Combine Rings 1-10 (104.6)
Gap 10
R_Combine Rings 11-20 (104.5)
Gap 10
R_Combine Rings 21-30 (bark) (110.7)
Gap 5
Trianda Oak Sample Bark = Felling Date
Phase Kommos, Crete, early LMIA charcoal
Phase K85A/62D/9:92
R_Date OxA-11251 (103.8)
R_Date VERA-2636 (98.6)
Phase K85A/66B/4:22+23
R_Combine Twig (96.1)
Phase K85A/62D/8:83
R_Date OxA-11253 (89.2)
R_Date VERA-2638 (75.1)
Phase 38/TP-KC-22
R_Date OxA-10731 (105.7)
Phase Space 25B, Tr.66B
R_Combine Outer Rings (99.3)
Boundary Early - Mature/Late LMIA
Before Short or Shorter-Lived Mature to Late LMIA Data
Phase Mature to Late LMIA
Phase Miletos, western Anatolia, LMIA bone samples
R_Date OxA-11954 (105.1)
R_Date OxA-11951 (99.7)
R_Combine Trianda, Rhodes, short-lived late LMIA twig (103.5)
R_Combine Akrotiri, Thera, VDL, Short-Lived Samples AD2000s data only (99.2)
Before Short-Lived samples from LMIB Destructions
Phase Khania, Crete (LMIB - phase to be determined)
R_Date OxA-2517 (110.7)
R_Date OxA-2518 (111.2)
R_Date OxA-2646 (106.7)
R_Date OxA-2647 (99.9)
R_Date OxA-10320 (99.8)
R_Date OxA-10321 (99.5)
R_Date OxA-10322 (101.3)
R_Date OxA-10323 (99.1)
Sequence
R_Combine Myrtos-Pyrgos, Crete (LMIB Late) (103.4)
R_Combine Mochlos, Crete (LMIB Final) (103.3)
Boundary End
3000
2500
2000
1500
1000
Modelled date (BC)

Fig. 1 (opposite). Analysis of an archaeological sequence aimed at determining the age range for a chronological period running from early/earlier Late Minoan IA (or MM IIIB to early LM IA following Girella 2007) to before points in mature and late Minoan IA. That is after or from the terminus post quem data from early/earlier Late Minoan IA contexts (or MM IIIB to early LM IA following Girella 2007) and before the data contemporary with mature or late Late Minoan IA contexts (themselves before data contemporary with several Late Minoan IB destruction contexts). This target date range to be modelled is defined as the Boundary "Early – Mature/Late LM IA". The Figure shows the full model (the Analysis Model – see text) and all the constituent elements. Fig. 2 shows in detail the modelled age range for the Boundary "Early – Mature/Late LM IA" – which is the aim of this paper. The hollow (outline) distributions show the calibrated ages for each individual sample or date (where a weighted average) on its own; the solid black distributions within these show the calculated ranges applying the Bayesian model based on the known sequence order: Condition 1 ≥ Target Date Range = Boundary "Early – Mature/Late LM IA" > Condition 2 > Condition 2+ (see text). The horizontal lines under each distribution indicate the 1σ and 2σ confidence calibrated calendar age ranges using IntCal04 and OxCal version 4.1.1 with curve resolution set at 5. Each run of such an analysis produces very slightly different results – a typical outcome is shown. The OxCal agreement index offers a test for problems and outliers. 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.

