Thera, the Aegean, Egypt, the Hyksos and Anatolia: rethinking the orthodox synchronisations and histories

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Long story short

The Minoan eruption of the Thera volcano has come to offer a pivotal event in the synchronisation of Aegean and East Mediterranean civilizations. In relative (ceramic) terms the eruption occurred late in or around the end of the Late Minoan (LM) IA period. The date was traditionally placed around 1500 BCE, not from any specific evidence, but because some subsequent (late) LMIB objects were found in Egypt in contexts associated with Tuthmosis III, and, since his reign of almost 54 years was placed, give or take debates of up to 25 years, around the first half of the 15th century BCE, this led to a minimum date for the end of LMIA and Thera conveniently summarized as ca. 1500 BCE (Marinatos 1939; Warren 1984). This placed much of the LMIA period during the earlier New Kingdom. Radiocarbon dates from the 1970s onwards upset this position by suggesting an earlier date for Thera. This raised the prospect of an alternative cultural synchronisation for LMIA (and indeed MMIII-LMIA overall) with the Hyksos era (Second Intermediate Period, SIP): the Aegean high chronology (AHC). The AHC in turn would affect surrounding cultural groups and their dates in the Aegean and East Mediterranean, from Greece to Cyprus (Manning 1999). Much effort has gone into refining the radiocarbon situation. Since 2020 the options are an 'earlier' date maybe 1611 BCE (when a major Northern Hemisphere volcanic eruption is attested in ice-core evidence) or broadly around 1600 BCE (if, for example, the Thera eruption is not represented in the available ice-core evidence investigated so far), and a later date perhaps about 1561 BCE (when another major Northern Hemisphere volcanic eruption is attested in ice-core evidence) (Manning 2022; 2024a; 2024b; Pearson *et al.* 2022; 2023). Either of these dates basically places LMIA contemporary with the Hyksos/SIP (i.e. the point of the AHC critique starting in the 1980s: Kemp and Merrillees 1980; Betancourt 1987; Manning 1988). Overall, the general scope of debate or 'dispute' is much narrowed to around 50 years, versus the gap of over a century in scholarship a couple of decades ago. A re-analysis now of radiocarbon dates recently published on an olive shrub from Therasia likely killed by the Thera eruption (Pearson *et al.* 2023), bringing to bear an appropriate integration of the temporal constraints on these dates from both the growth sequences of the olive branches in question and the contextual circumstance of their common death event (the eruption) (Manning 2024b), along with analysis of the data and temporal sequence in the period between final human occupation and abandonment at Akrotiri on Thera through to the Thera volcanic eruption (Manning 2022; 2024a), suggest to the author that we can in fact more likely resolve the date of the Thera eruption around the earlier date of 1611 BCE (or more broadly around 1600 BCE).

In a paper published in *JGA* 8, Tiziano Fantuzzi, to the contrary, tries largely to argue against the AHC and in favour of a more traditional position – although in an almost inevitable contradiction Fantuzzi ends up favouring a date around 1561 BCE and thus effectively a position that is, in fact, compatible with the original AHC critique and so against the traditional chronology. The present paper critically addresses the evidence and the Fantuzzi paper and lays out why the archaeological

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linkages do not contradict the AHC (and in fact likely support it) and shows how the radiocarbon evidence, appropriately analysed and integrated with the relevant known (prior) botanical-geological-archaeological sequence, defines a date for the Minoan eruption of Thera most likely ca.1611 BCE or broadly around 1600 BCE (with a date around 1561 BCE an unlikely but about the latest even possible alternative). Indeed, if the eruption was ca. 1561 BCE (or for that matter a later date as suggested by some, like 1525 BCE), we can observe that different radiocarbon measurements would be expected for the Therasia olive shrub samples – thus these suggested later Thera eruption dates are not supported by the currently available evidence. Hence, the New Palace Period of Crete likely begins (Middle Minoan, MM, IIIA) in the later 18th century BCE, MMIIIB and LMIA occupy the period through the end of the 17th century BCE (likely, and possibly into the earlier 16th century BCE), and (the long) LMIB period follows, ending in the earlier to mid-15th century BCE (and these dates in turn translate for linked contemporaries in mainland Greece, the Cyclades, Cyprus, etc.). The formation and floruit of New Palace Crete are thus associated with both the dynamic and transformative Hyksos/SIP era in the East Mediterranean (e.g. Mourad 2021) and the formative era leading to the creation of the Old Hittite Kingdom in Anatolia (e.g. Bryce 2005: 61-95; Weeden 2022: 537-550).

Introduction

Radiocarbon and Bayesian chronological modelling are redefining and (re-)forming the basis to a detailed calendar-situated pre- and proto-history, world-wide (just three examples: Birch *et al.* 2021; Whittle 2018; Higham and Higham 2009). On the 'wrong' side of Renfrew's (in)famous 'fault line' (1973: 115-116, Figure 21), the Aegean and East Mediterranean has been something of a hold-out in this most recent radiocarbon revolution (Bayliss 2009). A generation ago, Warren and Hankey (1989: 127) stated: "The radiocarbon dating evidence for Aegean chronology after about 2000 BC is for the most part less precise than dates obtainable from the Egyptian correlations". Although they suggested in the next paragraph that the various problems they saw with radiocarbon "are certainly capable of resolution with future close context collections and high-precision calibration" (Warren and Hankey 1989: 127), it remains true, 35 years later (as I write) and despite many such advances in dating resolution, that radiocarbon continues to be avoided, or treated with suspicion, by many scholars working in the second or first millennium BCE Aegean and East Mediterranean – unless it confirms what is already the standard or orthodox assessment. Suggestions otherwise have long been met with resistance.

A focal point has been the dating of the Minoan eruption of the Thera (Santorini) volcano, placed late in the LMIA period (e.g. Manning 1999). Here, from the mid-1970s onwards, radiocarbon has suggested that the original orthodox date estimate, ca. 1500 BCE, appeared too late. Over five decades the body of radiocarbon data from the Aegean and East Mediterranean has changed and greatly improved, and the radiocarbon calibration curve used to convert radiocarbon measurements into calendar ages has also been improved several times. Accelerator mass spectrometry (AMS) radiocarbon dating fundamentally changed the field, enabling dating of much smaller samples and especially a focus on short-lived sample material likely providing ages directly relevant to archaeological contexts of interest. Recently, the application of high-precision AMS radiocarbon dating to start to create a revised new annual resolution radiocarbon calibration curve, and in particular (as one of the first cases) such work across the period 1700-1480 BCE, has substantially modified the previous state of knowledge as regards the 'Thera debate' (Reimer *et al.* 2020; Pearson *et al.* 2018; 2020; Friedrich *et al.* 2020; van der Plicht *et al.* 2020). Despite on-going debate, the one thing no longer on the table is the original 1500 BCE date. Radiocarbon has pushed the date at least a little earlier, with the new orthodox or 'low' position centring around the mid-16th century BCE and especially a volcanic eruption dated 1561 BCE in ice-core evidence (while still paying lip service to investigation of suggested dates later to the 1520s BC) (Pearson *et al.* 2018; 2022; 2023), and the new 'high' position pointing perhaps to a different volcanic signal dated 1611 BCE in ice-core evidence or otherwise to a most likely radiocarbon-defined range from the late/end 17th to early 16th centuries BCE (Manning 2022; 2024a; 2024b).

But is this much ado about nothing? Why is the date of the Minoan eruption of the Thera volcano important? It does not change the relative relationships established in the Aegean thanks to well over a century of archaeological work. The date is, however, important for two reasons. First: in climate-environmental history terms, a secure date would allow a correct assessment of the impact of this enormous volcanic eruption, perhaps the largest of the last 10,000 years (Johnston *et al.* 2014), in terms of the regional and wider hemisphere/global palaeoclimate/palaeoenvironment (this is not the topic of the present paper). Second (and relevant especially for the present discussion): the correct date for the eruption, and thus also the LMIA (and generally New Palace) period, would permit (i) the correct synchronisation of the Aegean sequences of this era against those in Egypt, the Levant and Anatolia and also (ii) appreciation of the correct calendar scale (length) of the New Palace periods which in turn correctly frames discussions of the nature of social, economic, political, and landscape/environmental change across this era.

The latter, in turn, permits the appropriate assessment of the cultural, political, and economic influences and connections that likely played an important role in shaping the New Palace Aegean world on Crete and its contemporaries on the Mainland (e.g. the Shaft Grave period at Mycenae and other Late Helladic, LH, I Mainland groups of this period) and Islands. Since this era very much represents the beginnings/origins of the epic tradition leading to Homer (Sherratt 1990), it is basic to the construction of Classical Greece and much of the Western tradition – thus an accurate history is important for many topics. If the correct date is not around the traditional range (late/end 16th century BCE to ca. 1500 BCE), but instead either mid-16th century BCE or somewhere around or shortly before 1600 BCE, then – in either case – this requires a serious re-thinking of all the conventional or orthodox associations and assumptions since the associations for the LMIA period are not primarily with the early New Kingdom (18th Dynasty) of Egypt, but instead with the previous world of the Hyksos or Second Intermediate Period (SIP) and contemporaries (Manning 2022). Further, the wall paintings of Thera (and e.g. the Miniature Fresco and its likely associated epic stories/poetry: Morris 1989) and the set of contemporary later MB wall paintings known from the Levant to the Aegean (Pfälzner 2013), and the Shaft Graves of Mycenae, also then become at the latest early 16th century BCE, and more likely 17th century BCE, and hence in addition belong to a world on the periphery of the formation and expansion of the Hittite Old Kingdom in addition (Weeden 2022), and so the beginnings of an era of 'heroes' and encounters across central to western Anatolia and into the Aegean, and also to the south into the northern Levant. These scenarios represent a fundamental re-synchronisation in time, and thus also of myriad social, economic and political associations and explanatory narratives and trajectories across the Aegean and East Mediterranean.

To consider just one example. Davis *et al.* (2024) make a reasonable case that griffin iconography had come to be associated in the Aegean especially with Knossos (and Crete) by LMI. The griffin motif, and we can assume associated ideology, emanate from the Syro-Levantine-Egyptian world of the earlier second millennium BCE (Hyksos/SIP) and became popular in the Aegean in the New Palace Period (Morgan 2010), and, at Akrotiri on Thera, the Miniature Fresco directly represents a 'Nilotic' association for one griffin (Doumas 1992: fig. 32), while another griffin, shown in the presentation scene in Xesté 3 (Doumas 1992: Fig. 122), faces a monkey and hence again exhibits an Egyptian-Nubian association. Davis *et al.* (2024: 19-22) suggest that the griffin became a representation of Crete and particularly Knossos and counterpoise lion imagery and associations as representative of mainland identity, resistance, and, by LHIIA, independence from Knossos. In the other direction, the griffin links Crete and its New Palace Aegean world with the Hyksos-Levant and, with an AHC viewpoint, places this primarily as later 18th through earlier 16th centuries BCE (i.e. SIP). The Aegean-style griffin on the axe of Ahmose in the Ahhotep tomb from the very end of the SIP (e.g.

Morris 2022: 175-177; Judas 2022: 275-277) thus may reflect a newly claimed association with (and in Egypt at least) the act or ongoing efforts towards the take-over of the Hyksos capital of Avaris (Tell el-Dabᶜa) and the previous Hyksos-Aegean world and its connections by Ahmose in the earlier portion of his reign. The Aegean-style griffin in the so-called Hunt Frieze found in fragments at Tell el-Dabᶜa probably should also be associated with the Hyksos and dated to a Hyksos palace context and not the Tuthmosid period (see below for discussion on the dating of Tell el-Dabᶜa).

The paper of Tiziano Fantuzzi, "Minoan Eruption Chronology: a synthesis for the non-initiated", in *JGA* volume 8 (2024) seeks to address the topic of the Thera date, and, in essence, to support the new lowest plausible, or modified orthodox, dating. While his sympathies lie even later, Fantuzzi nonetheless ends up suggesting a date around 1561 BCE. He regards the archaeological evidence as requiring this lower-range chronology, and tries to claim that this position can also be compatible with the radiocarbon evidence (rather than investigating an appropriate modelling of the radiocarbon data given the relevant archaeological prior information). Fantuzzi, while noting the issue that an earlier date means a re-synchronisation with the Hyksos era and "a totally different time", then proceeds to avoid this issue despite ending up favouring a date, maybe around 1561 BCE, that places almost all the LMIA period contemporary with the later Hyksos/SIP. The regular appearance of studies like Fantuzzi's re-iterating the lowermost possible position deserves critical comment in view of: (1) the fact that several of the supposed key archaeological constraints on dating are either less than clear/secure or in fact likely incorrect; (2) the radiocarbon evidence, when considered appropriately in terms of available prior constraints from geological-archaeological-botanical knowledge, increasingly points clearly towards an earlier date; (3) the only way around (2) is resort to special pleading alleging a general substantive radiocarbon offset as relevant to the olive wood dates from Therasia but, on critical examination, this appears unlikely, even if real, to be large enough to change the assessment in (2); and finally (4) there is a worrying refusal to consider a disciplinary re-think and to (re-)centre a history and explanatory narrative for the Aegean and East Mediterranean in the Middle Minoan (MM) IIIA to LMIA periods as associated with (and so engaged with and influenced by) the Hyksos/SIP era (largely because of the weight of tradition or orthodoxy or convention that makes it difficult to start again and to conceive a different, even if correct, history).

The archaeological evidence – which does not disprove a higher chronology

It is regularly asserted that the archaeological evidence prevents a higher chronological interpretation for the start of the Aegean Late Bronze Age. But what is 'higher', and what is actually solid by way of a TPQ, and from what date, is far from established in nearly all cases. Indeed, this archaeological certainty has eroded and moved substantially over recent decades, indicative of the lack of unambiguous evidence that has long permitted uncertainty and differing interpretations (which led to the suggestions for, or of admission of the potential for, chronological change for the dating of the start of the Aegean Late Bronze Age from the 1980s onwards: e.g. Betancourt 1987; Hallager 1988; Manning 1988; 1999). Whereas the eruption of Thera was definitely somewhere 1530-1480 BCE (e.g. Bietak 2013: Fig.8.2) and before that around 1500 BCE (e.g. Warren 1984), 'low' chronology scholarship is now starting to accept a date of 1561 BCE, and is more or less accepting that later dates are unlikely (Fantuzzi 2024). This last position effectively is a 'higher' chronology (what Manning 1999 termed the possible compromise early chronology), with MMIII and LMIA contemporary with the Hyksos/SIP and LMIB from no later than the very beginning of the 18th Dynasty. Nonetheless, despite in reality supporting what can only really be described as a 'higher' (or compromise 'higher') chronology, Fantuzzi (2024) spends considerable time reviewing various aspects of the archaeological evidence which he argues rule against a 'high' chronology. But none of this evidence is at all definitive, and in every case this evidence can plausibly (or even better be) re-interpreted if not pre-determined to reach a desired result. Let us briefly review some of the main instances to illustrate this point.

(i) *Khyan lid, Knossos*. The appropriate find context of this celebrated discovery has been much debated post-Evans (1900/1901: 63-67). The meticulous study of Knappett *et al.* (2023: 149-150, 169-170) places it as late MMIIIA. This now reasonably becomes a fact. But what has really changed, however, in the last 13 years is the likely dating of Khyan from Egyptian evidence. Whereas Knappett *et al.* (2023: 169) cite various authors, including this author from quarter of a century ago, as giving what used formally to be the standard date assessment for Khyan around 1600 BCE, new evidence from excavation work in Egypt and careful re-assessments of the Egyptian king list information point to a need for a substantial revision of our understanding of SIP chronology. In particular, finds at Tell Edfu indicate a date for Khyan around a century earlier, ca. 1700 BCE or a little before, e.g. later 18th century BCE (Moeller *et al.* 2011; Forstner-Müller and Moeller 2018; Cahail 2022), and the text record (Turin Canon) for the length of time assigned to the Hyksos (15th) Dynasty overall can be plausibly re-read to accommodate this (Schneider 2018; see also Aston 2018). Fantuzzi cites Bietak saying this is all controversial: of course Bietak, with no evidence, objects since this new evidence and such reassessments entirely undermine the ultra-low chronology position he has relentlessly espoused for decades. Not wanting something is not a substantive counter argument. Many scholars have now accepted the need for revision of dates around Khyan (e.g. Forstner-Müller and Moeller 2018; Cahail 2022). Recent evidence also points to the reality of an Abydos Dynasty during the SIP adding to complexities (see discussion and synthesis of Cahail 2022). Thus, in marked contrast to Knappett *et al.* (2023) who anachronistically – since they are writing well after the necessity of a rethink of Khyan's dating became clear – instead choose to cite Wiener (2010), writing just before news of the Tell Edfu findings and consequent work, and state his (low) date of 1610-1580 BCE for Khyan, and so suggest an end for MMIIIA around 1600 BCE, Cahail (2022) places Khyan in the later 18th century BCE, and hence we instead have a likely date for late MMIIIA in the decades leading to or around 1700 BCE! Therefore, the Khyan lid from Knossos is now consistent with, and even suggests, a high Aegean chronology for the New Palace Period, and in no way acts as a limiting TPQ against such a position (see also Höflmayer 2018).

(ii) *Three re-worked Egyptian stone vases from Thera and Mycenae*. Fantuzzi (2024) argues that three stone vessels found in LHI or LMIA (Late Cycladic I) contexts in the Aegean are of New Kingdom date and hence these contexts must post-date the start of the Egyptian New Kingdom. We can agree that the approximate date for the start of the 18th Dynasty, the accession of Nebpehtyre Ahmose (with the New Kingdom, dated from the conquest of Avaris and end of the SIP, placed during his reign, either around his Year 11, or possibly later in Years 18-22), is well established and lies somewhere, between higher and lower date interpretations, from about 1565 to 1539 BCE (Fantuzzi 2024 says 1550-1540 BCE) (Hornung *et al.* 2006; Schneider 2010; Aston 2012; Gautschy 2014). What is not established at all is that any of these vessels is exclusively New Kingdom in date. As noted several times, the two Egyptian stone vessels from the Mycenae Shaft Graves (NM592, NM829: e.g. Warren 2006) cannot be securely placed as New Kingdom in terms of the available and secure limited typological comparanda (critical studies of type sequences are lacking). This issue has two important aspects, both undermining the use of any of these items as a TPQ.

First, we in fact have few well-dated earlier 18th Dynasty contexts in Egypt, and, as the discussion of Aston (2018) illustrates, even previous assessments are now increasingly open to critique with several types thought only to date after the initial 18th Dynasty now being recognized as potentially starting earlier – this in turn affects dating of Cypriot types by reference to Egyptian contexts which undermines any claims for a specific date such as after the reign of Amenhotep I as claimed by Fantuzzi (2024) in this case. A SIP date very much cannot be excluded – and indeed even Warren (2010: 68) accepts this for NM 829 (Höflmayer 2012a: 440-441; 2018: 161).

Second, the supposed parallels cited for these vessels often lack a sound and dated context. As explained previously (Höflmayer 2018: 161; Manning *et al.* 2014: 1166-1167), and I quote the latter citation: "The parallels Warren cites are not real examples of finds in Egypt, but artistic pastiches created from fragments (Höflmayer 2012b: 177-78). Warren refers to a plate depicting stone vessel shapes originally published by Howard Carter in his report on tomb AN B at Dra' Abu el-Naga and later re-used by Lilyquist (Carter 1916: pl. 22; Lilyquist 1995: 86, fig. 24). However, according to Carter himself, he found only "débris of broken stone vessels. . .scattered in the valley outside the entrance of the tomb, and on the floors of the interior" (Carter 1916: 151). Later, Lilyquist used the "shapes drawn by Carter from fragments found in AN B" for her publication of stone vessels from the Metropolitan Museum and notes the items and dates "[Carter] assigned to each shape" (Lilyquist 1995: 86, fig. 24). Thus, Warren's evidence rests on what Carter thought was present in highly fragmented material scattered around a single tomb in the early twentieth century AD". This is not a secure and dated typology nor context!

The reworked Egyptian stone vessel found at Akrotiri (Akrotiri 1800) is not a very close match with Egyptian examples and Fantuzzi (2024) ends up admitting that such less than satisfactory parallels range from "the early New Kingdom (NK) or late/final Second Intermediate Period (SIP)". Thus this vessel could easily be consistent with a higher chronology (e.g. production later 17th century BCE) and offers no discrimination requiring a lower chronology.

(iii) *Initial LMIB products in Egypt and Egyptian contexts?* Studies such as Aston (2007) and Bietak *et al.* (2007) argued that finds of LMIB products in Egypt (and some other ceramic types) do not date before the reign of Tuthmosis III, and likewise that Tell el-Dabᶜa Stratum C/3 dates to the reign of Tuthmosis III. This was held to support a lower chronology (i.e. no evidence for LMIB in the initial-early 18th Dynasty and so the mid-second half of the 16th century BCE). But, reassessing, Aston (2018: 27-31) highlights that the situation is in fact much less clear and states that it is uncertain when relevant types begin, and that the start dates could be much earlier than stated before, potentially allowing some assemblages previously considered with a Tuthmosis III accession TPQ to instead be earlier 18th Dynasty. For example, contrary his assessment in Aston (2006), Aston (2018: 27) now comments that red-splash bowls previously regarded as a type-fossil for Tuthmosis III-Amenhotep II must start earlier and he even speculates they "could have been produced much earlier" (to about the beginning of the New Kingdom). In turn, the sherd (RAT 530.1301) from Memphis, likely from a LMIB bridge-spouted jar, from a context placed somewhere from year 22 of Ahmose through the reign of Tuthmosis I (Bourriau and Eriksson 1997), need not now be problematic and could well reflect the existence of LMIB on Crete in the second half of the 16th century BCE consistent with a high (Thera eruption 1611 BCE or around 1600 BCE) or higher (Thera eruption 1561 BCE) Aegean chronology (Aston 2018: 28). As noted above, such reconsiderations affect also supposed TPQ dates previously applied to 'first appearances' of some Cypriot types.

Overall, looking at the potential discrimination offered by Egyptian contexts and finds, it is becoming evident that, whereas it was formerly argued that ceramic evidence in Egypt could clearly delineate early to mid 18th Dynasty contexts, it is now apparent that this is not in fact the case on existing knowledge and needs careful reassessment. More widely, it is evident looking at Egyptian assemblages that many of the domestic forms occur and continue largely unchanged from the earlier SIP (or before) and continue largely unchanged until well into the New Kingdom (and even beyond the 18th Dynasty) (Wodzińska 2010; Bourriau 1997). Looking at Tell el-Dabᶜa, for example, the same patterns of continuity (and so problematic discrimination) can be observed (e.g. Fuscaldo 2010). An example of continuity from SIP through earlier New Kingdom contexts is provided by the red-slipped bowl with a ring base. Aston (2001: 188) notes that the type "may have developed during Late Hyksos times", noting occurrences at Tell el-Yahudieh, Memphis (Kom Rabia) and Tell Hebwa I, while it "became more popular in the early New Kingdom" – again suggesting a largely stable form across the later SIP to New Kingdom.

(iv) *Minoan eruption pumice in the eastern Mediterranean.* Fantuzzi (2024) appeals to the occurrences of pumice from the Minoan eruption of Thera in the eastern Mediterranean. The pumice is found typically in contexts where it was used for crafting activities (absence in, e.g., a tomb is thus not significant). The argument is that it is recognized in New Kingdom (and later) contexts but not before the SIP/New Kingdom transition. This has always been a weak argument (see e.g. Höflmayer 2018: 162-163; 2012a: 441-442), as Fantuzzi himself observes: "it should be noted, however, that the available samples from the NK/LBA significantly outnumber the samples available from SIP/MBA contexts. Hence, a more extended data set, especially from SIP/MBA stratified samples, would be appreciated and hence Minoan pumice remains a chronological argument *ex silentio*". Issues of re-dating some of the Egyptian contexts (see iii above) apply but most particularly the absence of data from securely dated later SIP crafting contexts where pumice might be expected, if it was available, render the whole basis to an *ex silentio* case very weak. Instead, as Fantuzzi concludes, the "Minoan pumice, where present, offers more a *terminus ante quem* (TAQ) than a *terminus ad quem*". Thus contexts with Minoan eruption pumice must be after the eruption. Hence, e.g., radiocarbon dates for such contexts provide a TAQ for the Thera eruption, for example: the transition between Tell el-ᶜAjjul H6 to H5, and the start of Tell el-Dabᶜa Stratum C/2 (see Manning 2024b; and see below).

(v) *White Slip (WS) I bowl from Thera.* This bowl has unfortunately been lost for a century, but has achieved near-legendary status. Arguments can be made over details, whether earlier classic WSI style (Manning 1999) or more mature WSI style (Merrillees 2001), but the fundamental fact is that the date for the beginning of WSI production on Cyprus is contested but could very likely be 17th century BCE or in the SIP (Manning 2014: 39-41; Höflmayer 2018: 161-162). As discussed in (iii) above, some of the relevant Egyptian contexts for dating Late Cypriot I products like Base Ring (BR) I and WSI are less clear than previously thought, and could reach back to the start of the New Kingdom or in fact the later SIP. The Tell el-Dabᶜa Stratum C/3 WSI is fragmentary and not from any primary deposit, rather it is from secondary even tertiary deposits, and thus only sets at best non-specific TAQ evidence. The claim by Fantuzzi that we can construct "a synchronism between Cyprus, the Aegean, the Levant and Egypt through the site of Tell el-Dabᶜa", is thus not in any way plausible. The supposed New Kingdom and indeed Tuthmosis III TPQ asserted by Bietak is undermined because, even as published, some finds in Egypt and the Levant could also be later SIP or later Middle Bronze Age (as Fantuzzi states towards the end of his discussion of this topic but chooses to downplay in favour of the later dating scenario). Indeed, if the radiocarbon dating of the Tell el-Dabᶜa contexts is used (Kutschera *et al.* 2012), then in fact the Stratum C/3 material indicates higher dates for WSI during the SIP and not a first appearance around the reign of Tuthmosis III as Bietak asserts. Fantuzzi then generalizes to include other Cypriot types and following Bietak states that there is a sequences of types "that always reflect the same relative sequence observable in Cyprus from MC III to LC IA2/B". Where? I believe Cypriot archaeologists would be very interested to know which site offers such a well-defined Middle Cypriot III to Late Cypriot IA2/B stratigraphically defined settlement sequence (tomb evidence, often mixed, is inherently problematic). As I have noted many times, this 'first appearances' or 'timelines' logic ignores (and is undermined by) the clear evidence of regionalism in Cyprus across this very period (Merrillees 1971; Manning 2001; Crewe 2007). Indeed, regionalism in Egyptian ceramic sequences of this period (e.g. Bourriau 1997) creates another important variable all too rarely acknowledged in such chronological discussions.

(vi) *Increasing support for the Mesopotamian Middle Chronology and higher MBA dates in the Levant.* Work combining tree-ring series with extensive radiocarbon dating from sites in Anatolia provides strong evidence for a Middle Chronology solution for Old Babylonian/Old Assyrian chronology (Manning *et al.* 2020a; 2016). Extensive radiocarbon dating and analysis from sites from the southern to northern Levant also provide evidence either consistent with the Middle Chronology (Herrmann *et al.* 2023) or a higher Middle Bronze Age timeframe (consistent with the Middle Chronology) (Höflmayer and Manning 2022). This in turn runs against the overall 'low' chronology synthesis for the earlier to mid-second millennium BCE promulgated by Bietak (e.g. 2013) and others. In consequence, the set of sites in the Levant from the late MB with wall paintings that show associations with those at Akrotiri on Thera (Pfalzner 2013) are likely 17th century BCE, consistent with an earlier date for the Thera eruption.

Tell el-Dabᶜa and chronology

This amazing site, centre of the Hyksos world, has been the basis for a decades-long program led by Bietak trying to enforce a low-chronology perspective on the East Mediterranean. It is thus to be commended that Bietak participated in a large-scale radiocarbon dating project for the site. Inconveniently for Bietak, this study (Kutschera *et al.* 2012) produced a coherent outcome that supported a timeframe entirely contradictory to Bietak's chronology, and instead a result largely compatible with the higher chronologies for the Middle Bronze Age observed from radiocarbon across the Levant, the Aegean 'high' chronology, and the Middle Chronology for Mesopotamia (e.g. see Herrmann *et al.* 2023; Höflmayer and Manning 2022 and references; Manning 2022; Manning *et al.* 2020a). In particular, the Kutschera *et al.* (2012) study found that Stratum C/2–3 placed into the Hyksos period and was not contemporary with Tuthmosis III as Bietak claims (after he revised the original view of a Hyksos date for the palace platform). Very ironically, the original Hyksos dating (P. Jánosi in Bietak *et al.* 1994: 20-38) would work well with the radiocarbon data and analysis. The supposed archaeological evidence for the later Tuthmosis (re-)dating is unclear/debatable on basic archaeological grounds (Manning *et al.* 2014: 1174-1175). With the recent evidence indicating that Khyan likely ruled around a century earlier than previously thought (see above), the Tell el-Dabᶜa sequence and its radiocarbon dates offer a timeframe that is quite consistent with a 'higher' chronology (e.g. Höflmayer 2018; Manning 2018; Höflmayer and Manning 2022).

Fantuzzi (2024) is correct to state that the radiocarbon dates and the analysis of these leads to a coherent chronology for the site that is "unreconcilable with the archaeological/historical chronology of the site". Fantuzzi therefore turns to try to discredit the radiocarbon dating of Tell el-Dabᶜa, rather than consider the more obvious response: asking whether the archaeological/historical chronology of the site is in fact robust? This is despite Kutschera *et al.* (2012: 410-413) explaining how they made best efforts to select appropriate samples (short-lived seed "charred material from archaeological settings, i.e. the result of human activity": Kutschera *et al.* 2012: 411), applying "best possible archaeological knowledge" (Kutschera *et al.* 2012: 410) from the Tell el-Dabᶜa excavator (second author on the paper). Fantuzzi alleges that because the study identified 7 of the initial 47 samples as having provenances that are unclear and/or disturbed and thus excluded these samples from the analysis (Kutschera *et al.* 2012: 411, 414, Table 1b), that somehow this indicates a wider problem, rather than the application of good science and careful and critical analysis. Of the 40 measurements used and assessed via outlier analysis, just 2 of 40 (5%) have an outlier probability above 10%, and just 3 of 40 (7.5%) have an outlier probability above 5%. This shows a pretty good, consistent, data set and indicates "the applied model agrees very well with the measured data" (Kutschera *et al.* 2012: 418). Thus there is no reason we should ignore the coherent picture from the vast majority of these carefully selected samples assigned "with the best possible archaeological knowledge" (Kutschera *et al.* 2012: 410) and instead believe that somehow many of the samples must have 'floated' through the stratigraphy and be out of context. Indeed, to achieve such a consistent result for the 40 samples in the analysis, we must assume they all somehow were consistently out of context, somehow, by about the same amount (a little over a century), a scenario which borders on the absurd. Inter-laboratory and humic contamination issues were excluded (Kutschera *et al.* 2012: 413-414). The resulting data offer a relatively good, coherent, analysis, just not one consistent with the Bietak low site chronology.

Fantuzzi (2024) proceeds then to raise the question of whether the relatively small changes in the radiocarbon calibration curve introduced with many new AMS ^{14}C single-year known-age data starting with IntCal20 might somehow change the situation, and solve the 100/120 calendar year difference between the radiocarbon and Bietak chronologies. Pending the next version of IntCal which will have revised annual data for the most recent few thousand years, we can estimate the likely scale of change using the period 1700-1480 BCE where we already have such revised known-age single-year calibration data (Pearson *et al.* 2020; Friedrich *et al.* 2020; Reimer *et al.* 2020; van der Plicht *et al.* 2020). If we compare the IntCal09 data (Reimer *et al.* 2009) as used by Kutschera *et al.* (2012) with IntCal20 between 1700-1480 BCE, there are 44 pairs of data and the weighted average offset is 11.5 ± 2.6 ^{14}C years (IntCal20 older ages). We could thus assume (in the absence of any other information) that something close to this average offset likely applies for the earlier portion of the second millennium BCE before the already modified 1700-1480 BCE period. In addition, there is the question of an Egyptian growing-season offset (see Dee *et al.* 2010; Manning *et al.* 2020a; 2020b). Comparison with recent AMS ^{14}C calibration data suggests that the Egyptian growing season offset should be revised to around 12 ± 5 ^{14}C years (Manning *et al.* 2020a). Thus we can re-run the Tell el-Dabᶜa dating model, adjusting the IntCal20 values before 1700 by 11.5 ± 2.6 ^{14}C years and then applying an overall Delta_R factor of 12 ± 5 ^{14}C years to allow for the likely Egyptian growing season offset (model version as in Höflmayer and Manning 2022). For this exercise, being conservative, I exclude the 7 dates on humic acids in Kutschera *et al.* (2012: Table 1a).