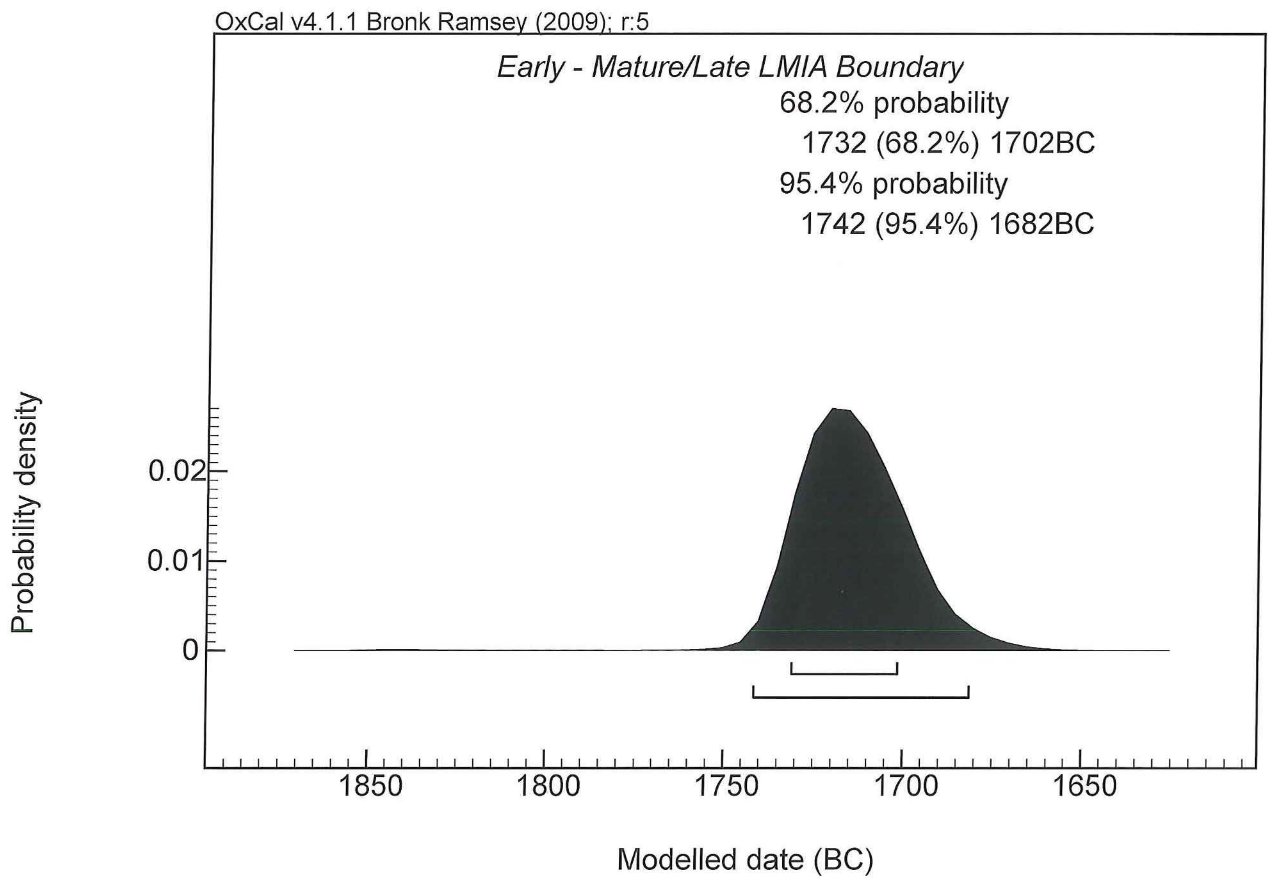
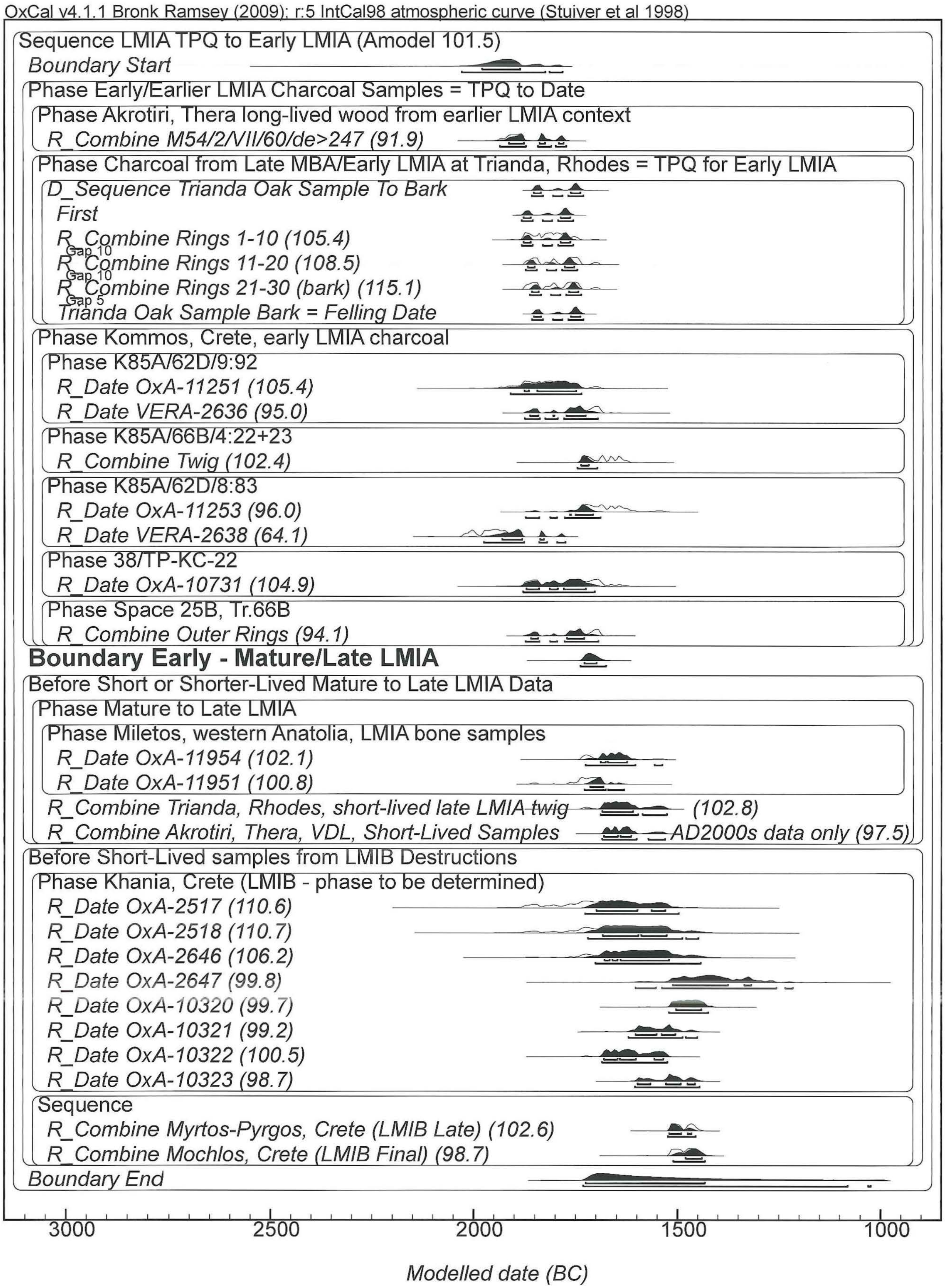


Fig. 2. Detail of the target date range (early/earlier Late Minoan IA – or MM IIIB to early LM IA following Girella 2007 – and before points in Mature – Late/Late Minoan IA) represented by the Boundary "Early – Mature/Late LM IA" from Fig. 1.



OxCal v4.1.1 Bronk Ramsey (2009); r:5 IntCal98 atmospheric curve (Stuiver et al 1998)
Sequence LMIA TPQ to Early LMIA (Amodel 101.5)
Boundary Start
Phase Early/Earlier LMIA Charcoal Samples = TPQ to Date
Phase Akrotiri, Thera long-lived wood from earlier LMIA context
R_Combine M54/2/VII/60/de>247 (91.9)
Phase Charcoal from Late MBA/Early LMIA at Trianda, Rhodes = TPQ for Early LMIA
D_Sequence Trianda Oak Sample To Bark
First
R_Combine Rings 1-10 (105.4)
Gap 10
R_Combine Rings 11-20 (108.5)
Gap 10
R_Combine Rings 21-30 (bark) (115.1)
Gap 5
Trianda Oak Sample Bark = Felling Date
Phase Kommos, Crete, early LMIA charcoal
Phase K85A/62D/9:92
R_Date OxA-11251 (105.4)
R_Date VERA-2636 (95.0)
Phase K85A/66B/4:22+23
R_Combine Twig (102.4)
Phase K85A/62D/8:83
R_Date OxA-11253 (96.0)
R_Date VERA-2638 (64.1)
Phase 38/TP-KC-22
R_Date OxA-10731 (104.9)
Phase Space 25B, Tr.66B
R_Combine Outer Rings (94.1)
Boundary Early - Mature/Late LMIA
Before Short or Shorter-Lived Mature to Late LMIA Data
Phase Mature to Late LMIA
Phase Miletos, western Anatolia, LMIA bone samples
R_Date OxA-11954 (102.1)
R_Date OxA-11951 (100.8)
R_Combine Trianda, Rhodes, short-lived late LMIA twig (102.8)
R_Combine Akrotiri, Thera, VDL, Short-Lived Samples AD2000s data only (97.5)
Before Short-Lived samples from LMIB Destructions
Phase Khania, Crete (LMIB - phase to be determined)
R_Date OxA-2517 (110.6)
R_Date OxA-2518 (110.7)
R_Date OxA-2646 (106.2)
R_Date OxA-2647 (99.8)
R_Date OxA-10320 (99.7)
R_Date OxA-10321 (99.2)
R_Date OxA-10322 (100.5)
R_Date OxA-10323 (98.7)
Sequence
R_Combine Myrtos-Pyrgos, Crete (LMIB Late) (102.6)
R_Combine Mochlos, Crete (LMIB Final) (98.7)
Boundary End
3000
2500
2000
1500
1000
Modelled date (BC)

Fig. 3 (opposite). As Fig. 1 but employing IntCal98.