Table 1 compares the modelled calendar age ranges from this revised/adjusted model versus those run with IntCal09 (as Kutschera *et al.* 2012), and Table 2 compares the individual modelled calendar age ranges for the dates used from Stratum E/1 to Stratum C/2-3 from the revised/adjusted model versus the age ranges listed in Kutschera *et al.* (2012: Table 1a). In line with the adjustments included, the revised model version offers calendar ages that are typically a little more recent (later) than those in Kutschera *et al.* (2012). The 95.4% highest posterior density (hpd) ranges for the transition Boundaries in Table 1 start on average ca. 25.2 calendar years later and end ca. 43.5 calendar years later. This reduces a little the ca. 100-120 calendar year offset reported in Kutschera *et al.* (2012), *but* still leaves a clear and large consistent offset to older ages of the order of ca. 75-95 calendar years. As shown in Table 1, the modelled ages from the revised/adjusted model remain entirely incompatible with the Bietak dates for the site strata. Thus we may estimate that there is no likely expectation that the forthcoming new single-year AMS-based calibration curve (extending this form of calibration record earlier than its present coverage 1700-1480 BCE for the second millennium BCE in IntCal20), will offer a major change to the calendar placement of the Tell el-Dabᶜa data from radiocarbon evidence. Instead, as in Table 1 and Table 2, the Stratum C/2-3 data indicate the 16th century BCE, and not the earlier 15th century BCE, the Stratum D/2 to D/1 transition which Bietak dates ca. 1530 BCE is instead dated 1619-1580 BCE (68.3% hpd), 1646-1554 BCE (95.4% hpd), and the Stratum E/1 to D/3 transition, which Bietak places about 1595 BCE and associates Khyan as immediately following, instead dates 1715-1689 BCE (68.3% hpd), 1739-1674 BCE (95.4% hpd). Notably, this Stratum E/1 to D/3 transition date range is very compatible with

Tell el-Dab‘a Stratigraphic Phase Transitions (Boundaries in dating model)	**IntCal09 – as Kutschera *et al.* (2012)**		**IntCal20 adding pre-1700 BCE likely AMS ^{14}C adjustment and an Egyptian growing season offset (versus IntCal20 AMS ^{14}C based) – see text**	
	68.3% hpd BCE	***95.4% hpd BCE***	***68.3% hpd BCE***	***95.4% hpd BCE***
Boundary L to K *Bietak date ca. 1868 BCE*	2013-1942	2069-1916	1991-1914	2021-1861
Boundary K to I	1972-1915	2018-1898	1961-1889	1994-1835
Boundary I to H	1932-1899	1955-1889	1918-1832	1946-1785
Boundary H to G/4	1909-1887	1925-1881	1897-1786	1912-1777
Boundary G/4 to G/1-3	1889-1865	1905-1822	1882-1767	1887-1758
Boundary G/1-3 to F *Bietak date ca. 1715 BCE*	1870-1825	1876-1794	1867-1753	1871-1747
Boundary F to E/3 *Bietak date ca. 1680 BCE*	1841-1782	1859-1767	1846-1744	1856-1741
Boundary E/3 to E/2 *Bietak date ca. 1650 BCE*	1790-1748	1829-1725	1769-1726	1810-1712
Boundary E/2 to E/1 *Bietak date ca. 1620 BCE*	1767-1708	1773-1700	1736-1708	1750-1695
Boundary E/1 to D/3 *Bietak date ca. 1595 BCE*	1747-1696	1751-1694	1715-1689	1739-1674
Boundary D/3 to D/2 *Bietak date ca. 1560 BCE*	1715-1684	1738-1675	1692-1653	1715-1625
Boundary D/2 to D/1 *Bietak date ca. 1530 BCE*	1687-1649	1720-1611	1649-1605	1679-1594
Boundary D/1 to C/2-3 *Bietak date ca. 1500 BCE*	1667-1617	1681-1573	1619-1580	1646-1554
Boundary Start of C/2 *Bietak date ca. 1460 BCE*	1661-1578	1670-1556	1607-1564	1634-1545
Boundary End of C/2-3 *Bietak date ca. 1410 BCE*	1611-1553	1618-1514	1580-1530	1608-1508

Table 1. Modelled Transitions from Stratum L to Stratum C/2-3 at Tell el-Dab‘a using the Kutschera *et al.* (2012) radiocarbon dataset, here n=40 samples and n=50 radiocarbon measurements excluding those on humic acids, in the slightly revised model as employed in Höflmayer and Manning (2022), comparing results from using IntCal09 and no Egyptian growing season offset (thus as Kutschera *et al.* 2012) versus the same re-run using IntCal20 and adjusting the IntCal20 calibration curve before 1700BCE to allow for likely average single-year AMS ^{14}C calibration difference (based on 1700-1480 BCE period) versus IntCal09 and including the likely approximate Egyptian growing season offset versus modern AMS ^{14}C calibration data (see text for discussion and values used). Model run with OxCal General Outlier model (5% outlier prior) and with kIterations set at 3000. The ‘Bietak dates’ are estimated from Bietak (2013: Fig. 8.1) and Kutschera *et al.* (2012: Fig.3).

the recent arguments from archaeology and a re-consideration of the textual record that move the reign of Khyan earlier to somewhere around or a little before 1700 BCE (see above).

Dating the eruption of Thera: early 2024

The Thera debate has become such a long-running, multi-faceted, topic that many scholars see it simply as a problem, and go no further. There are endless rabbit holes, and one of the typical challenges is trying to avoid a quagmire of non-associated or different types of evidence and perspectives. In the long-run, a definitive exact year dating will come from recognition of secure unequivocal Thera eruption products replicated in more than one well-dated ice-core (or potentially linked with tree-ring archives). So far this has not occurred. Radiocarbon evidence at present is the primary directly relevant absolute dating method. For a long time sceptics argued that radiocarbon data on samples from Thera itself might be affected by volcanic carbon dioxide; however, recent work has shown that this is not the case and the dates from Thera from volcanic destruction contexts are valid (Pearson *et al.* 2023; Manning 2022). Nor is radiocarbon chronology static: as in all good science, radiocarbon data have improved over time, and in particular the radiocarbon calibration curve which describes the relationship between the radiocarbon and

Tell el-Dab‘a Individual Radiocarbon dates Stratum (General Phase) E/1 to C/2-3	Kutschera *et al.* (2012) modelled age ranges* 95.4% hpd BCE	Modelled age ranges with IntCal20 adding pre-1700 BCE likely AMS ^{14}C adjustment and an Egyptian growing season offset *(versus IntCal20 AMS ^{14}C based)* – see text – 95.4% hpd BCE
Tell el-Dab‘a Stratum (General Phase) **E/1**		
OxA-15948 – AMS-30	1759-1694	1745-1692 O:5/7
OxA-15949 – AMS-30	1759-1694	1742-1689
VERA-3618 – AMS-30	1759-1694	1743-1688
VERA-3636 – AMS-31	1757-1694	1742-1690
VERA-3617 – AMS-29	1756-1694	1742-1687
VERA-2626 – AMS-11	1754-1693	1742-1685
Tell el-Dab‘a Stratum (General Phase) **D/3**		
VERA-3033 – AMS-27	1745-1682	1725-1643 O:5/8
VERA-2896 – AMS-19	1741-1677	1724-1644
VERA-2895 – AMS-18	1741-1681	1724-1644
VERA-3619 – AMS-36	1739-1674	1727-1644
VERA-2629 – AMS-14	1738-1674	1730-1641
VERA-3620 – AMS-37	1738-1673	1730-1641
Tell el-Dab‘a Stratum (General Phase) **D/3-D2**		
VERA-3645 – AMS-45	1731-1656	1734-1516
Tell el-Dab‘a Stratum (General Phase) **D/2**		
OxA-15901 – AMS-39	1708-1633	1696-1621 O:5/10
OxA-15953 – AMS-39	1708-1633	1687-1618
VERA-3621 – AMS-39	1708-1633	1686-1612
VERA-3622 – AMS-46	1722-1633	1688-1617
VERA-2627 – AMS-12	1722-1633	1687-1617
VERA-2628 – AMS-13	1698-1631	1687-1613
VERA-3616 – AMS-28	1723-1630	1687-1610
Tell el-Dab‘a Stratum (General Phase) **D/1**		
VERA-3032 – AMS-26	1688-1601	1666-1574
Tell el-Dab‘a Stratum (General Phase) **C/2-3**		
VERA-3725 – AMS-49	1668-1546	1621-1532
OxA-15957 – AMS-48	1665-1543	1618-1535
OxA-15959 – AMS-48	1665-1543	1617-1531
VERA-3724 – AMS-48	1665-1543	1618-1535
Tell el-Dab‘a Stratum (General Phase) **C/2**		
VERA-3031 – AMS-25	1667-1537	1626-1537 O:5/8

Table 2. Comparison of the modelled calendar age ranges for individual samples from Tell el-Dab‘a for Stratum E/1 to C/2-3 from those published in Kutschera *et al.* (2012: Table 1a) versus those using the revised calibration dataset employed in Table 1 above and as described in the main text and using the very slightly revised Tell el-Dab‘a dating model in Höflmayer and Manning (2022). This selected range of dates is listed as it covers the particularly disputed period of the 17th-15th centuries BCE. *Note in our slightly revised version of the Tell el-Dab‘a model (Höflmayer and Manning 2022) we have not combined dates (OxCal command R_Combine) since these are not identical samples (rather collections of seeds) or dates by different laboratories, but instead employed the archaeological grouping (the Phase) as the analytical unit. Where Kutschera *et al.* (2012) give a sequenced range for such a weighted average value I list this against the individual dates above in Table 2. The four modest outliers are indicated as prior (5%) versus posterior probability (e.g. O:5/7 for OxA-15948).

calendar timescales has been improved several times since the first internationally recommended high-precision calibration curves were released in 1986 – these revisions lead to relatively small but important changes. In particular, for this discussion, the time period relevant to the Thera eruption, 1700-1480 BCE, thanks to much work in the later 2010s, is at present by far the best delineated high-resolution section of the radiocarbon calibration curve in the BCE era as a result of work by several different laboratories, all incorporated into the IntCal20 radiocarbon calibration dataset (Reimer *et al.* 2020; Pearson *et al.* 2020; Friedrich *et al.* 2020; van der Plicht *et* *al.* 2020), and so we may hope for accurate calendar ages. The other key development over the past generation is Bayesian chronological modelling which permits the integration of prior known information, e.g. from archaeology, geology, botany, history and other sources, with radiocarbon dating probabilities in order to obtain calendar dating probabilities that reflect the combination of available information as a best estimate (posterior probability) (see e.g. Buck *et al.* 1996; Bronk Ramsey 2009a; Bayliss 2009; Hamilton and Krus 2018). I note that this is (with the exception of fixed sequence wiggle-matching, e.g. of tree-ring sequences) fundamentally different from the randomizing Gaussian Monte Carlo Wiggle Matching developed by Weninger in his CalPal software (https://zenodo.org/records/7769791), as used by Fantuzzi (2024). In particular, Bayesian chronological modelling is both more powerful and relevant because it is capable of providing holistic probability information, that specifically incorporates and addresses archaeological/ historical knowledge and defined questions.

All this means we can employ radiocarbon and Bayesian chronological modelling to give us a best dating estimate (in this paper the OxCal software is employed: Bronk Ramsey 2009a; 2009b). Since the material culture evidence available relevant to this topic is not clear-cut and precise – rather ambiguous, non-precise, or debated (see above) – radiocarbon offers our best dating evidence. For present purposes and for reasons of space, it is desirable to keep it simple: thus for the main analysis discussed here I use only (i) two sets of radiocarbon evidence from Thera/Therasia (Santorini) directly associated with the Thera eruption, each comprising multiple, replicated, samples, and (ii) the stratigraphically defined temporal sequence known from Thera for the period immediately leading to the eruption. Use of other data related to the eruption or this period points to similar conclusions (see e.g. Manning 2022).

The prior temporal sequence information is the stratigraphic sequence of events (ordered time) recorded on Thera and at the archaeological site of Akrotiri immediately before the eruption (Evans and McCoy 2020; Manning 2022), comprising, in order, the following phases:

1. Major earthquake (note: the Akrotiri phases are sometimes also listed as (i) to (v)).
2. Systematic clearance/repair works at Akrotiri.
3. Abandonment of the Akrotiri town – this is presumably because of the first signs of volcanic activity or renewed seismicity – people appear to have removed most valuables but left stored foodstuffs and other materials, carefully secured, behind (so there was an apparent intention to return). The time period between Stages 1-3 and Stage 5 below has been much discussed and debated. Evidence of humus formation and colonization of soil above the seismic debris of Stage 1 by plants likely indicates a period of several years before Stage 4, and, since there is another gap (assumed fairly brief) between Bo_0 layers 3-4, some temporal space may exist. The consensus is that the time span between late/end Stages 2/3 and Stage 5 is relatively brief but must involve some time; this is variously assessed as between months, to a season, to a few/ several years (but not much longer).
4. Subsequent precursory minor volcanic eruptions which left four very thin pumice layers, Bo_0 layers 1-4, with some evidence of a gap (a period of time from days to months?) between Bo_0 layers 3 and 4, given evidence that people returned to the site and started clearance and some repairs.
5. The massive Minoan eruption (Bo_{1-4}).

The first dataset employed here is the well-known set of radiocarbon dates specifically on short-lived (annual) plant samples, and one insect pest from this material, left stored at Akrotiri on Thera at the time the site was abandoned in Stage 3 (so samples from late/end Stages 2/3) shortly before the eruption (often referred to as the volcanic destruction level, VDL). If we include only the stored short-lived (i.e. annual) plant matter and insect pest and exclude the three older measurement technology and widely varying Heidelberg measurements, and, being ultra-conservative, one case where the available description perhaps leaves a question over whether the sample came from a secure Stages 2/3 context (K-5353 pulses), this VDL dataset comprises 24 dates. These data can be considered as best modelled as forming an exponential distribution in time, the end (peak) of this distribution should be placed most likely immediately before (e.g. the harvest immediately before) the abandonment, but some of the data could be from a previous harvest, or residual, and part of the earlier portions of the ramped exponential distribution (see Manning 2024a: Fig. 8.1). Such a model can be achieved in OxCal by placing the VDL Phase of data between an initial Tau_Boundary paired with a closing Boundary, with this close of Phase Boundary providing the date estimate for the immediately subsequent eruption (as Höflmayer 2012a; Manning *et al.* 2014; Manning 2022). As noted previously: such an exponential (Tau Boundary) model is particularly suitable in this case as it assumes that all the radiocarbon-dated samples are older than the eruption (most by a very little), but a few may be older, even potentially by a substantial margin, ensuring that any dates on individual residual samples or individual samples older for some other reason will not cause us to overestimate the age of the eruption. (Contrast use of an average value: I note, contra Fantuzzi (2024), since alternatives to the R_Combine function became available for modelling, that the Thera dating has not been based on a weighted average value in most studies – see e.g. Höflmayer 2012a; Manning *et al.* 2014; Manning 2022; 2024a; 2024b – and instead there has been use of methods to incorporate the full probabilities from both the measurements and calibration dataset.) We can even consider adding a time constant, a parameter Tau, for the exponential distribution, since we believe that all these short-lived plant materials (and insect) should derive from likely the last harvest or possibly last two harvests (since a 0-2 year storage window is suggested from palaeobotanical analysis: e.g. Sarpaki 1992) excepting any possible residual material. This time constant should not have hard limits and we can therefore test whether the data are, or are not, consistent with the assumption. In view of the 0-2 year expectation, a log-normal function of the form LnN(ln(2),ln(2)); should be appropriate with a 68.3% hpd range from about 6 months to nearly 3 years and 95.4% hpd range from under 3 months to six and half years.

The second recently available and now key dataset comprises the published dates on four different branches of an olive shrub on Therasia that was killed by the eruption (Pearson *et al.* 2023). Dates are available in each case for a time-sequence from an inner (older) portion of the branch to an outermost (most recent) portion of the branch that in each case is thought to reflect when the olive shrub was killed by the eruption – and hence these outermost elements date the Thera eruption (Pearson *et al.* 2023). These outermost segments thus date Stage 5 in the Thera/Akrotiri sequence above. In this case, as prior information, we have the four temporal sequences for the dates from each branch, but there are two other fundamental priors: (i) olive growth in the Mediterranean region is flexible, and while this may lead to a single growth increment for a year, it is also common/usual for there to be two or more apparent growth increments, so-called intra-annual density fluctuations (Cherubini *et al.* 2013), thus the number of observed growth increments stated for each branch sample is the (utter) maximum number of calendar years represented and in fact the correct temporal span is likely less, perhaps even substantially less, and thus the total period of calendar time represented by each branch sequence may be constrained at the very minimun as no more than the stated number of growth increments (I treat this as a uniform possible probability in years between 0 and the stated maximum number of growth increments for each branch sequence); and (ii) in each case based on their analysis Pearson *et al.* (2023) argue that the last dated growth segment should represent the time the shrub was killed by the eruption – hence, even allowing for slight temporal variations in segment portions dated, this means each of the radiocarbon dates on the outermost dated segments/bark of the four branches should represent approximately the same calendar age and certainly the same calendar age within a very few years (see discussion of Manning 2024b with details on increment estimations) (Note: the latest radiocarbon date for a previous olive wood series published by Friedrich *et al.* 2006 does not explicitly date the outermost/

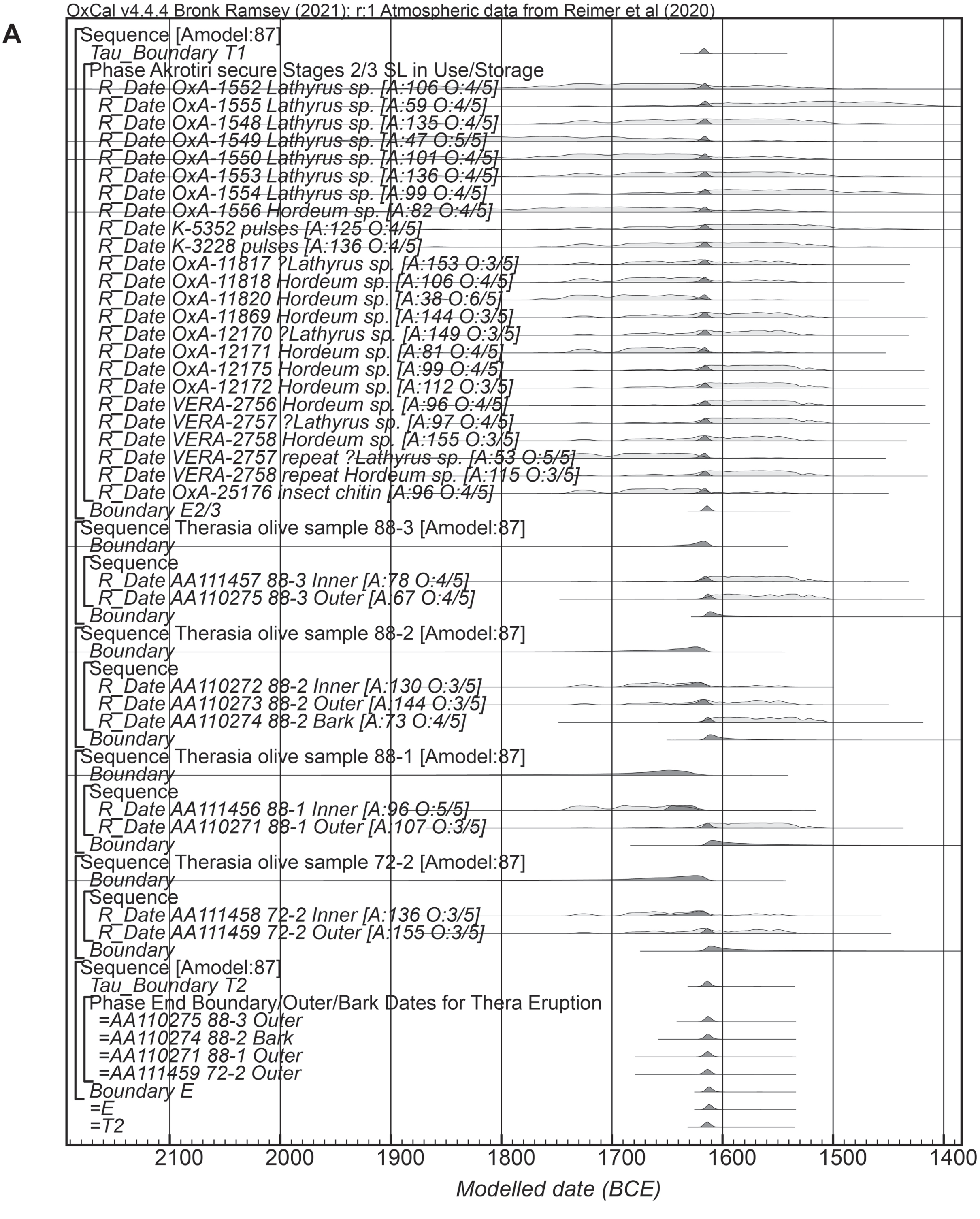
bark growth increment, and so while offering a very similar analysis, see Manning 2024b, it is not employed here.) We might therefore use the non-hard limits LnN(ln(2),ln(2)); constraint, as employed above, to cover such an assumption of approximate contemporaneity within a very few years total time variation, or, to be much more conservative, we could also consider uniform probability constraints of more loosely of ca. 0-10 years, or even ca. 0-20 years.