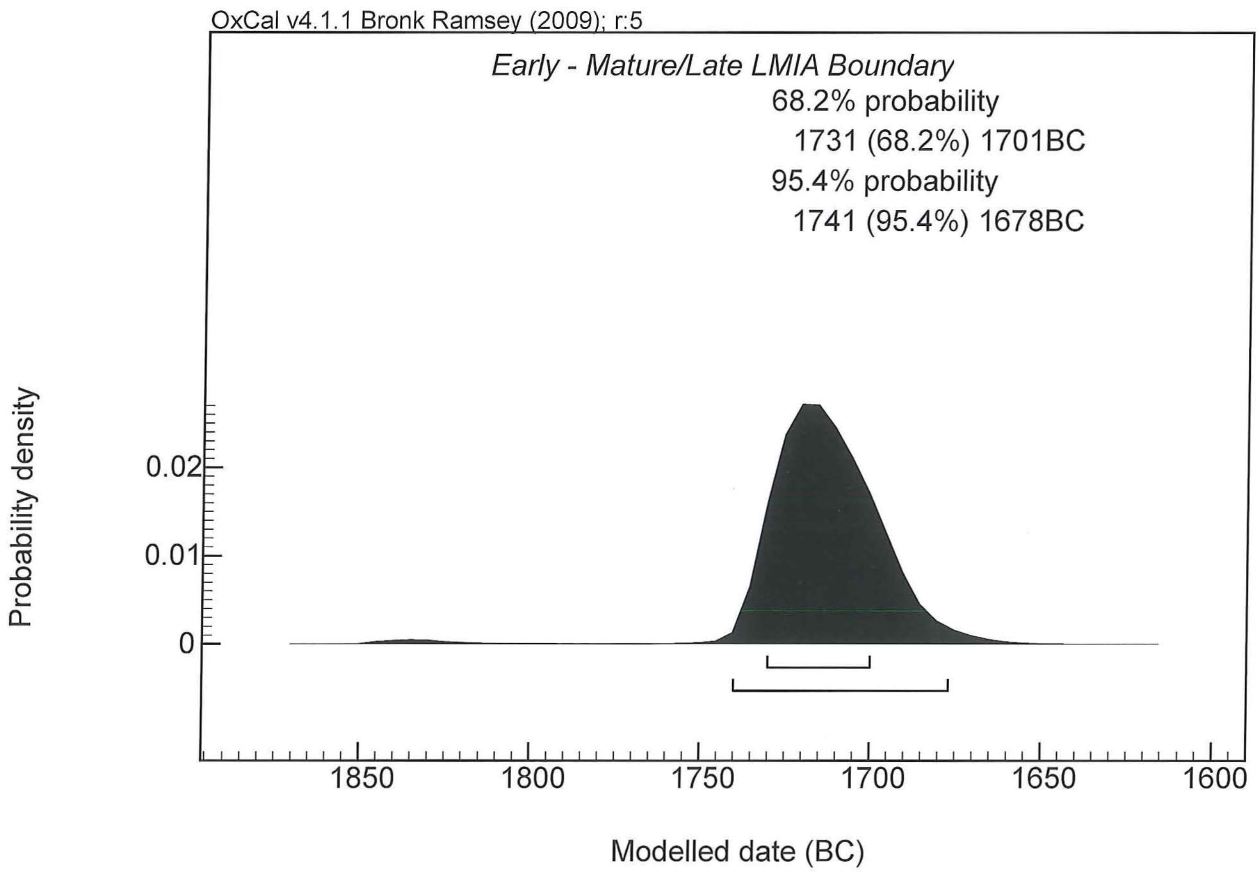


Fig. 4. Detail of the target date range (early/earlier Late Minoan IA – or MM IIIB to early LM IA following Girella 2007 – and before points in Mature-Late/Late Minoan IA) represented by the Boundary "Early – Mature/Late LM IA" from Fig. 3.

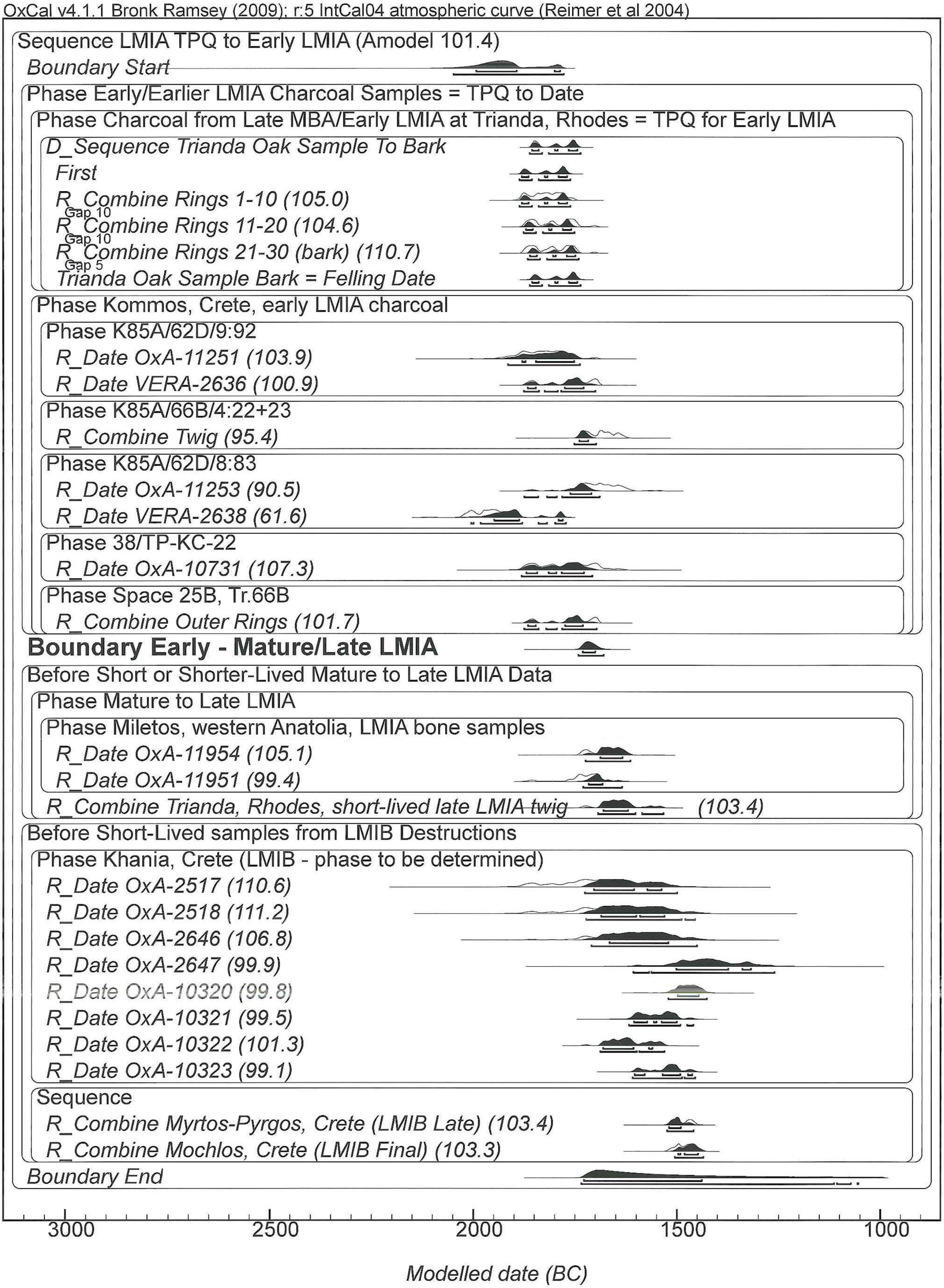

OxCal v4.1.1 Bronk Ramsey (2009); r:5 IntCal04 atmospheric curve (Reimer et al 2004)
Sequence LMIA TPQ to Early LMIA (Amodel 101.4)
Boundary Start
Phase Early/Earlier LMIA Charcoal Samples = TPQ to Date
Phase Charcoal from Late MBA/Early LMIA at Trianda, Rhodes = TPQ for Early LMIA
D_Sequence Trianda Oak Sample To Bark
First
R_Combine Rings 1-10 (105.0)
Gap 10
R_Combine Rings 11-20 (104.6)
Gap 10
R_Combine Rings 21-30 (bark) (110.7)
Gap 5
Trianda Oak Sample Bark = Felling Date
Phase Kommos, Crete, early LMIA charcoal
Phase K85A/62D/9:92
R_Date OxA-11251 (103.9)
R_Date VERA-2636 (100.9)
Phase K85A/66B/4:22+23
R_Combine Twig (95.4)
Phase K85A/62D/8:83
R_Date OxA-11253 (90.5)
R_Date VERA-2638 (61.6)
Phase 38/TP-KC-22
R_Date OxA-10731 (107.3)
Phase Space 25B, Tr.66B
R_Combine Outer Rings (101.7)
Boundary Early - Mature/Late LMIA
Before Short or Shorter-Lived Mature to Late LMIA Data
Phase Mature to Late LMIA
Phase Miletos, western Anatolia, LMIA bone samples
R_Date OxA-11954 (105.1)
R_Date OxA-11951 (99.4)
R_Combine Trianda, Rhodes, short-lived late LMIA twig (103.4)
Before Short-Lived samples from LMIB Destructions
Phase Khania, Crete (LMIB - phase to be determined)
R_Date OxA-2517 (110.6)
R_Date OxA-2518 (111.2)
R_Date OxA-2646 (106.8)
R_Date OxA-2647 (99.9)
R_Date OxA-10320 (99.8)
R_Date OxA-10321 (99.5)
R_Date OxA-10322 (101.3)
R_Date OxA-10323 (99.1)
Sequence
R_Combine Myrtos-Pyrgos, Crete (LMIB Late) (103.4)
R_Combine Mochlos, Crete (LMIB Final) (103.3)
Boundary End
3000
2500
2000
1500
1000
Modelled date (BC)

Fig. 5 (opposite). As Fig. 1 but with no data from Santorini, and employing IntCal04. Modified Analysis Model – see text.