Since the analyses I report below on the olive shrub data from Therasia achieve a different dating outcome compared with the date findings reported in the publication of these data in Pearson *et al.* (2023), it is useful to explain why this is so, before moving to these results (see in more detail Manning 2024b). Pearson *et al.* (2023) claim the data support a mid-16th century BCE date range because they do not consider the four branch sequences together, but instead treat them separately – minimizing the constraints available. This approach thus encourages the probability to spread across the plateau in the radiocarbon calibration curve in the mid-16th century BCE. However, this approach is not using important known (prior) information. As noted above, two additional key parameters are available: (i) the outermost dated increments (or bark) in each case are argued to date the time the shrub was killed and hence the date of the Thera eruption: thus all four of these outermost or bark dates should be more or less contemporary and certainly all within a very few years given any reasonable variance factors; and (ii) given knowledge of olive growth in the Mediterranean, the number of reported growth increments between inner and outer dated increments is the maximum number of calendar years involved, and, in reality, the real time period is likely shorter given occurrences of intra-annual density fluctuations leading to more than one apparent growth increment per year in olives (Cherubini *et al.* 2013). Incorporating these two additional prior parameters leads to a likely dating just before or around 1600 BCE and not around 1561 BCE (Manning 2024b). Indeed, as we will see below, no plausible radiocarbon offset applied to these published data (a topic we will come to below) leads to a result around 1561 BCE and any plausible option points to a range from the late 17th century BCE to early 16th century BCE; to obtain a date result of ca. 1561 BCE radiocarbon dates that are different to those published for these samples by Pearson *et al.* (2023) would be required (see below). As discussed elsewhere, including the indications for a Thera eruption signal as approximately dated (as a TAQ) in the Sofular Speleothem (Badertscher *et al.* 2014) also increases the probability for a Thera eruption date around or just before ca. 1600 BCE (Manning 2022; 2024b).

Before we consider our analyses there are two other important priors. First, the Thera/Akrotiri stratigraphic sequence informs us that there is a sequence in time. The Akrotiri Stages 2/3 dataset must be older than the outermost growth segements of each Therasia branch placed as Stage 5, Thera eruption. Second, the time period between the Stages 2/3 dataset and the Stage 5 dataset must be be relatively short: somewhere between months, to a season, to a few/several years. As in Manning (2022), we might consider a very short time interval constraint, LnN(ln(0.75),ln(3)); which assumes a mode value around 2.5 months, a 68.3% hpd range from 0.04 to 1.29 years and a 95.4% range from 0.01 to 4.81 years; and also a slightly longer constraint, LnN(ln(3),ln(2)); with a mode around 2 years and a standard deviation giving a 68.3% range from <1 year to ≤5 years and a 95.4% range from around <0.5 year to around 10 years.

This corpus of prior information and the two sets of radiocarbon data should be all considered together as one comprehensive analysis to achieve the most likely calendar date placement incorporating all the available information. The ability to undertake such comprehensive analyses is the great strength of Bayesian approaches given modern computing power. The dating probabilities and ranges achieved in such an analysis, properly constructed, are both much more refined, but also robust, than anything achieved by any *ad hoc*, selective, or best-fitting methods.

Figures 1-4 illustrate and quantify the results of modelling the above information. Figure 1 illustrates an example of the model structure and the data employed (the OxCal runfile for this example is provided in the Appendix). Figures 2 and 3 show the modelled dating probability and calendar age ranges for the Thera eruption from six slightly different versions of the dating model (see text above for descriptions). Figure 4 shows the Therasia olive wood sequences (and the Therasia radiocarbon dates) from the model used for Figure 3A as placed against the IntCal20 radiocarbon calibration curve, showing how the four sequences of data each ending (outermost growth increment or bark) about the same time (when the olive shrub was killed by the Thera



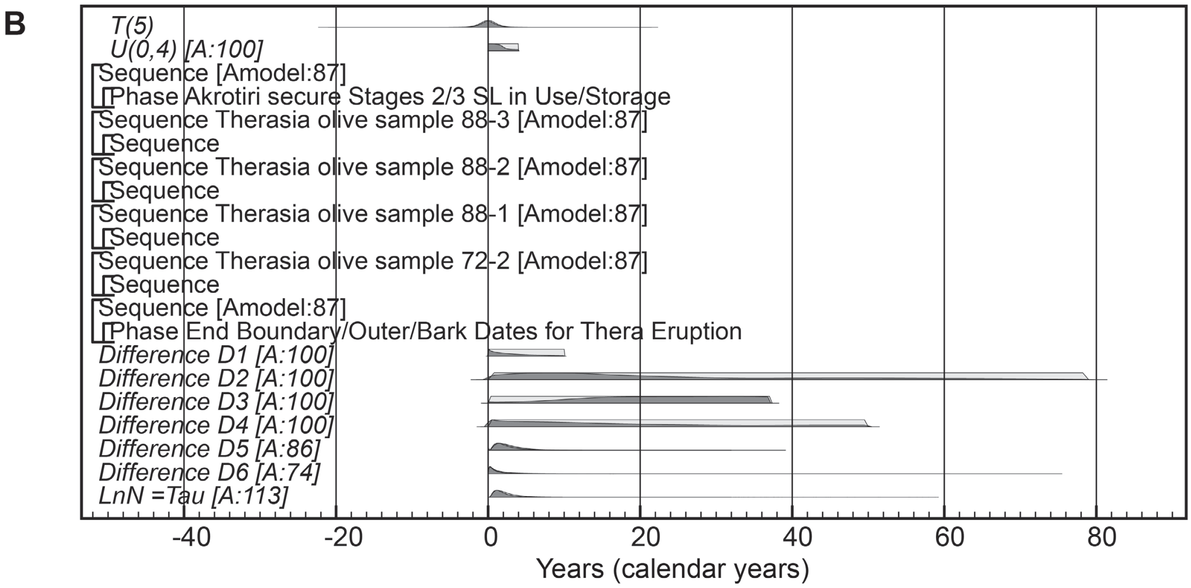


Figure 1. Data and model structure for the model result shown in Figure 2A. This model uses the very short LnN(ln(0.75),ln(3) constraint between stages 2/3 and 5 of the eruption sequence and the LnN(ln(2),ln(2) constraint for the same/short time period represented by the four outermost/bark segments of the Therasia olive sequences. A. shows all the data employed and the model structure. The square brackets down the left-hand side and the OxCal keywords define the overall model. B. shows the parameters used/modelled. Differences D1 to D4 apply the uniform time constraint of 0 years to the maximum number of growth increments as years between the mid-point of the inner and outer dated segments as approximately determined from the growth increments reported in Pearson *et al.* (2023: Table 2) for each Therasia olive branch (see Manning 2024b). Difference D5 is the short LnN(ln(2),ln(2)); time constraint applied to the period represented by the stored foodstuffs at Akrotiri. Difference D6 is the very short time time constraint applied to the period of time from the end of Stages 2/3 to Stage 5 (the Eruption, E) of LnN(ln(0.75),ln(3)); Tau= is the time constant for the same/short period represented by the outermost growth increment/bark on each of the four Therasia olive branches killed by the Thera eruption and Tau& is the LnN(ln(2),ln(2)); prior time constraint is applied to this (see Appendix). The OxCal General Outlier model is applied to each date and the prior/posterior outlier (O) probability is shown along with the individual and overall OxCal agreement (A) values (≥ ca. 60 is regarded as satisfactory). Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year. Model run with kIterations = 3000. The OxCal runfile for this model is listed as an example in the Appendix. Only models with satisfactory overall agreement (Amodel >60) and all data with Convergence ≥95 were used. Hollow, light-shaded, histograms show the non-modelled calendar probability; the smaller solid, dark-shaded, histograms show the modelled calendar probability.

eruption) fit best (inner to outer growth segments) in the later 17th century BCE. The Difference query ranges at 68.3% hpd from the model for the time (in calendar years) between the inner and outer dated segments from each branch sample are also listed, and compared with the uniform probability prior applied from 0 years to the stated approximate number of intervening growth increments (between the mid-points of the dated segments as derived from Pearson *et al.* 2023: Table 2 – see discussion in Manning 2024b) which offers the 100% maximum possible number of years (see above). We may observe that for samples 88-3, 88-2 and 72-2 the Difference query most likely indicates an interval less than half the reported number of growth increments; sample 88-1, by contrast, suggests an interval between about 50-100% of the reported number of growth increments. In each case the data appear compatible with the prior assumptions. Across the six model versions, the Thera eruption is placed from (extremes) 1616 to 1606 BCE at 68.3% hpd, and 1619 to 1599 BCE at 95.4% hpd. These results indicate that the Thera eruption could potentially be represented by the Northern Hemisphere volcanic signal recognized at 1611 BCE (Pearson *et al.* 2022), which therefore deserves greater investigation and scrutiny. We could now spend many pages considering additional radiocarbon samples or dating information that could be added (see for example in Manning 2022; 2024a; 2024b). Similar conclusions result: the difference is that adding all the other data increases 'noise' a little and thus data spread somewhat, and hence in some cases there can be some more probability into the early 16th century BCE. However, in search

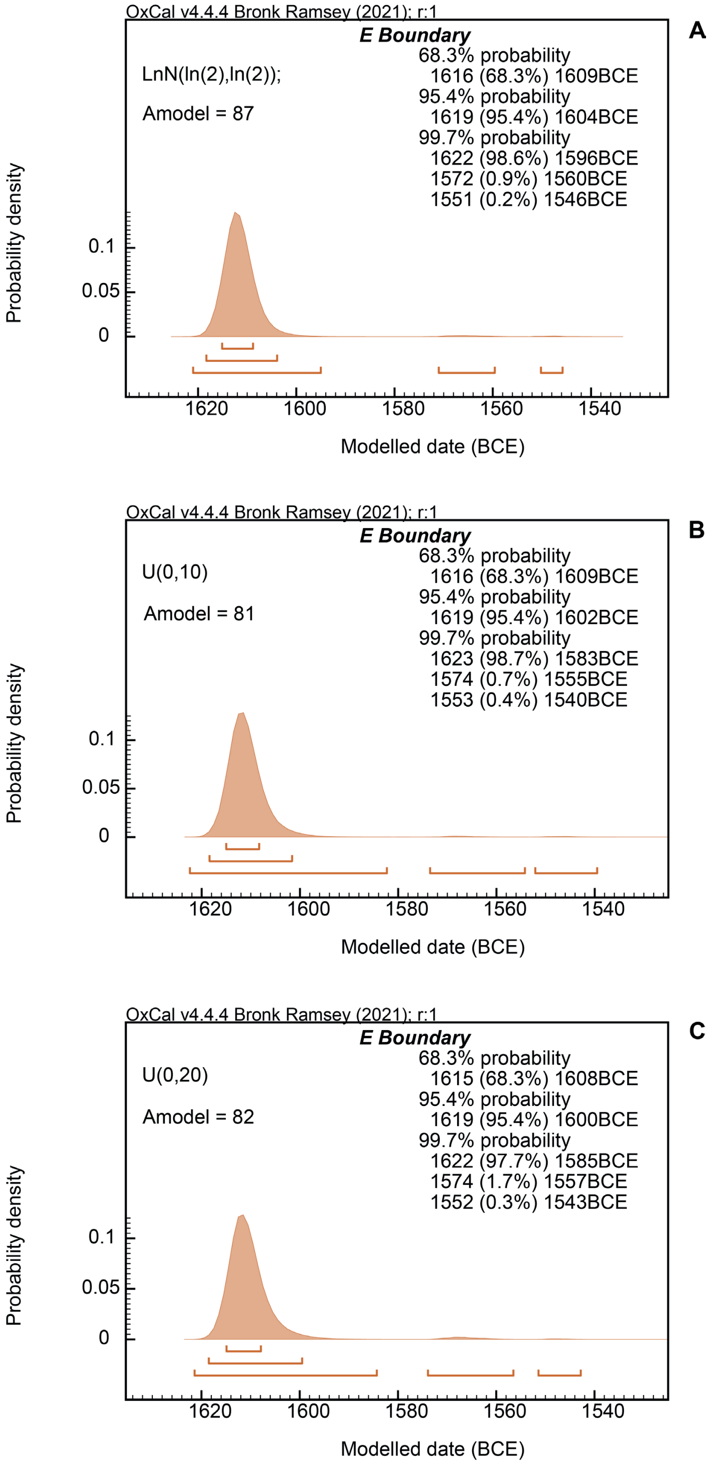


Figure 2. The modelled Thera eruption date estimates (E Boundary) from the set of three models employing the very short time constraint (LnN(ln(0.75),ln(3));) between the end of Stages 2/3 and Stage 5 and then three different prior constraints considered for the time constant for the same/short period represented by the outermost growth increment/bark on each of the four Therasia olive branches killed by the Thera eruption. Model structure as shown in Figure 1. Calendar age ranges shown for 68.3%, 95.4% and 99.7% highest posterior densities (hpd). Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year. Model run with kIterations = 3000. Only models with satisfactory overall agreement (Amodel >60) and all data with Convergence ≥95 were used.