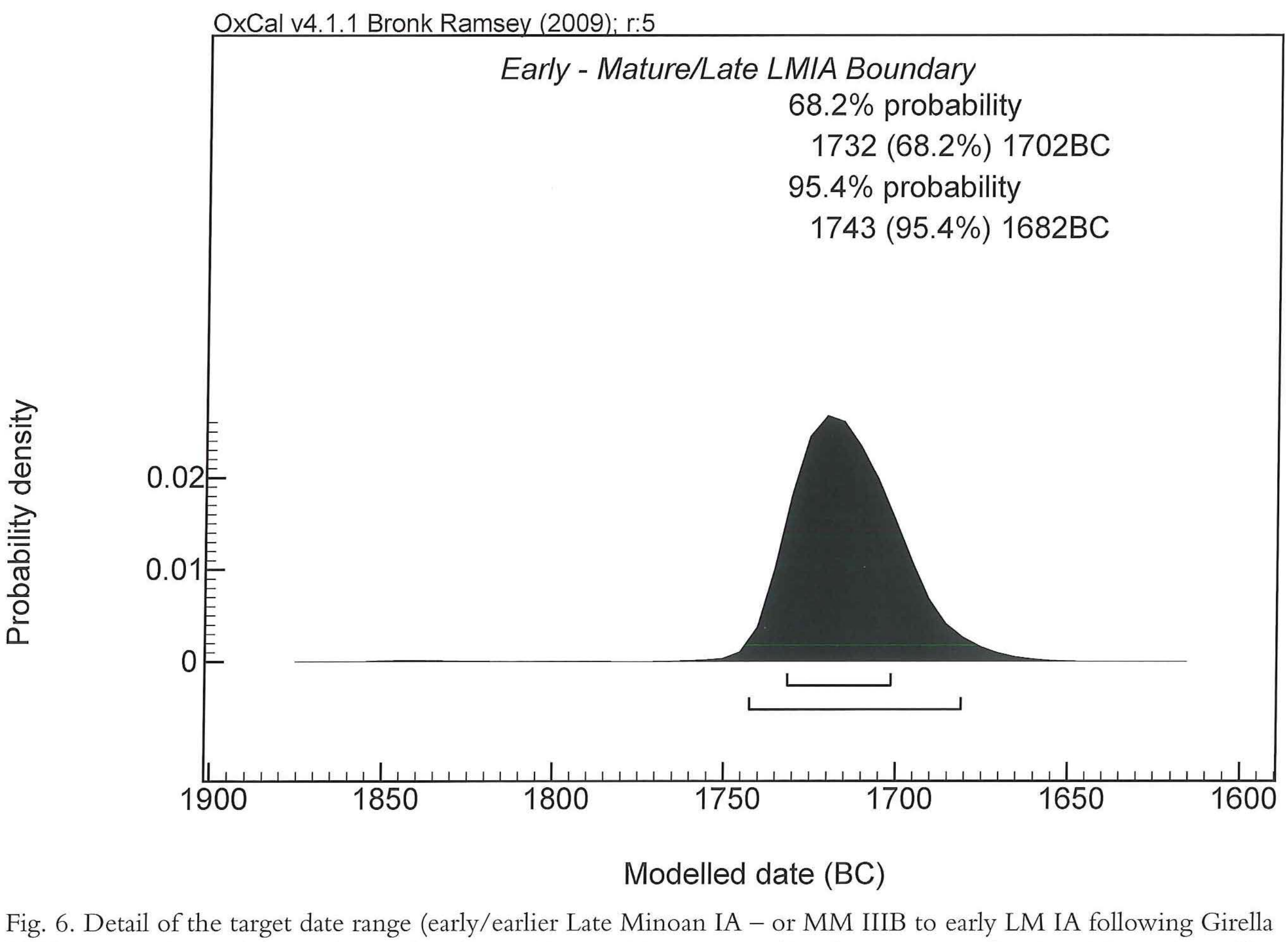
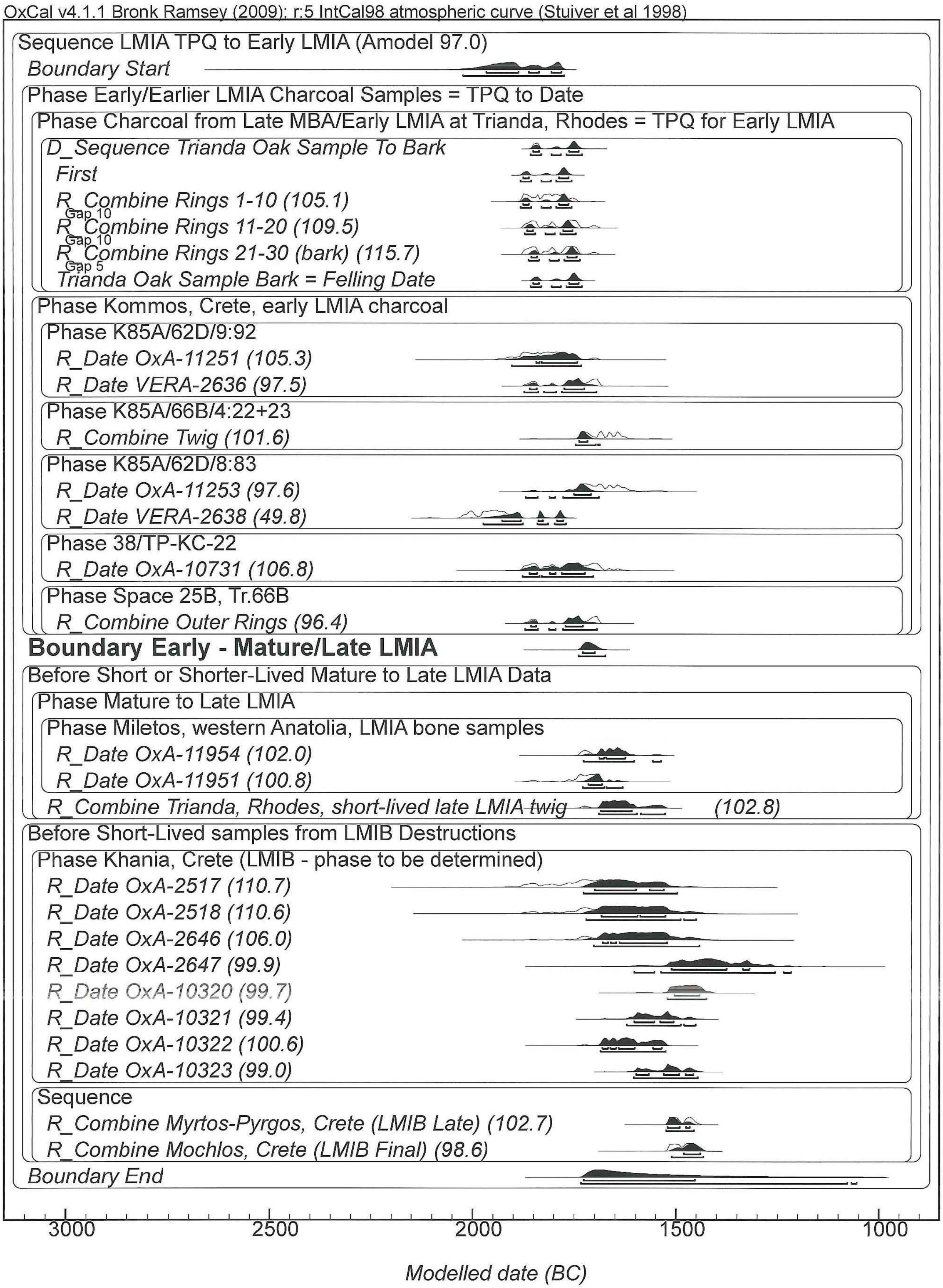


Fig. 6. Detail of the target date range (early/earlier Late Minoan IA – or MM IIIB to early LM IA following Girella 2007 – and before points in Mature-Late/Late Minoan IA) represented by the Boundary "Early – Mature/Late LM IA" from Fig. 5.



OxCal v4.1.1 Bronk Ramsey (2009); r:5 IntCal98 atmospheric curve (Stuiver et al 1998)
Sequence LMIA TPQ to Early LMIA (Amodel 97.0)
Boundary Start
Phase Early/Earlier LMIA Charcoal Samples = TPQ to Date
Phase Charcoal from Late MBA/Early LMIA at Trianda, Rhodes = TPQ for Early LMIA
D_Sequence Trianda Oak Sample To Bark
First
R_Combine Rings 1-10 (105.1)
Gap 10
R_Combine Rings 11-20 (109.5)
Gap 10
R_Combine Rings 21-30 (bark) (115.7)
Gap 5
Trianda Oak Sample Bark = Felling Date
Phase Kommos, Crete, early LMIA charcoal
Phase K85A/62D/9:92
R_Date OxA-11251 (105.3)
R_Date VERA-2636 (97.5)
Phase K85A/66B/4:22+23
R_Combine Twig (101.6)
Phase K85A/62D/8:83
R_Date OxA-11253 (97.6)
R_Date VERA-2638 (49.8)
Phase 38/TP-KC-22
R_Date OxA-10731 (106.8)
Phase Space 25B, Tr.66B
R_Combine Outer Rings (96.4)
Boundary Early - Mature/Late LMIA
Before Short or Shorter-Lived Mature to Late LMIA Data
Phase Mature to Late LMIA
Phase Miletos, western Anatolia, LMIA bone samples
R_Date OxA-11954 (102.0)
R_Date OxA-11951 (100.8)
R_Combine Trianda, Rhodes, short-lived late LMIA twig (102.8)
Before Short-Lived samples from LMIB Destructions
Phase Khania, Crete (LMIB - phase to be determined)
R_Date OxA-2517 (110.7)
R_Date OxA-2518 (110.6)
R_Date OxA-2646 (106.0)
R_Date OxA-2647 (99.9)
R_Date OxA-10320 (99.7)
R_Date OxA-10321 (99.4)
R_Date OxA-10322 (100.6)
R_Date OxA-10323 (99.0)
Sequence
R_Combine Myrtos-Pyrgos, Crete (LMIB Late) (102.7)
R_Combine Mochlos, Crete (LMIB Final) (98.6)
Boundary End
3000
2500
2000
1500
1000
Modelled date (BC)

Fig. 7 (opposite). As Fig. 5 with no data from Santorini but employing IntCal98. Modified Analysis Model – see text.

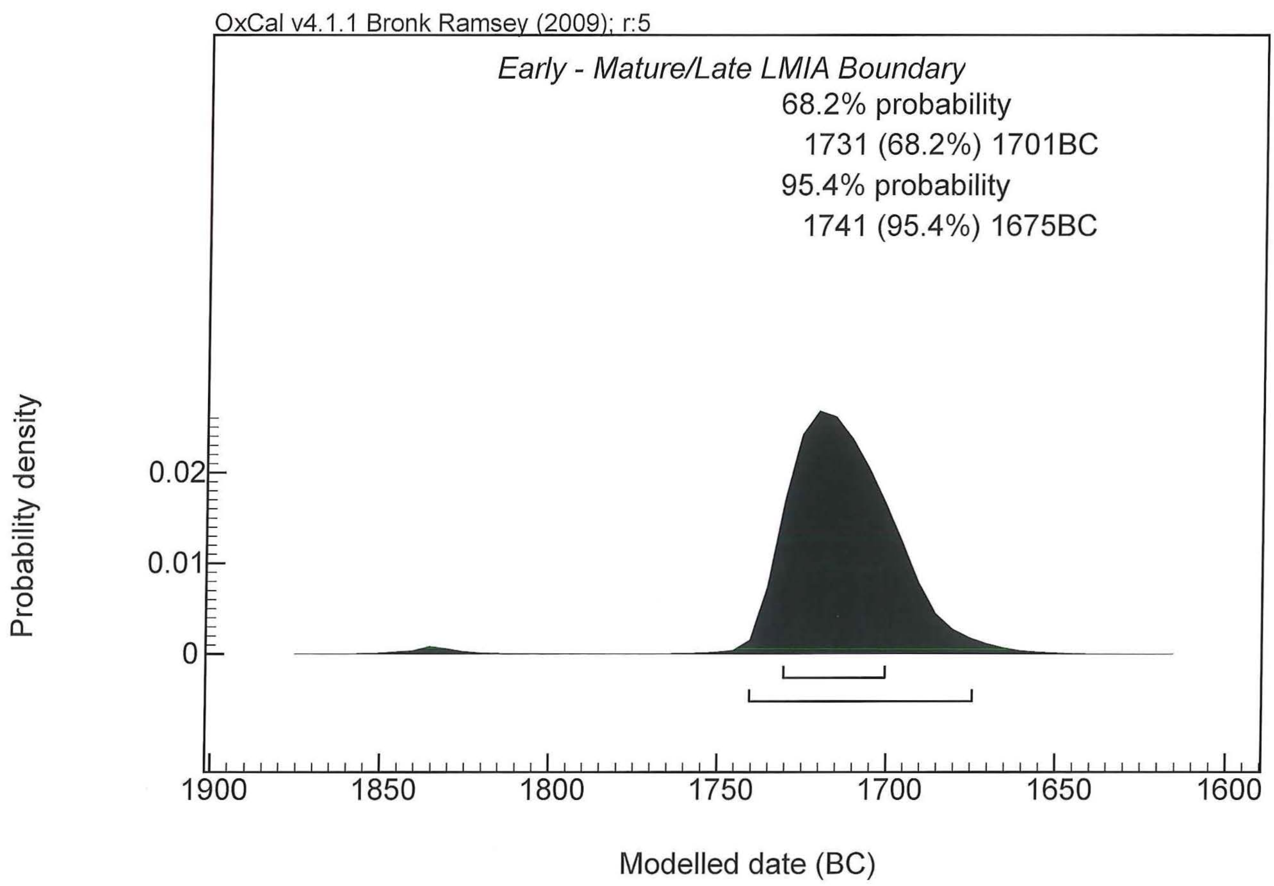


Fig. 8. Detail of the target date range (early/earlier Late Minoan IA – or MM IIIB to early LM IA following Girella 2007 – and before points in Mature-Late/Late Minoan IA) represented by the Boundary "Early – Mature/Late LM IA" from Fig. 7.