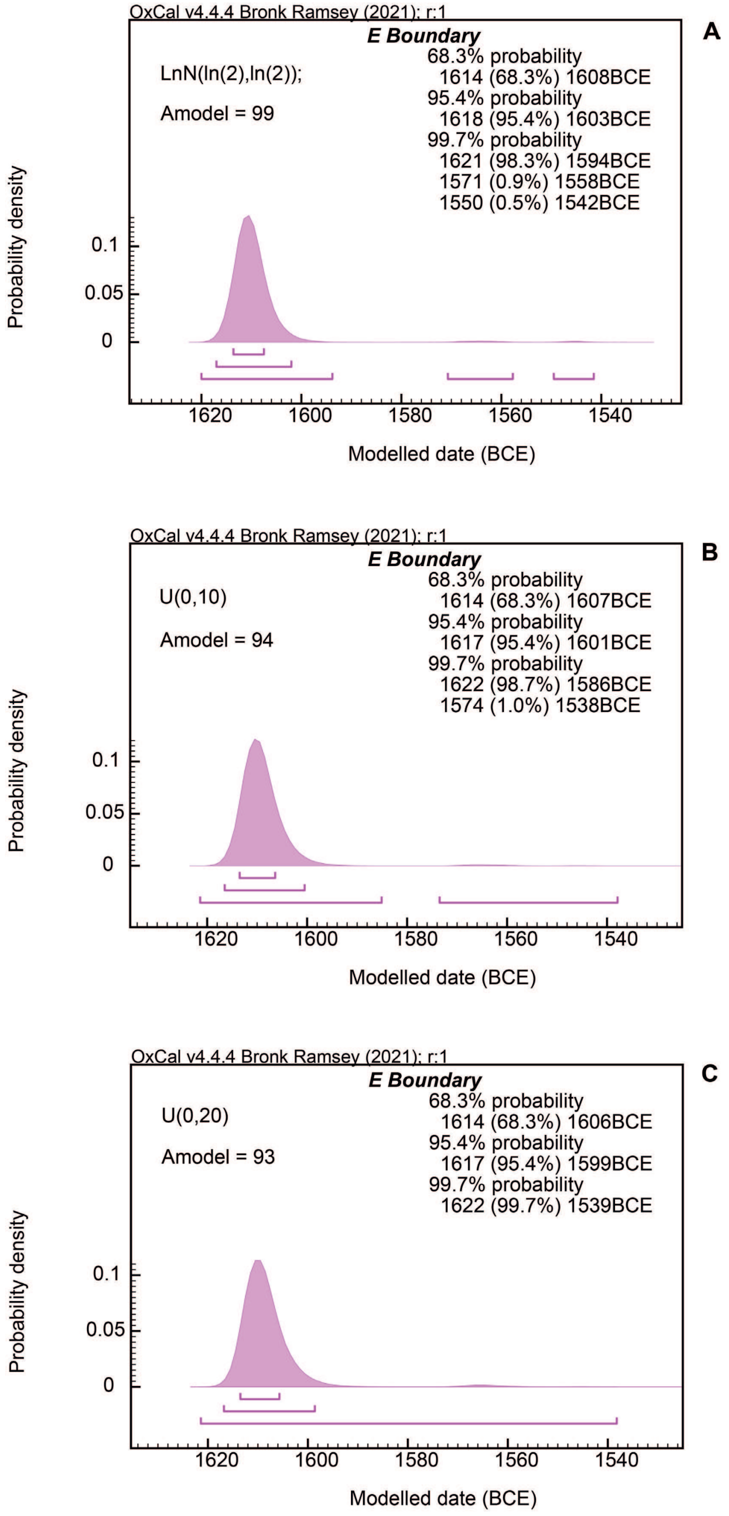
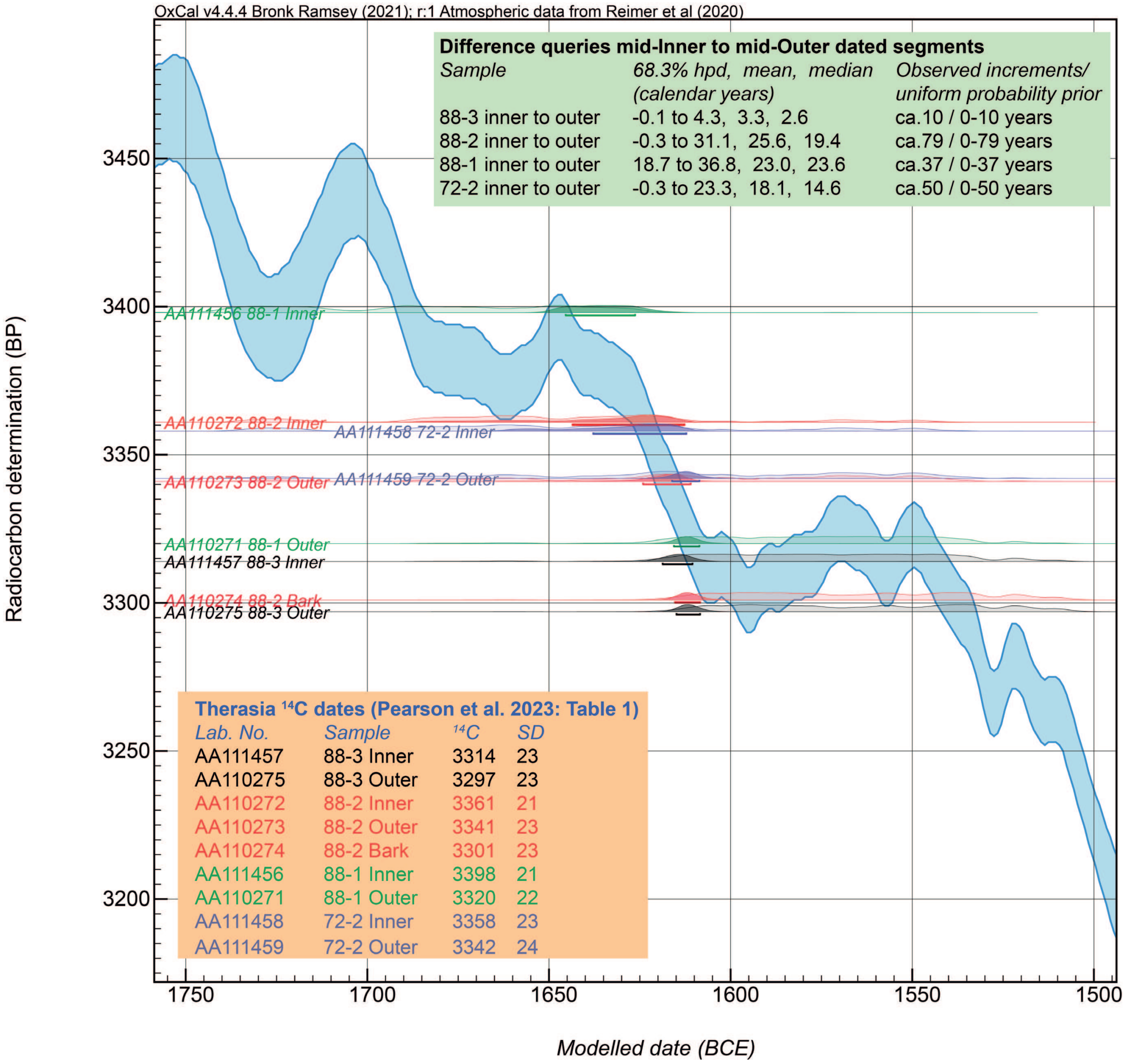


Figure 3. The modelled Thera eruption date estimates (E Boundary) from the set of three models employing the short time constraint (LnN(ln(3),ln(2));) between the end of Stages 2/3 and Stage 5 and then three different prior constraints considered for the time constant for the same/short period represented by the outermost growth increment/bark on each of the four Therasia olive branches killed by the Thera eruption. Model structure as shown in Figure 1. Calendar age ranges shown for 68.3%, 95.4% and 99.7% highest posterior densities (hpd). Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year. Model run with kIterations = 3000. Only models with satisfactory overall agreement (Amodel >60) and all data with Convergence ≥95 were used.



Difference queries mid-Inner to mid-Outer dated segments

Sample	*68.3% hpd, mean, median (calendar years)*	*Observed increments/ uniform probability prior*
88-3 inner to outer	-0.1 to 4.3, 3.3, 2.6	ca.10 / 0-10 years
88-2 inner to outer	-0.3 to 31.1, 25.6, 19.4	ca.79 / 0-79 years
88-1 inner to outer	18.7 to 36.8, 23.0, 23.6	ca.37 / 0-37 years
72-2 inner to outer	-0.3 to 23.3, 18.1, 14.6	ca.50 / 0-50 years

Therasia ^{14}C dates (Pearson et al. 2023: Table 1)

Lab. No.	*Sample*	*^{14}C*	*SD*
AA111457	88-3 Inner	3314	23
AA110275	88-3 Outer	3297	23
AA110272	88-2 Inner	3361	21
AA110273	88-2 Outer	3341	23
AA110274	88-2 Bark	3301	23
AA111456	88-1 Inner	3398	21
AA110271	88-1 Outer	3320	22
AA111458	72-2 Inner	3358	23
AA111459	72-2 Outer	3342	24

Figure 4. The modelled fit placements showing the 68.3% hpd ranges (lines underneath) for the four olive wood sequences (inner to outer wood segments) on the branches of the Therasia olive shrub from the Figure 3A model shown placed against the IntCal20 radiocarbon calibration curve (1σ probability band shown). The published Therasia olive shrub radiocarbon dates are listed bottom left, and the modelled Difference query results for the time interval in calendar years between the inner and outer dated segments for each branch as 68.3% hpd ranges and as mean and median values, are listed top right and compared with the uniform probability prior applied in the model.

of direct evidence without complications, the two datasets just employed offer the best dating evidence with the Therasia outmost growth segments – the key 'new' evidence that greatly helps – specifically dating the eruption event.

The modelling (based on the prior archaeological, geological, and tree/plant information) summarized in Figures 1-4 follows a described and explicit logic path. Only results from models that achieve a satisfactory (or better) OxCal Model Agreement Index (Amodel), ≥60, and with all individual elements with Convergence values ≥95 are employed. Outliers are identified and downweighted using the OxCal General Outlier model, with a prior probability for a measurement being regarded as an outlier set at >5%. The prior assumptions and the observed data are each consistent and offer coherent results in the models reported. Fantuzzi (2024), however, writes a section in his paper which nonetheless alleges that, despite applying a such sound and explicit method (and giving full transparency with relevant computer code, for example in Manning 2022, which Fantuzzi cites at this point) and mathematical techniques:

> “**The problem is not in the Bayesian approach to radiocarbon – which is extremely useful, and can be refined to take into account all the potential new variables**, but in the way in which the combination of results of different models obtained with *some specific applications* of Bayesian techniques has been pushed to the public of archaeologists as the only possible way towards the refinement of the eruption (and, in general, of radiocarbon) dating, creating a sort of research monopolisation effect which has ultimately slowed down the development of research on the subject.”

I follow and agree with the first two lines of this quote by Fantuzzi (in bold above), but there is no argument or logic to explain/justify the remainder of this quoted section of text by Fantuzzi. Simply because Fantuzzi (or e.g. Manfred Bietak, who is cited repeatedly by Fantuzzi 2024) do not ‘like’ the calculated calendar dating probabilities determined by an analysis that is soundly constructed using a large dataset and which conforms with modelled assumptions, does not form the basis of an academic argument, merely a subjective prejudice/preference. The great advantage of Bayesian chronological modelling is that it explicitly and holistically enables use and testing of data and assumptions (and all variables) – i.e. whether the data conform well, or not, with the modelled assumptions – and avoids what are otherwise typically *ad hoc* and likely more subjective analyses/solutions (Buck and Meson 2015).

Is there a radiocarbon offset relevant to the Therasia olive dates run by Arizona?

One important final issue should be noted and discussed. This is the suggestion by Pearson *et al.* (2023) that there should be allowance for a 13.7 ± 2 ^{14}C years offset between measurements on the Therasia olive samples and IntCal20. This is quite a large offset, indeed, it is of the scale (or more) of the Egyptian growing season offset when calculated against IntCal20 (Manning *et al.* 2020a). Such an offset in Egypt along the Nile where the growing season is known, because of the timing of the Nile flood, to be literally almost the opposite of the regular Northern Hemisphere cycle (Dee *et al.* 2010) is plausible, and some similar offsets appear to exist for other cases where the relevant plants have substantially different growing seasons versus the mid-higher latitude (temperate-boreal) trees that form the IntCal dataset (Manning *et al.* 2018; 2020a; 2020b). For the Thera date such an offset is very relevant. Clearly, if a large enough ‘offset’ correction is applied, then it will eventually shift dating probability later (although, interestingly in this case, not to a range around 1561 BCE(!), see below). But is it plausible that an olive shrub growing near sea level on Therasia would have a growing season and thus radiocarbon record (the radiocarbon incorporated into the growth increments by the tree while it is growing/photosynthesizing) that is markedly offset from the regular spring through summer/autumn growing season in the Northern Hemisphere? Here I express doubts for a few reasons. Most particularly: it must be noted that the suggestion for the offset is *not* derived from any experimental or observational data from the southern Aegean. Rather it is based on what appears to be an indirect and likely spurious argument. Pearson *et al.* calculate a 13.7 ± 2 ^{14}C years offset between a time-series of central Anatolian juniper run at Arizona versus IntCal20 – Manning *et al.* (2020a) had previously calculated this same offset at around 11.2 ^{14}C years (with an error of 1.9 ^{14}C years with a few outliers removed, or 2.8 ^{14}C years employing all data). But, when we note that Arizona measurements were also run around the same time on Irish Oak and that these can be directly compared versus ETH Zürich measurements on the same Irish Oak, and these data show the Arizona data as offset (older) by 6.2 ± 1.8 ^{14}C years, then this suggests that the real ‘net’ Arizona central Anatolia juniper offset versus IntCal20 was perhaps more like about 5 ± 2.6 ^{14}C years (Manning *et al.* 2020a). This scale of offset would be much more plausible.

However, in contrast, Pearson *et al.* (2023) argue that the large offset they determine between the Arizona measurements on the central Anatolian juniper is relevant to the Therasia olive shrub “[d]ue to the common laboratory factors and latitude”. We can all agree that the laboratory is common. But otherwise there is nothing in common and indeed two other sets of factors are much more important and undermine the scale and potentially the existence of this particular offset claim.

First: what is distinctly not common are the growing circumstances and thus timings of the incorporation of radiocarbon into the respective trees involved (juniper in central Anatolia versus olive shrub on Therasia). Anatolian junipers on the central Anatolian plateau, or from growth loci likely higher again in the mountains, primarily grow (photosynthesize) earlier in the year through to (ending) early summer, thus they primarily represent a spring to early summer signal (and include the intra-annual 'low' in atmospheric ^{14}C levels). This is partially distinct from the later spring through summer to start autumn signal incorporated into most of the wood in the trees used to build the IntCal curve which in contrast represents the intra-annual 'high' in atmospheric ^{14}C levels (Manning *et al.* 2018; 2020a; 2020b). Hence some degree of offset for the juniper data is possible/plausible and the Arizona reported value could be within the range of the known intra-annual seasonal variation. But the value stated, 13.7 ± 2 ^{14}C years, is probably substantially too large (as noted above), since comparison of Arizona measurements on Irish Oak run about the same time and compared to ETH measurements on the same Irish Oak indicate an offset (Arizona older ^{14}C ages) of 6.2 ± 1.8 ^{14}C years and comparison of the same Arizona Irish Oak data versus IntCal20 yields an offset of 5.8 ± 2.7 ^{14}C years. Hence a net Arizona offset for the central Anatolian juniper should likely be reduced and using the data discussed in Manning *et al.* (2020a) would likely be more around 5 ± 2.6 ^{14}C to 5.4 ± 3.3 ^{14}C ^{14}C years. But regardless of the exact number here, the relevance of this central Anatolian juniper offset to an olive shrub on Therasia is very unclear. In marked contrast with the central Anatolian juniper, typical olive growth in lowland Aegean-East Mediterranean contexts is late spring through summer and also through the autumn (e.g. Ehrlich *et al.* 2021). Thus no offset similar to that proposed for the Anatolian juniper case is plausible.

Recent data from Israel further contradicts the Pearson *et al.* (2023) suggestion: radiocarbon measurements on *Pinus halepensis* in northern Israel lie between the Northern Hemisphere zone 1 or zone 2 atmospheric radiocarbon record but are much closer to NH zone 1 (Raj *et al.* 2023). This means that equivalent data from this area in the pre-bomb-curve period (when intra-annual variation is much reduced versus the very exaggerated bomb period) would thus lie very close to the Northern Hemisphere IntCal values (which cover both zones 1 and 2 but are more strongly zone 1), and accordingly provide no evidence of any substantive, consistent, offset anywhere near the scale suggested by Pearson *et al.* (2023). For the *Pinus halepensis* the recognition of early and late wood and an annual overall growth period is clear and the growth increments can accurately be assigned to a specific calendar year by dendrochronological methods. Raj *et al.* (2023), meanwhile, however, suggest that measurements on an olive sample differ, and might suggest an offset. This olive offset claim is very different to the one in Pearson *et al.* (2023), based on supposed growing period, and not latitude; brief investigation is merited here as it illustrates the problems with the olive 'offset' topic. The fundamental problem with the Raj *et al.* case is that there is no secure dendrochronological basis to the calendar placements of the data they report from the olive sample. As the caption to Raj *et al.* (2023: Fig.2) states: "olive data points have been adjusted to match other Δ^{14}C records". The assessment, based just on such data matching, that the olive grew in spring and early summer in 1964 but then only late summer to winter in 1965, and did not grow in spring or summer in 1966, 1967 and 1968, appear entirely unsatisfactory (implausible) and against what is known of olive tree growth behaviour (e.g. Cherubini *et al.* 2013; Ehrlich *et al.* 2021), and indeed most crucially run contrary to the detailed stable carbon isotope record measured and previously reported from the very same olive wood sample (Ehrlich *et al.* 2021: Fig. 2B). This stable isotope record seems to exhibit a spring (start) to a summer or later peak to autumn/winter (end) δ^{13}C signal for each year and thus demonstrates photosynthesis and growth each year and across the later spring through autumn and *not* only at the different partial periods reported in Raj *et al.* (2023), and indeed even in contradiction to those partial periods reported in Raj *et al.* (2023). For example, the 1964 δ^{13}C record seems to have a largely symmetical shape and mid-year peak as does

1965, directly contrary to the claimed very different claimed growth periods from the radiocarbon 'matching' and stated growth periods in Raj *et al.* (2023). Therefore, the only conclusion is that the calendar year placements/associations for the wood portions used for the ^{14}C measurements are not correct as placed in Raj *et al.* (2023: Fig. 2). In turn, for the present at least, there is no good evidence to demonstrate any, or any consistent, olive wood radiocarbon offset. And the relationship of olive growth in northern Israel with an olive shrub on Therasia remains also to be elucidated.

Review of this first aspect of the topic thus suggests, contrary the Pearson *et al.* (2023) offset suggestion, that it is not common latitude by itself that explains a common growing season (and so similar radiocarbon record), but rather the actual settings where elevation and local climate determine local growing seasons (in support: the relevance of differing elevation explaining different growth responses is noted by dendrochronological studies in the East Mediterranean: e.g. Griggs *et al.* 2014; Coulthard *et al.* 2017). Thus the period of olive growth and incorporation of radiocarbon likely covers the spring through autumn of each year, and so, like many Mediterranean species, a longer/wider potential growth period(s) overall each year than for most species in temperate to boreal areas (see Deslauriers *et al.* 2017), but, since it includes all the (shorter) period of temperate-boreal growth, and does not cease by the end of summer, but continues through the autumn, then there should be little substantive growing season offset assumed for this case (and contrast cases where the growth period ends by earlier summer: Manning *et al.* 2018; 2020b). Likewise, for the other plant samples (cereals and legumes) dated from Akrotiri (the Stages 2/3 samples) we may note the traditional harvest information for such food crops in the southern Aegean islands (Halstead and Jones 1989) points to late spring to summer dates, again only a little offset versus the average IntCal tree growth periods. Thus a relatively large ^{14}C offset as suggested by Pearson *et al.* (2023) appears inappropriate.