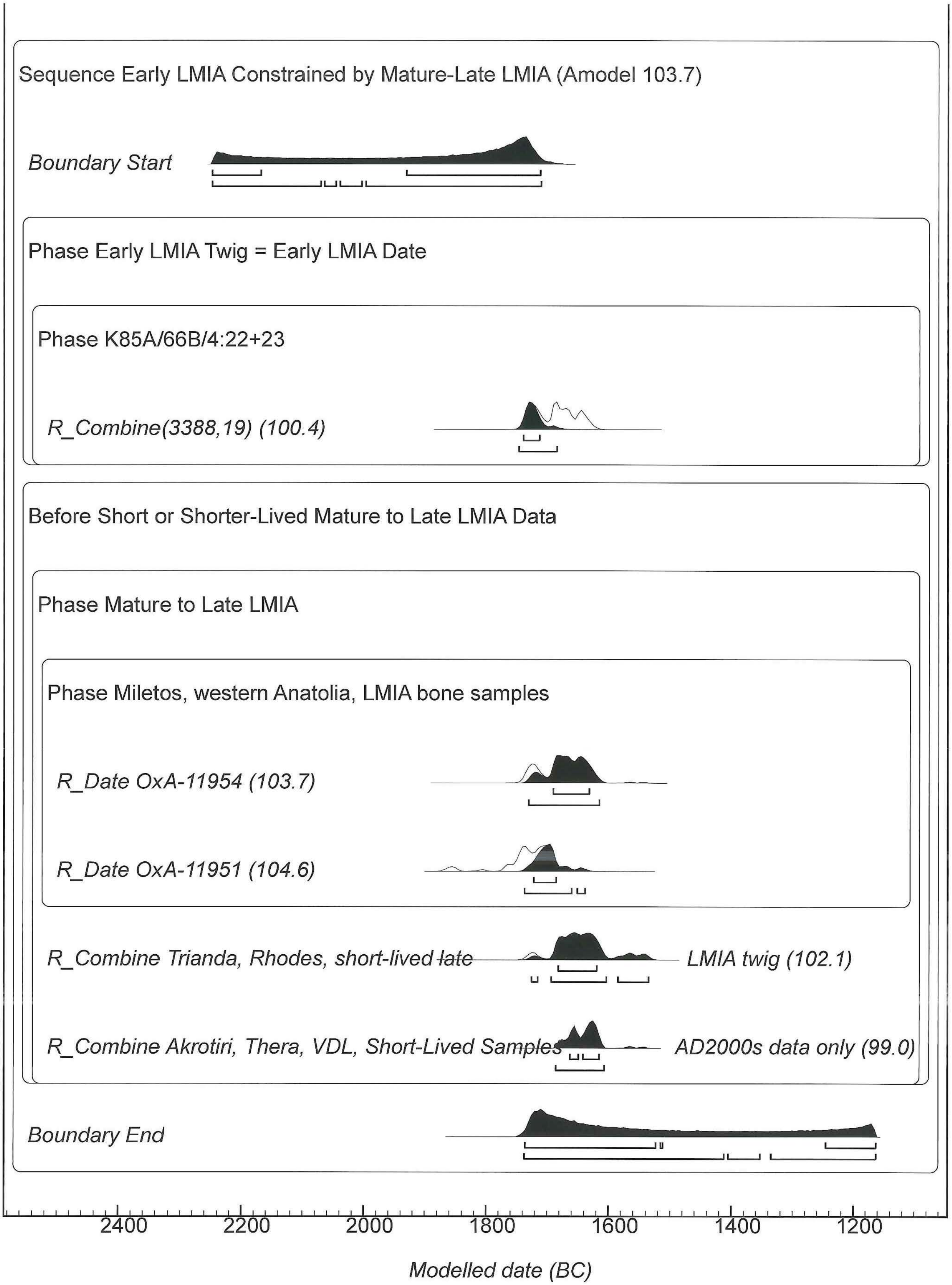

Sequence Early LMIA Constrained by Mature-Late LMIA (Amodel 103.7)
Boundary Start
Phase Early LMIA Twig = Early LMIA Date
Phase K85A/66B/4:22+23
R_Combine(3388,19) (100.4)
Before Short or Shorter-Lived Mature to Late LMIA Data
Phase Mature to Late LMIA
Phase Miletos, western Anatolia, LMIA bone samples
R_Date OxA-11954 (103.7)
R_Date OxA-11951 (104.6)
R_Combine Trianda, Rhodes, short-lived late LMIA twig (102.1)
R_Combine Akrotiri, Thera, VDL, Short-Lived Samples AD2000s data only (99.0)
Boundary End
2400
2200
2000
1800
1600
1400
1200
Modelled date (BC)

Fig. 9 (opposite). Abbreviated version of the Analysis Model (see Fig. 1) to show the modelled date for the twig from the early Late Minoan IA (or MM IIIB to early LM IA following Girella 2007) Kommos context K85A/66B/4: 22+23 given the constraint of the short or shorter-lived data from mature to late Late Minoan IA (which yield ages contemporary with these contexts and thus set a terminus ante quem range for the early Late Minoan IA (or MM IIIB) period date. The modelled calendar date ranges for the twig at 1σ are: 1740-1714 BC and at 2σ: 1747-1685 BC (solid histogram in the figure). Data from IntCal04 and OxCal. For information on how to read the figure, see also the caption to Fig. 1. Without the modelling (that is without the application of the constraints because of the mature to late Late Minoan IA data), the calibrated calendar age range for this early Late Minoan IA (or MM IIIB) twig are 1σ: 1736-1713 BC (24.9%), 1695-1663 BC (34.6%) and 1651-1641 BC (8.7%) and 2σ: 1741-1631 BC (hollow histogram in the figure). Even "raw", and without any Bayesian analysis (and with no input from any sample from Santorini), this date range indicates that a point in early Late Minoan IA (or MM IIIB) lies no later than 1641 BC (1σ) or 1631 BC (2σ), and, more likely, that such a point in early Late Minoan IA (or MM IIIB to early LM IA following Girella 2007) in fact lies somewhere *c.*1736-1663 BC (taking the main 59.5% sub-ranges of the 1σ range). These dates (whether for Early LM IA, Kommos definition, or MM IIIB following Girella 2007) require a "High" or "Long" Aegean chronology.

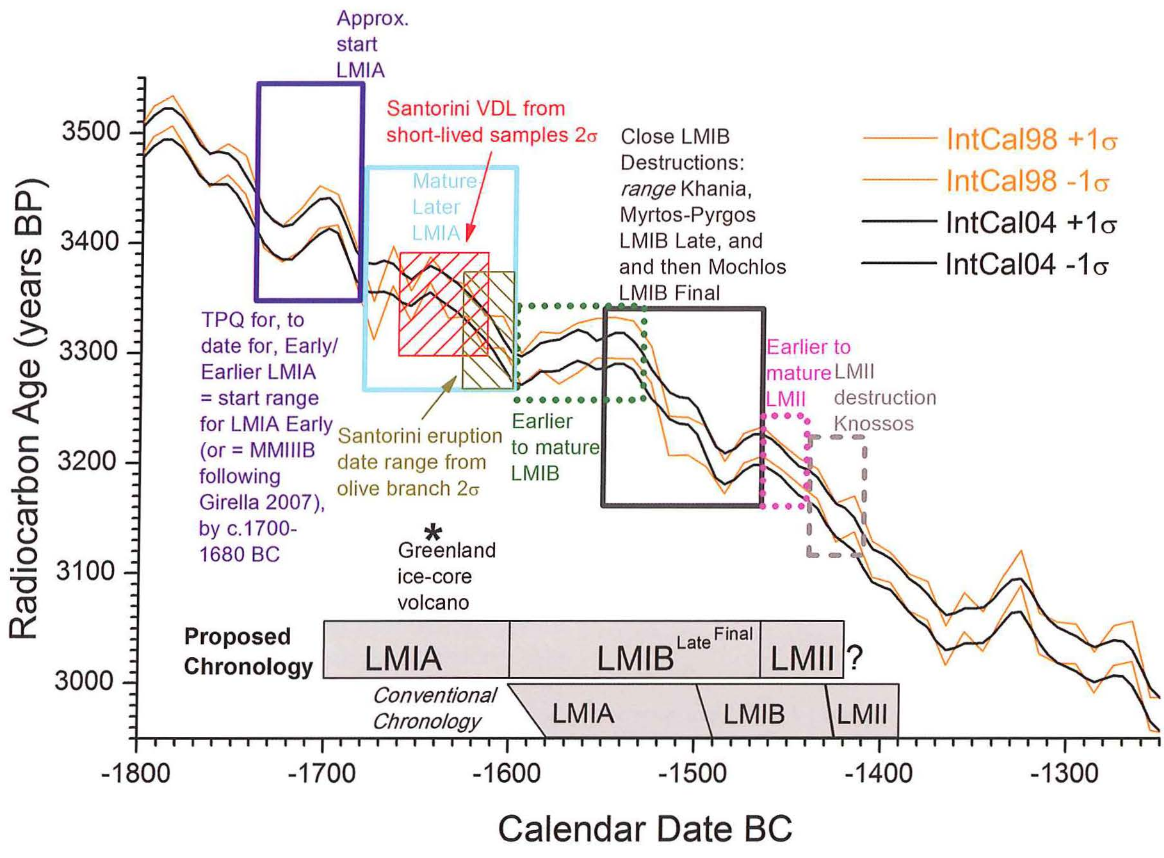


Fig. 10. Schematic representation of Late Minoan IA to Late Minoan II absolute chronology, and the major radiocarbon-dated periods or episodes, set against the radiocarbon calibration curve (both IntCal04 and IntCal98) on the basis of the analyses in this paper, along with those in other recent papers. The approximate proposed overall absolute chronology for Late Minoan IA to Late Minoan II based primarily on the radiocarbon evidence is shown below, and compared to the conventional chronology. VDL = volcanic destruction level at Akrotiri. The date of the end of the Late Minoan II period could perhaps be another *c.* 10 years later (and we presently lack good Late Minoan IIIA1 or Late Helladic IIIA1 radiocarbon evidence to offer clarification). This would indeed seem helpful if the new revised Egyptian chronology (Krauss & Warburton this volume) is accepted (and the dates for Thutmose III are lowered 11 years). Note: if the Girella (2007) scheme is employed, then the time range down to about 1685/1680 BC (see Fig. 9 and footnote 23) could be labelled as Middle Minoan IIIB.