Second: the offset claimed by Pearson *et al.* (2023) appears clearly to be substantially over-stated, as noted above. What is more noticeable is that the radiocarbon measurements from the Arizona laboratory from the relevant period indicate that this laboratory was somewhat offset versus the laboratory forming the modern core of IntCal: ETH Zürich. AA measurements on Irish Oak show a 6.2 ± 1.8 ^{14}C years offset versus ETH measurements on the same Irish Oak. Thus, if we adjust the 11.2 ± 1.9 ^{14}C years offset by this we are left with a small 5 ± 2.6 ^{14}C years offset. Or, using the larger value Pearson *et al.* (2023) report, of 13.7 ± 2 ^{14}C years, this reduces to 7.5 ± 2.7 ^{14}C years (note also, since numerous Arizona measurements are included for the relevant portion of the IntCal20 calibration curve, that this Arizona 'bias' is already substantially included in IntCal20, and should not therefore be double-corrected for). Within the frame of Arizona data in isolation, there is also no real evidence for a large difference between data on temperate-boreal 'IntCal' data and the central Anatolian juniper. If we compare Arizona measurements on Irish Oak (a classic IntCal tree) with their measurements on the Gordion juniper for the samples with single years from 1666 BCE to 1580 BCE (87 pairs), the difference is only 3.6 ± 3.5 ^{14}C years (data from Pearson *et al.* 2020; 2018). This small value in fact suggests no substantive latitude-based difference between the Irish Oak and the central Anatolian juniper (contrary Pearson *et al.* 2023).

If we, nonetheless, consider a putative radiocarbon offset applied to the Therasia olive wood samples, then what is the effect? Figure 5 shows the E (Thera Eruption) Boundary for the models shown in Figure 2A and Figure 3A re-run, first with the Pearson *et al.* (2023) 13.7 ± 2 ^{14}C years suggested offset applied to the Therasia olive wood samples, and then, second, with the more plausible reduced 7.5 ± 2.7 ^{14}C years offset (see above). The modelled Thera eruption date in fact is only very slightly changed comparing the results in Figure 5 versus those in Figures 2 and 3. Figure 6 shows the fit placement for the the LnN(ln(3),ln(2)); case (that is the re-run Figure 3A model = Figure 5B) placed against the IntCal20 radiocarbon calibration curve. Compare this with the non-offset-adjusted version shown in Figure 4. We see that even with the large 13.7 ± 2 ^{14}C years suggested offset applied to the Therasia olive wood samples following Pearson *et al.* (2023),

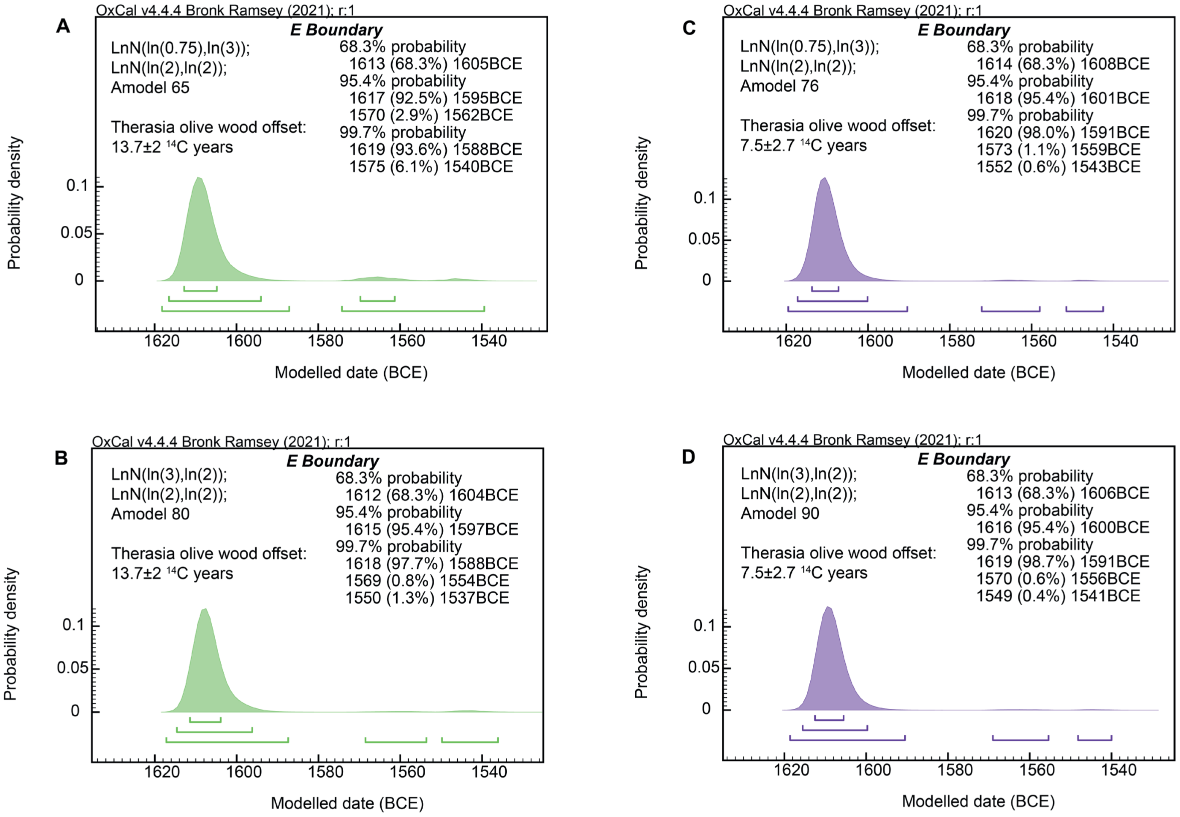


Figure 5. The modelled Thera eruption (E) Boundary from the Figure 2A and 3A models when re-run employing either (A, B) the (large) Pearson *et al.* (2023) suggested radiocarbon offset for the Therasia olive wood samples of 13.7 ± 2 ^{14}C years, or (C, D) the more possibly realistic version of this possible offset of 7.5 ± 2.7 ^{14}C years (see main text). Modelled probabilities at 68.3% hpd, 95.4% hpd and 99.7% hpd shown. Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year. Model run with kIterations = 3000. Only models with satisfactory overall agreement (Amodel >60) and all data with Convergence ≥95 were used.

the modelled fit – given the constraints of inner to outer sequence and maximum calendar period represented, and the constraint that all four of the outer/bark samples date close in time using the LnN(ln(2),ln(2)); constraint – likely places the outer/bark growth increments in the late 17th century BCE (68.3% hpd ranges indicated) and not in the mid-16th century BCE. As evident in Figure 5, this is even more clearly the case if the more realistic smaller possible radiocarbon offset factor is used.

Indeed, one interesting observation is worth highlighting. Let us consider just the four Therasia olive shrub dating sequences and their dating estimate for the Thera eruption, and assume an exponential distribution for the Phase of the four outer/bark samples assuming all should be more or less dating immediately before the Thera eruption that killed them. We allow the time constant for the exponential distribution to have a prior that is uniform between 0 and 10 years and consider the effect of an arbitrary radiocarbon offset applied to all the data progressively from -20 ^{14}C years to +70 ^{14}C years. And let us consider one model where the periods of time allowed between the inner and outer increments are between 0 and the full (100%) stated increments treated as years in Pearson *et al.* (2023), and a second model where we assume typically two growth increments per year or more and so a period of 0 to 50% of the stated number of growth increments (rounded up to nearest integer) (OxCal model code listed in the Appendix). The resultant 68.3% hpd calendar age ranges are shown according to the radiocarbon offset (Delta_R adjustment) for both model versions in Figure 7. For the plausible offsets (at up to more than 50% of the stated measurement errors of the radiocarbon dates reported, and up to or more than the maximum radiocarbon offsets observed for recent AMS ^{14}C data (see above)) of -15 to +15 ^{14}C years, the most

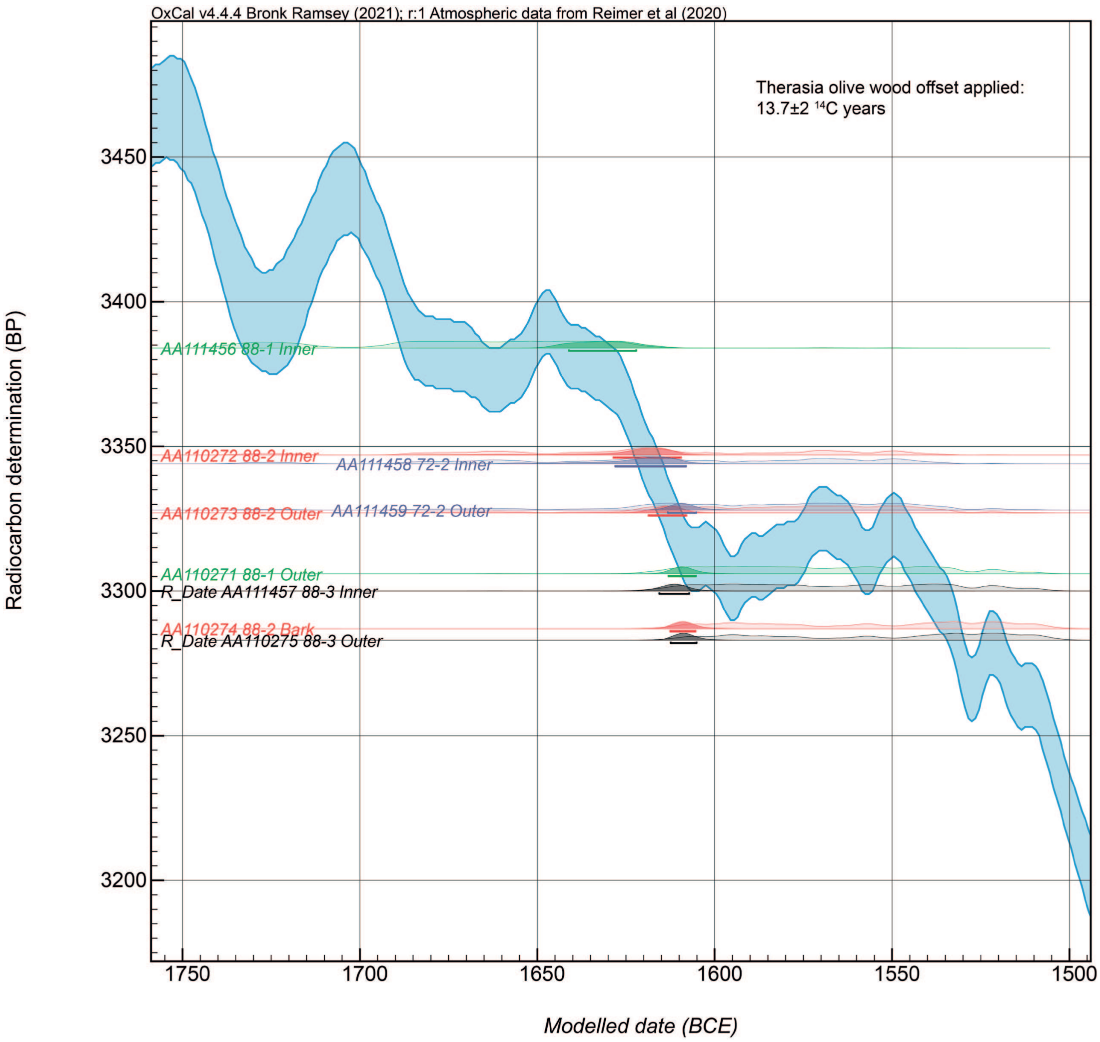


Figure 6. The modelled fit placements showing the 68.3% hpd ranges (lines underneath) for the four olive wood sequences (inner to outer wood segments) on the branches of the Therasia olive shrub from the Figure 3A model – when re-run with the (large) Pearson *et al.* (2023) suggested radiocarbon offset of 13.7 ± 2 ^{14}C years applied to the Therasia olive wood samples as in Figure 5B – shown placed against the IntCal20 radiocarbon calibration curve (1σ probability band shown). Compare with Figure 4 which shows the same model run without the radiocarbon offset applied.

likely 68.3% hpd ranges point to dates in the late 17th to early 16th century BCE. If (entirely implausibly) the radiocarbon offset is further increased, then a date range around 1561 BCE is not found. Instead, once the offset factor allowed for becomes sufficiently large, in particular once the radiocarbon offset is 30 ^{14}C years or greater, the eruption is placed most likely in the late 16th century BCE. I hasten to add that a systematic Arizona laboratory radiocarbon offset of 30 ^{14}C years or more is entirely implausible; during the relevant period when these samples were measured at the University of Arizona radiocarbon facility, they reported many data from oak and juniper and bristlecome pine that demonstrate much smaller offsets (less than 50% of this figure) at the very most (e.g. Pearson *et al.* 2018; 2020; 2023).

The end position is that, if prior constraints are applied for the growth order sequence, and the maximum calendar period represented by each branch sequence of growth increments, and a constraint is also applied requiring that the outer/bark segments of the olive shrub, representing when killed by the eruption, to have closely similar calendar ages, then, *even if* an additional plausible to likely overly large radiocarbon offset is applied, the Therasia olive samples point to a most likely eruption date within the period 1614-1604 BCE (extremes of the 68.3% hpd ranges in

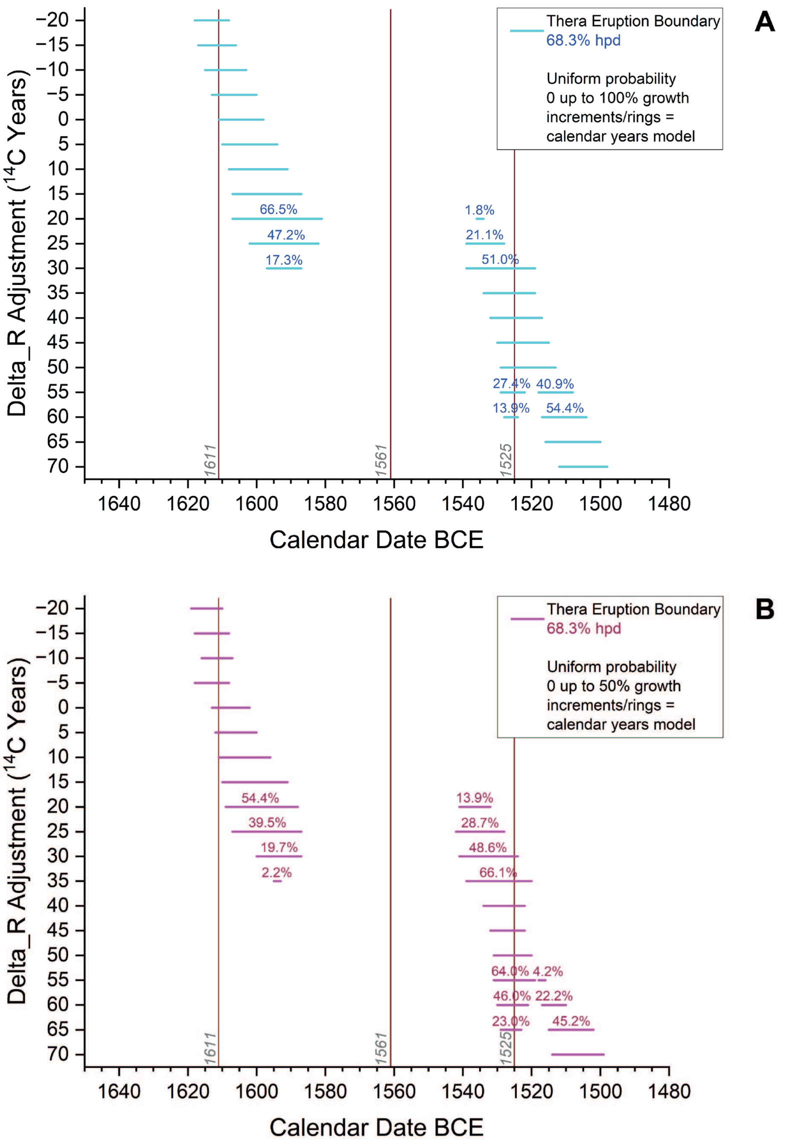


Figure 7. The 68.3% calendar years hpd ranges for the Thera Eruption Boundary from runs of a dating model for just the four Therasia olive shrub branch Sequences, together, considering the effects of a radiocarbon offset adjustment of -20 to +70 ^{14}C years. The dates of the two known large volcanic eruptions 1611 BCE (V3) and 1561 BCE (V5) (Pearson *et al.* 2022) and the proposed Thera eruption date of 1525 BCE (e.g. Wiener 2010) are also indicated. A. Model version assuming the time interval between inner and outer increments of each olive branch sequence are somewhere (uniform probability) from 0 years to the stated number of observed increments (so 100%) = years in Pearson *et al.* (2023) (for the time interval between the mid-points of the dated segments: see Manning 2024b), while the date of the outer/bark increments are assumed likely very similar and are modelled as a Phase with an exponential distribution with a time constant of 0-10 calendar years. The modelled date for the Thera eruption is the Boundary immediately after this Phase. B. Model version assuming the time intervals between the mid-points of the dated inner and outer increment Sequences for each olive branch are somewhere (uniform probability) from 0 to typically half (so 50%, rounded up to nearest integer) of the stated number of observed increments = years in Pearson *et al.* (2023); the date of the outer/bark increments are again assumed likely very similar and are modelled as a Phase with an exponential distribution with a time constant of 0-10 calendar years. The modelled date for the Thera eruption is the Boundary immediately after this Phase. Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year. Models run with kIterations = 3000.

Figure 5). At 95.4% hpd all or, in one case, 92.5% hpd, of the probability points to dates at extremes between 1618-1595 BCE. A later mid-16th century BCE date is highly unlikely with probabilities within 99.7% hpd for this across the four models in Figure 6 ranging from 1%, 1.7%, 2.1% to 6.1%. And, if such an additional radiocarbon offset is not applied, then, as shown in Figures 1-4, the data even more clearly support a late/end 17th century BCE date for the Thera eruption.

If the Therasia olive shrub was killed in 1561 BCE: what should the radiocarbon dates be?

Examination of the modelling in Figures 1-6, and previous work (Manning 2024b), suggests that, if we incorporate the known associated prior information, the radiocarbon dates published by Pearson *et al.* (2023) on the Therasia olive shrub yield values that satisfactorily place the outermost growth increments/bark and thence the Thera eruption in the late 17th century to early 16th century BCE. A date around 1561 BCE is unlikely. This raises the question of what, approximately, should the radiocarbon dates have been if, in fact, the Therasia olive shrub was instead killed around 1561 BCE, or indeed around a low chronology choice like 1525 BCE (Wiener 2010), and how different do these alternative radiocarbon dates look versus the published radiocarbon dates? We can get one indication if we exchange the published radiocarbon ages (but keep the published laboratory measurement errors) with the expected average values for given calendar years from the IntCal20 dataset (Reimer *et al.* 2020) (which is informed by a substantial number of annual resolution known-age tree-ring samples in the 1700-1480 BCE period) assuming (from the Pearson *et al.* 2023 sample descriptions) that the bark/outermost increments for samples 88-3 and 88-2 would then (for the 1561 BCE case) equate with 1561 BCE and the outer dated increments for 88-1 as 1562 BCE and 72-2 as 1563 BCE. We can then further consider two cases: (i) where we assume that the observed growth increments between the mid-points of these outer samples and the inner dated portions of each branch represent (maximum case) approximately the number of calendar years involved (thus like the maximum of the 100% model in Figure 7A) and so employ the respective IntCal20 values for the expected inner years (so, for the 100% 1561 BCE model, these are 88-3 inner at 1570 BCE, 88-2 inner at 1639 BCE, 88-1 inner as 1598 BCE and 72-2 inner as 1612 BCE); or (ii) we assume that the observed growth increments are not typically annual but one or more intra-annual density fluctuations and over each branch we thus assume real calendar intervals of perhaps 50% the number of observed growth increments (like the maximum of the Figure 7B model), so we employ the respective IntCal20 values for the expected inner years (so, for the 50% 1561 BCE model, these are 88-3 inner at 1565 BCE, 88-2 inner at 1600 BCE, 88-1 inner as 1580 BCE and 72-2 inner as 1587 BCE). Figure 8 shows the IntCal20-based average ^{14}C ages (±1σ) for the inner and outer/bark samples and their mean ±1σ calendar modelled placements against IntCal20 for (top) the Therasia olive shrub data as published (Pearson *et al.* 2023) and then (below) compared with the hypothetical 1561 BCE 100% and 1561 BCE 50% models, and compares also the respective Thera eruption Boundaries that are defined. Figure 9 repeats the exercise but with the assumption now of a 1525 BCE Thera eruption date. Here the outermost/bark increments are placed 1525 BCE for samples 88-3 and 88-2 and 1526 BCE for sample 88-1 and 1527 BCE for sample 72-2. For the 100% model the innermost portions are placed with 88-3 inner at 1534 BCE, 88-2 inner at 1603 BCE, 88-1 inner at 1562 BCE and 72-2 inner at 1576 BCE; and for the 50% model with 88-3 inner at 1529 BCE, 88-2 inner 1564 BCE, 88-1 inner at 1544 BCE and 72-2 inner at 1551 BCE. Subject to the appropriate changes noted above, the model structure is otherwise as in the Therasia sample model listed in the Appendix.

Inspection of Figures 8 and 9 shows that the radiocarbon values that offer approximate 1561 BCE and 1525 BCE compatible modelled Thera eruption date ranges distinguish themselves as different – noticeably later/lower – than the radiocarbon values actually published in Pearson *et al.* (2023). In particular, looking at Figure 8, whereas 5 of the 9 (56%) radiocarbon dates (the stated mid-point value ± error) published by Pearson *et al.* (2023) are greater than 3340 ^{14}C years BP (see Figure

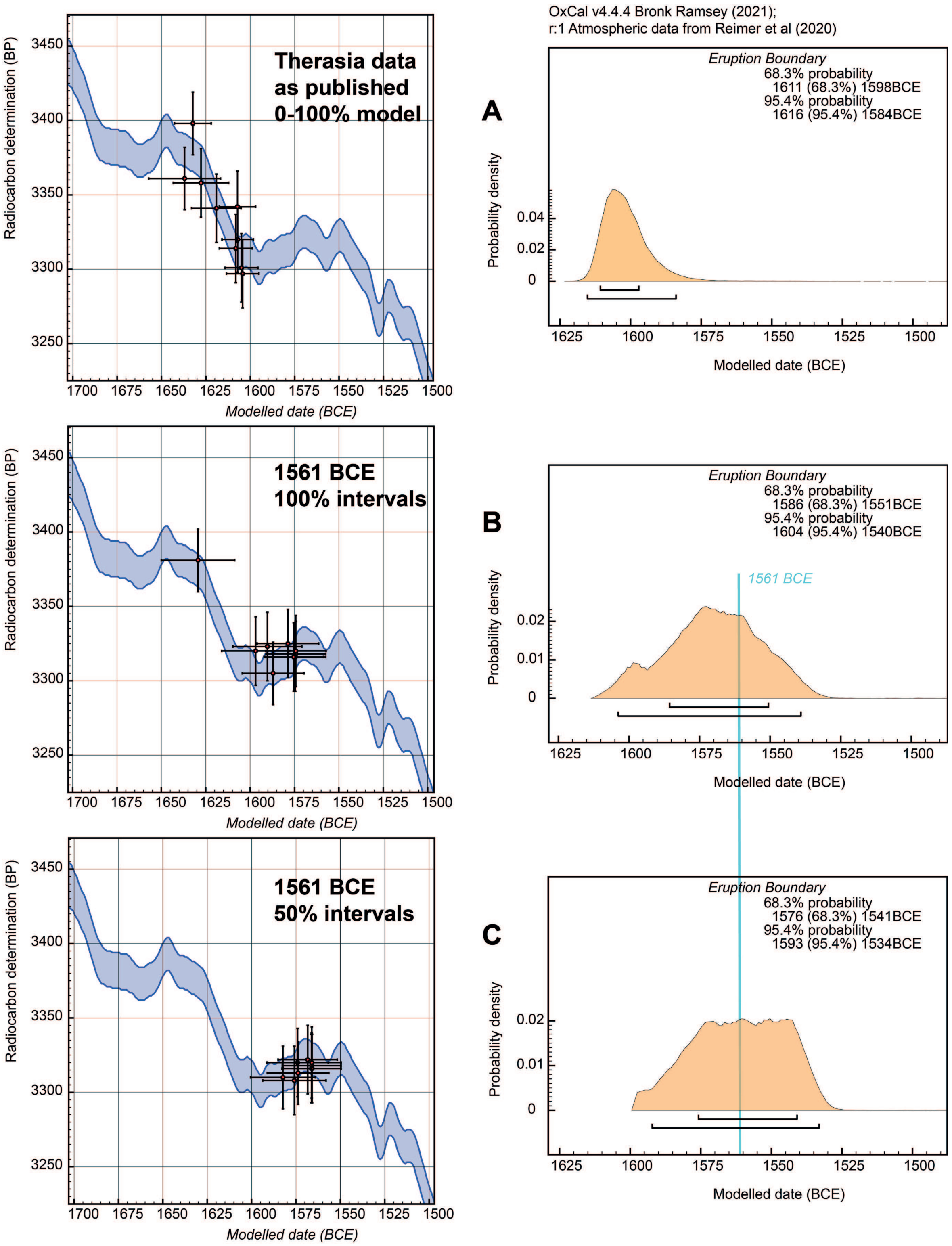


Figure 8. Comparison of the Figure 7A model with the published radiocarbon dates from the Therasia olive branch Sequences and their calendar placements (^{14}C age ±1σ, modelled calendar age as mean ±1σ) and the modelled Thera eruption Boundary from the published data with no Delta_R adjustment (as Figure 7A, 0 offset version) (A) versus two interpolated approximate models for a 1561 BCE solution. The first using the same measurement errors and information for the intervals between inner and outer dated segments (the 100% model as used for the maximum possible value in the Figure 7A model) but with the sample ^{14}C values drawn from IntCal20 given starting points of 1561 BCE – see text for information (B), and the second using the 50% model (Figure 7B) assuming observed growth increments on average offer about 2 such increments per calendar year – see text for information (C). A putative Thera eruption date of 1561 BCE is indicated by the cyan line. Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year. Models run with kIterations = 3000.

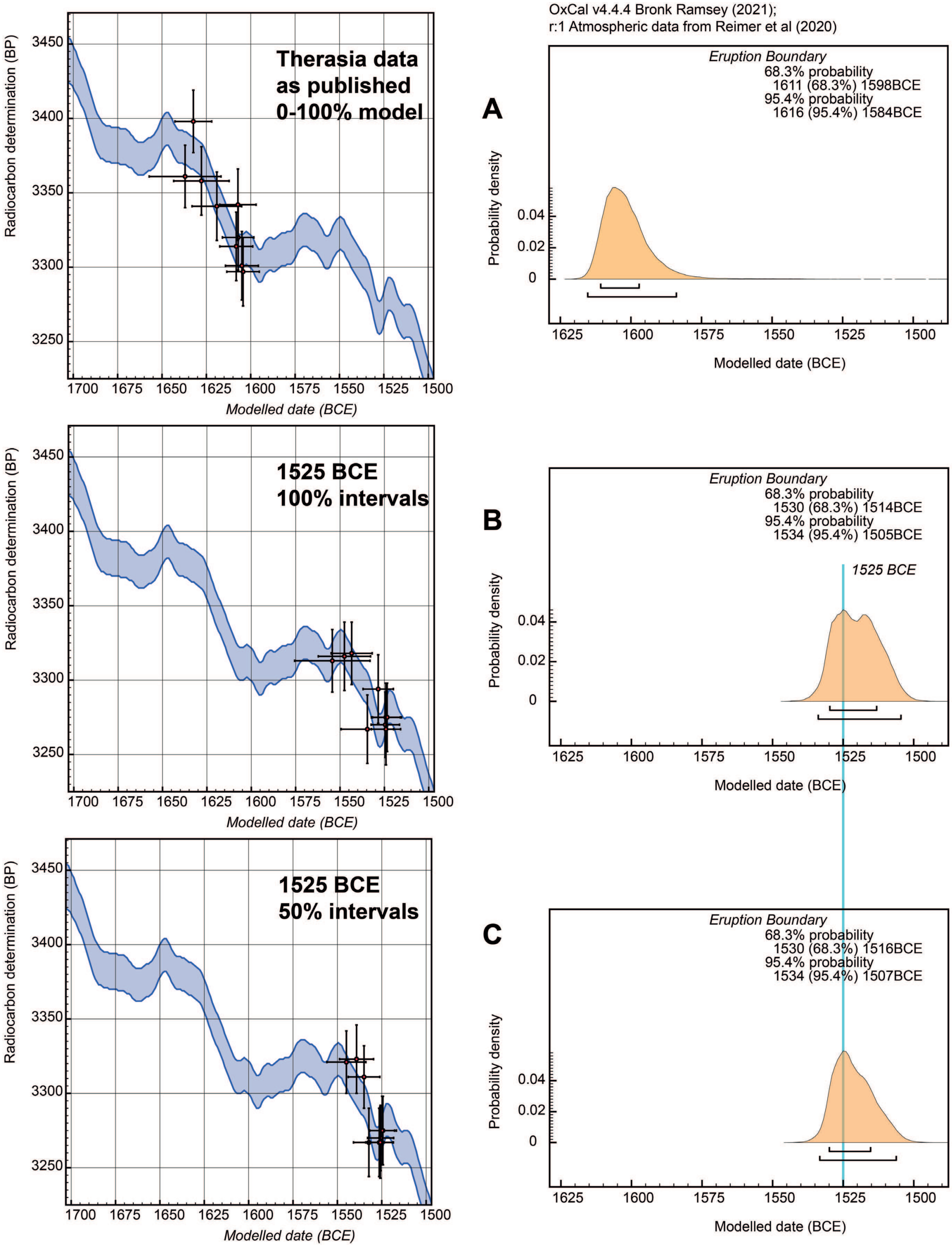


Figure 9. Comparison of the Figure 7A model of the published radiocarbon dates from the Therasia olive branch Sequences and their calendar placements (^{14}C age ±1σ, modelled calendar age as mean ±1σ) and the modelled Thera eruption Boundary from the published data with no Delta_R adjustment (as Figure 7A, 0 offset version) (and same as Figure 8A) (A) versus two interpolated approximate models for a 1525 BCE solution. The first using the same measurement errors and information for the intervals between inner and outer dated segments (the 100% model as used for the maximum possible value in the Figure 7A model) but with the sample ^{14}C values drawn from IntCal20 given starting points of 1525 BCE – see text for information (B), and the second using the 50% model (Figure 7B) assuming observed growth increments on average offer about 2 such increments per calendar year – see text for information (C). A putative Thera eruption date of 1525 BCE is indicated by the cyan line. Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year. Models run with kIterations = 3000.

4), just 1 of the dates (11%) in the 100% 1561 BCE compatible model is, and none of the dates in the 50% 1561 BCE compatible model. Indeed, the single 'older' ^{14}C date in the 100% 1561 BCE model (Figure 8B, top left) is the inner segment of sample 88-2 when it is assumed to be ca. 79 years (growth increments) earlier than 1561 BCE (so 1639 BCE). But, Pearson *et al.* (2023: Table 2) discussing sample 88-2, state that there were "c. 76-81 inconsistent growth bands < 400 µm, most visible at outer edge, counts uncertain due to high fracturing and erratic growth", thus the ca. 79 increments/years estimate in this case, especially, is perhaps highly uncertain and is a total maximum, and the time interval involved might be much less. If in reality it is any value ≤60 years, then its average mid-point ^{14}C age from IntCal20 would be <3340 ^{14}C years BP, and so there would then be no ^{14}C dates in the 1561 BCE model with mid-points >3340 ^{14}C years BP, in strong contrast to the published Therasia date set where 5 of 9 dates (56%) have mid-point values of >3340 ^{14}C years BP (see Figure 4). If, overall, a more compressed growth increments to calendar time scenario is envisaged instead, for example a 50% interval model, then there are no dates with mid-point values >3340 ^{14}C BP, very different for the published Therasia dataset with 5 of 9 (56%) of dates with mid-points >3340 ^{14}C years BP (see also Figure 4). While for both 1561 BCE models the Boundary offering a Thera eruption date includes 1561 BCE within its most likely 68.3% hpd range, it is apparent that the more compressed 50% model offers a better fit and result.

The 100% and 50% 1525 BCE models in Figure 9 highlight the even larger differences in this case between the published radiocarbon dates on the Therasia olive shrub samples and the radiocarbon dates that would be necessary to achieve a likely modelled Thera eruption date placement around 1525 BCE.

The exploratory models in Figures 8 and 9 indicate the sorts of radiocarbon ages for the Therasia olive shrub samples that would plausibly lead to a Thera eruption date either around 1561 BCE or 1525 BCE. This exercise serves to indicate a clear distinction between these '1561 BCE' or '1525 BCE' radiocarbon dates and the radiocarbon dates actually published by Pearson *et al.* (2023) for the Therasia olive shrub samples which – instead – suggest a modelled Thera eruption date a little before or around 1600 BCE.

The *terminus ante quem (TAQ)* evidence from contexts subsequent to the Thera eruption

Fantuzzi (2024) argues that "another argument in favour of an eruption dating during the 16th century may come from the re-analysis of radiocarbon dates for the subsequent LM IB period". The all-important point, noted by, but effectively ignored by, Fantuzzi is that these data all come from *end* of LMIB destructions at their respective sites. The entire of each site's LMIB period was before the destruction. How long was the LMIB period? It used to be considered short, but recent evaluations have tended to suggest much longer ranges (see various papers in Brogan and Hallager 2011; Manning 2009). Fantuzzi notes the analysis of Manning (2022) that finds a 95.4% hpd range of 59-203 calendar years between (in that paper) the modelled Thera eruption and the dated LMIB destructions, and then somehow Fantuzzi arbitrarily applies a time range of 60 ± 40 years to achieve a desired result. This is clearly invalid. Selecting the minimum of a total 95.4% range and then adding a 66.7% error around this such that at 2 sigma the date range could be -20 to 100 years, over half of this outside the plausible 95.4% hpd range, represents no version of reality. Of course, since the close of LMIB dating evidence points to a period from the later 16th through mid-15th centuries BCE, arbitrarily allocating a reasonably short overall period will lead to estimating the start of the period in the mid-16th century BCE.