sites on Crete, Rhodes and West Anatolia. These locations are all well away from Santorini (over 100 km to over 200 km away), and it is implausible that plants or animals in these locations were affected in any substantive way by pre- or post- eruption CO_2 emissions on Santorini. Figs 5 and 7 show the Modified Analysis Model with no Santorini data, with the calibrated calendar date ranges determined against the IntCal04 and IntCal98 datasets respectively. Figs 6 and 8 show the target Boundary labelled "Early – Mature/Late LM IA" in detail for these analyses with no data from Santorini. Agreement for the Modified Analysis Model overall, and for the individual elements within the model, is good, with just one sample being somewhat inconsistent (too old) when employing IntCal98 (VERA-2638, agreement index value of 49.8 < 60). The calendar age range determined with the IntCal04 calibration dataset is 1732-1702 Cal BC at 1σ and 1743-1682 Cal BC at 2σ. The calendar age range determined with the previous IntCal98 calibration dataset is very similar: 1731-1701 Cal BC at 1σ and 1741-1675 Cal BC at 2σ.

Discussion

It is noticeable that the dating outcomes for the Boundary "Early – Mature/Late LM IA" from both the full Analysis Model, and from the Modified Analysis Model with no data from Santorini, are almost identical. Thus the age ranges determined are clearly robust and stable, and in no way affected by supposed effects from volcanic CO_2 emissions or any other Santorini specific factors which might be suggested or hypothesized. This dated time interval is defined as *after* either the *terminus post quem* or direct dating (if outer tree-rings were dated, or wood samples with relatively few constituent tree-rings: see Fig. 9) evidence of the charcoal samples from early or earlier Late Minoan IA contexts (or MMIIIB to early LMIA following Girella 2007), and *before* the short or shorter-lived dating evidence for Mature – Late/Late Minoan IA, and in turn the short-lived dating evidence from the Late Minoan IB destructions.[23] The analyses considered in this paper thus provide good evidence for the dating of the early/earlier Late Minoan IA period from, or around, the start of the 17th century BC.

The data and analyses considered in this paper provide support for the so-called "High"or "Early" or "Long" Aegean chronology.[24] They indicate this finding whether or not any of the radiocarbon data from Santorini are included. Thus this date finding cannot be questioned on the basis that somehow the Santorini volcano affected samples and measured ages there. Instead, the fact that these data – with or without the Santorini samples – find a chronology consistent with the dates provided by the Santorini samples, would indicate that it is likely that the Santorini samples also do in fact provide more or less accurate dates. In turn, this situation provides additional support for the likely mid-later 17th

[23] For example, the twig sample from an early Late Minoan IA (or MM IIIB following Girella 2007) context at Kommos (K85A/66B/4: 22+23) might be argued to offer the best evidence for a direct date for some point *in* early Late Minoan IA (or MM IIIB following Girella 2007): the weighted average (3388±19 BP) of the two measurements (in isolation, with no constraints) yields calibrated calendar age ranges with IntCal04 and OxCal of 1σ: 1736-1713 BC (24.9%), 1695-1663 BC (34.6%) and 1651-1641 BC (8.7%) and 2σ: 1741-1631 BC. But, given the date ranges for the short or shorter-lived samples offering dates contemporary with points in mature to late Late Minoan IA (see fig. 1), we can constrain some of the later part of this overall date range. If, for example, the K85A/66B/4: 22+23 date (by itself) is constrained by a *terminus ante quem* from the mature to late Late Minoan IA context shorter or short-lived samples – offering ages contemporary with points in mature to later Late Minoan IA – in a reduced version of the Analysis Model in fig. 1 (leaving out the other early/earlier Late Minoan IA data, and the Late Minoan IB data), then the K85A/66B/4: 22+23 early Late Minoan IA (or MM IIIB following Girella 2007) date becomes – 1σ: 1740-1714 BC and 2σ: 1747-1685 BC: see Fig. 9. These dates are of course entirely compatible with those for the Boundary labelled "Early – Mature/Late LM IA" in the full Analysis Model and Modified Analysis Model (Figs 1–8).

[24] Manning *et al.* 2006a; Manning & Bronk Ramsey 2003; Manning 2007; 1999; 1995, 217–29; 1988.

[25] As Manning *et al.* 2006a; 2009; Friedrich *et al.* 2006; 2009. It remains to be seen whether other possible evidence which might be associated with the eruption of Santorini from ice cores, speliothems, or tree-rings, may yet provide more precise dates (if and when one or more of these signals can be tied specifically to the Minoan erup-

century BC dating of the mature–late Late Minoan IA eruption of the Santorini volcano.[25] Taking the analyses in this paper together with other recent work, a "High" or "Long" primarily radiocarbon-based chronology for the period from Late Minoan IA to Late Minoan II, including a mid-later 17th century BC date for the Minoan eruption of the Santorini volcano, may be described in schematic terms, and shown against the radiocarbon calibration curve(s): see Fig. 10.[26] This approximate chronology is based on a body of direct evidence, and quantified analysis.

Acknowledgements

We thank a reviewer for comments, the editor David Warburton and Erik Hallager.

tion of the Santorini volcano). For the ice core case, see Vinther *et al.* 2006 and especially 2008 (responding to criticism and arguing why Santorini remains a plausible cause or association); for the speliothem evidence to date, see Frisia *et al.* 2008 and Siklósy *et al.* 2009; for tree-rings, see Pearson *et al.* 2009.

[26] Re fig. 10: see Friedrich *et al.* 2006; 2009[; and contributions signed by Friedrich *i.a.* in this volume – note ed.] for the date range of the waney edge – that is the outermost final growth ring under the bark of the olive branch recovered from Minoan eruption pumice on Santorini; Manning *et al.* 2006a for the LM IA to LM II ranges – but as modified for LM IB and II by Manning this volume, and as elaborated in the present paper. The Greenland ice core volcano signal (1642±5 BC), which is suggested to be potentially the Santorini eruption, comes from Vinther *et al.* 2006 (and especially see Vinther *et al.* 2008 with discussion of why those authors maintain the signal could be the Santorini eruption). [For ice cores, *cf.* Muscheler this volume – note ed.]. For the conventional date ranges, see *e.g.* Warren and Hankey 1989, 169; Warren 1984; 1999; 2006; Cadogan 1978; Wiener 2006a. The figure is an up-dated and edited version of Manning *et al.* 2006a, fig. 3.