More useful is to consider the range of TAQ data that exists relevant to the dating of the Thera eruption, comprising: the TAQ for the start of LMIB (at a minimum, since data are all close of LMIB destruction, from the start Boundary for the Phases of LMIB destruction dates from Chania and

Myrtos-Pyrgos), the TAQ for the start of LHIIA (again as the start Boundary for Phases of data from LHII at Iklaina and LHIIA at Kakovatos: Cosmopoulos *et al.* 2019; Eder and Hadzi-Spiliopoulou 2021), and TAQ for the Thera eruption as before the transition from Phases H6 to H5 at Tell el-ᶜAjjul when Thera pumice is present (Fischer 2009), before the start of Stratum C/2 at Tell el-Dabᶜa when Thera pumice is present (Kutschera *et al.* 2012), and before the TAQ for the Thera tsunami reported from Malia on Crete (Lespez *et al.* 2021). In addition, the long radiocarbon sequence analysis for Kolonna on Aigina provides an estimation – unfortunately not well-defined (Wild *et al.* 2010: 1019) – either for the Thera eruption or a point in time very shortly afterwards via the LHI to LHII transition between Phases K to L. We can thus consider a model where a start Boundary for a Phase of data comprising each of these TAQs offers a reasonable estimate for the post-Thera eruption/start LMIB period. The Kolonna K/L boundary should offer an estimate of approximately the same time period and can perhaps best be associated with this Boundary (revising slightly Manning 2024b: Fig.7; for further details and data, see that paper and its supplementary material). The analysis is shown reported in Figure 10 and Table 3. The Boundary for Kolonna Transition K/L and the post-Thera Eruption and start to Early LMIB/LHIIA period is placed 1620-1568 BCE (68.3% hpd) and 1649-1546 BCE (95.4% hpd). These data and the analysis are more suggestive of a higher chronology, with a Thera eruption perhaps 1611 BCE or perhaps generally around or shortly before 1600 BCE. It does not rule out an eruption perhaps 1561 BCE, but is less compatible. These data and the analysis shown certainly do not, contrary Fantuzzi (2024), suggest that the LMIB period only began *c.* 1520 ± 14 BCE. Instead, the scenario shown in Figure 10 and detailed in Table 3 is much more compatible with the re-thinkings in Egyptian assemblages and likely occurrences of LMIB and Late Cypriot Base Ring and White Slip in the early 18th Dynasty and perhaps even before the end of the SIP, as noted above, and the likely reassessment of the date for Khyan (and thus late MMIIIA) onwards, as noted above.

Conclusions

Increasingly extensive and high-quality radiocarbon data (both from archaeological contexts and refining the radiocarbon calibration curve), combined with appropriate analysis incorporating archaeological, botanical and geological prior information, allows us to better resolve radiocarbon calibration curve ambiguities (e.g. plateaus, as in the 16th century BCE, or 16th century CE) (e.g. Pearson *et al.* 2018; 2020; 2023; Birch *et al.* 2021; Manning and Birch 2022; Manning 2022; 2024a; 2024b). Altogether, this progress enables better definition of the likely date range for the Minoan eruption of the Thera volcano central to Aegean and East Mediterranean chronology in the mid-second millennium BCE. These new data and work have greatly narrowed the range of the 'Thera date debate': from over a century (Hardy and Renfrew 1990) to now ca. 50 years between 'lower' positions (e.g. Fantuzzi 2024; Pearson *et al.* 2018; 2023) and likely 'higher' dating assessments (e.g.

	68.3% hpd BCE	**95.4% hpd BCE**
Boundary = Kolonna Transition K/L associated Post-Thera Eruption and Start to Early LMIB/LHIIA or LHI/II Transition	1620-1568	1649-1546
Tell el-ᶜAjjul Transition H6 to H5	1538-1513	1557-1504
Tell el-Dabᶜa start of Stratum C/2	1587-1550	1609-1539
Boundary TAQ for start of Iklaina LHII	1554-1514	1593-1505
Boundary TAQ start LHIIA Kakovatos	1573-1524	1605-1511
Boundary Start Chania Late LMIB	1584-1536	1614-1518
Boundary Start Myrtos-Pyrgos Late LMIB	1535-1499	1556-1464
TAQ Malia tsunami	1556-1487	1596-1451

Table 3. The modelled calendar age ranges at 68.3% and 95.4% hpd from Figure 10.

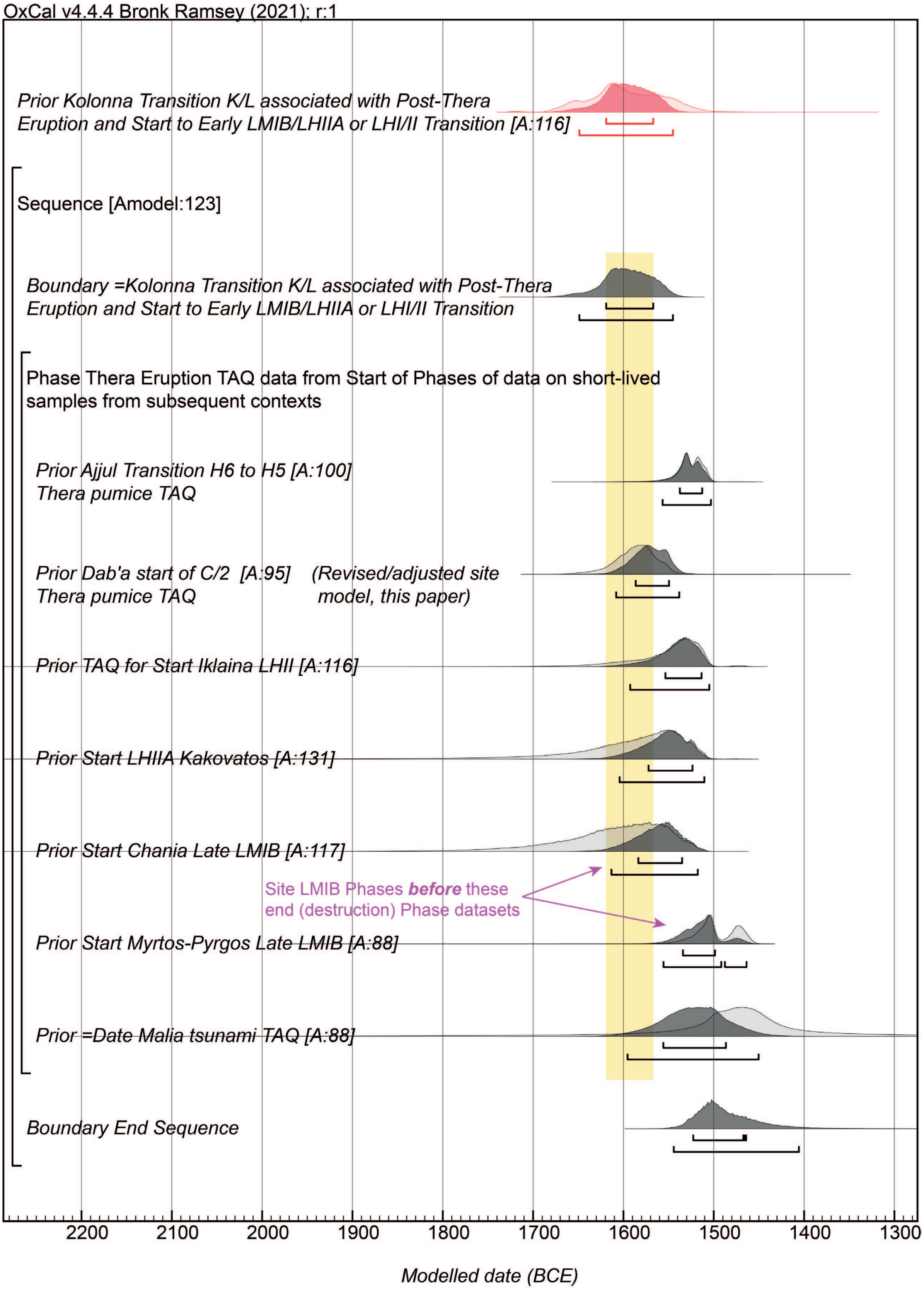


Figure 10. The modelled Boundaries or a Date query from a Phase containing these prior modelled data from respective site sequences (see Manning 2024b with all data in the Supplementary Material there) that each set a *terminus ante quem* (TAQ) for the Thera volcanic eruption. Some are close TAQs and some involve more substantial periods of time (e.g. the gap from close of LMIB site destructions to the start of LMIB phase, see text). A Boundary placed before this Phase therefore offers an estimate for the date of the Thera eruption as before this subsequent evidence (the 68.3% hpd range is shown as the shaded bar). For the modelled calendar ranges, see Table 3. Data obtained using OxCal (Bronk Ramsey 2009a; 2009b) version 4.4.4 with IntCal20 (Reimer *et al.* 2020) with curve resolution set at 1 year and kIterations = 3000.

Manning 2022; 2024a; 2024b; present paper). Already, this coalescence substantially changes past convention and hence historical and cultural structures, since either current position places the LMIA period as entirely or almost entirely contemporary with the Hyksos/SIP era (and also the formation era of the Old Hittite Kingdom in Anatolia), and separate from the New Kingdom of Egypt, contrary the original formulation and associated cultural associations where the start of the Late Bronze Age in the Aegean was effectively coeval with the start of the New Kingdom in Egypt (e.g. Evans 1921-1935; Furumark 1950; Betancourt and Weinstein 1976).

The addition of the sequences of radiocarbon dates on four branches from an olive shrub from Therasia killed by the Minoan eruption of the Thera volcano (Pearson *et al.* 2023), when analysed integrating prior constraints around date order from inner to outer/bark samples, maximum possible calendar time represented by each branch sequence, and an assumption that the outer/bark growth increments all date more or less a same/similar period when the olive shrub was killed by the Thera eruption, allows even better refinement of the Thera eruption date (present paper; Manning 2024b). This conclusion remains the case *even if* a radiocarbon offset is applied to the Therasia olive wood samples as suggested by Pearson *et al.* (2023) – although in reality the offset suggested appears too large and in fact there is a lack of any good evidence – for this case – for any substantive offset at all. Analysis of the Therasia data suggests that a date for the Thera eruption around 1561 BCE (when ice-core evidence attests a major volcanic eruption) is now about as late as is even possible, to borderline very unlikely, whereas a much more likely solution is a date either ca. 1611 BCE (when ice-core evidence attests another major volcanic eruption), or a date somewhere around 1600 BCE or end 17th century BCE (with Thera missing, perhaps, in currently available ice-core records). Hence even the current *ca.* 50-year 'Thera date debate' range seems to be narrowing. New discoveries and re-assessments – especially around Khyan and earlier New Kingdom assemblages in Egypt – make the archaeological evidence much more amenable to, or even favourable towards, such an earlier Aegean chronology for the MMIII-LMIB periods. And so, rather than endlessly trying to defend the traditional archaeological-historical chronology come what may, it perhaps becomes time to consider the alternative history and cultural context of an Aegean-East Mediterranean-Anatolian synthesis based around a coherent radiocarbon timeframe with a higher Aegean MMIII-LMI chronology.

Endnote: The volume of Driessen and Fantuzzi (2024) had not appeared by the time this paper had to be submitted to *JGA*. Hence there is no discussion of the papers published there.

Acknowledgements

I thank John Bintliff for the invitation to write this response essay; I thank Tizziano Fantuzzi for his enthusiastic and stimulating paper, notwithstanding that I disagree with the main conclusions. I thank Jacob Damm for discussions and advice on Egyptian and Levantine material culture. I should also acknowledge Malcolm H. Wiener who, through his determined and financially generous efforts over many years to disprove a higher (earlier) date for the Thera eruption (hoping instead to find evidence for something like his preferred date, from recent publications like his paper in Driessen and Fantuzzi 2024, or Wiener 2010, around 1525 BCE), has supported the production of key data such as those reported in Pearson *et al.* (2023). At a minimum, such recent data and analysis serve, ironically, to show an increasing coalescence and agreement that the possible Thera eruption dates are somewhere between the late 17th century to mid-16th century BCE (and likely the range of debate is now about 50 years in total and perhaps between e.g. 1611 BCE and 1561 BCE), and they rule out the former conventional date estimates in the later 16th century BCE or around ca. 1500 BCE. This all means a Thera eruption date and a LMIA period that is contemporary with both the SIP and the formation era of the Old Hittite Kingdom, and hence the real story is that the Aegean and Near Eastern fields have a revised historical context and synthesis to consider and work through. This is especially the case since, with appropriate analysis (see this paper and

especially Manning 2024b), the new data in Pearson *et al.* (2023) in fact support the earlier end of the new ‘consensus’ range, and thus an earlier/high Aegean chronology with a Thera eruption date perhaps ca. 1611 BCE or more generally around 1600 BCE.

Appendix: example OxCal runfiles

This is the OxCal runfile for the model shown in Figure 1 (results in Figure 2A). Variations of this model, as described in the text and captions, are used for the models reported in Figures 2-6. The kIterations value is increased to 3000 (x100 from default) to ensure good convergence in the model runs.

```
Options()
 {
  Resolution=1;
  Curve=”intcal20.14c”;
  kIterations=3000;
 };
 Plot()
 {
  Outlier_Model(“General”,T(5),U(0,4),”t”);
  Sequence()
  {
   Tau_Boundary (“T1”);
   Phase (“Akrotiri secure Stages 2/3 SL in Use/Storage”)
   {
    R_Date(“OxA-1552 Lathyrus sp.”,3390,65)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“OxA-1555 Lathyrus sp.”,3245,65)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“OxA-1548 Lathyrus sp.”,3335,60)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“OxA-1549 Lathyrus sp.”,3460,80)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“OxA-1550 Lathyrus sp.”,3395,65)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“OxA-1553 Lathyrus sp.”,3340,65)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“OxA-1554 Lathyrus sp.”,3280,65)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“OxA-1556 Hordeum sp.”,3415,70)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“K-5352 pulses”,3310,65)
    {
     Outlier (“General”,0.05);
    };
    R_Date(“K-3228 pulses”,3340,55)
    {
```

```
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-11817 ?Lathyrus sp.”,3348,31)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-11818 Hordeum sp.”,3367,33)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-11820 Hordeum sp.”,3400,31)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-11869 Hordeum sp.”,3336,34)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-12170 ?Lathyrus sp.”,3336,28)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-12171 Hordeum sp.”,3372,28)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-12175 Hordeum sp.”,3318,28)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“OxA-12172 Hordeum sp.”,3321,32)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“VERA-2756 Hordeum sp.”,3317,28)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“VERA-2757 ?Lathyrus sp.”,3315,31)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“VERA-2758 Hordeum sp.”,3339,28)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“VERA-2757 repeat ?Lathyrus sp.”,3390,32)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“VERA-2758 repeat Hordeum sp.”,3322,32)
  {
   Outlier (“General”,0.05);
  };
  R_Date (“OxA-25176 insect chitin”,3368,29)
  {
   Outlier (“General”,0.05);
  };
 };
 Boundary(“E2/3”);
};
Sequence(“Therasia olive sample 88-3”)
{
 Boundary();
 Sequence()
 {
  R_Date(“AA111457 88-3 Inner”,3314,23)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“AA110275 88-3 Outer”,3297,23)
```

```
  {
   Outlier (“General”,0.05);
  };
 };
 Boundary();
};
Sequence(“Therasia olive sample 88-2”)
{
 Boundary();
 Sequence()
 {
  R_Date(“AA110272 88-2 Inner”,3361,21)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“AA110273 88-2 Outer”,3341,23)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“AA110274 88-2 Bark”,3301,23)
  {
   Outlier (“General”,0.05);
  };
 };
 Boundary();
};
Sequence(“Therasia olive sample 88-1”)
{
 Boundary();
 Sequence()
 {
  R_Date(“AA111456 88-1 Inner”,3398,21)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“AA110271 88-1 Outer”,3320,22)
  {
   Outlier (“General”,0.05);
  };
 };
 Boundary();
};
Sequence(“Therasia olive sample 72-2”)
{
 Boundary();
 Sequence()
 {
  R_Date(“AA111458 72-2 Inner”,3358,23)
  {
   Outlier (“General”,0.05);
  };
  R_Date(“AA111459 72-2 Outer”,3342,24)
  {
   Outlier (“General”,0.05);
  };
 };
 Boundary();
};
Sequence()
{
 Tau_Boundary(“T2”);
 Phase(“End Boundary/Outer/Bark Dates for Thera Eruption”)
 {
  Date(“=AA110275 88-3 Outer”);
  Date(“=AA110274 88-2 Bark”);
  Date(“=AA110271 88-1 Outer”);
  Date(“=AA111459 72-2 Outer”);
 };
 Boundary(“E”);
};
Difference(“D1”,”AA110275 88-3 Outer”,”AA111457 88-3 Inner”,U(0,10));
```

```
  Difference(“D2”,”AA110274 88-2 Bark”,”AA110272 88-2 Inner”,U(0,79));
  Difference(“D3”,”AA110271 88-1 Outer”,”AA111456 88-1 Inner”,U(0,37));
  Difference(“D4”,”AA111459 72-2 Outer”,”AA111458 72-2 Inner”,U(0,50));
  Difference(“D5”,”E2/3”,”T1”,LnN(ln(2),ln(2)));
  Difference(“D6”,”E”,”E2/3”,LnN(ln(0.75),ln(3)));
  Tau=(E-T2);
  Tau&=LnN(ln(2),ln(2));
 };
```

This is an example of the OxCal runfile for the model used to produce the results reported in Figure 7. Here is the sample with Delta_R, the radiocarbon offset factor in ^{14}C years, considered as 10±0 ^{14}C years. Adjust this from `Delta_R(“test”,-20,0);` to `Delta_R(“test”,70,0);` for all the model results reported in Figure 7. This is the version with the interval between inner and outer increments as 0-100% reported increments = calendar years. For the 0-50% version, change the four Difference lines at the end to:

```
Difference(“D2”,”AA110275 88-3 Outer”,”AA111457 88-3 Inner”,U(0,5));
Difference(“D3”,”AA110274 88-2 Bark”,”AA110272 88-2 Inner”,U(0,40));
Difference(“D4”,”AA110271 88-1 Outer”,”AA111456 88-1 Inner”,U(0,19));
Difference(“D5”,”AA111459 72-2 Outer”,”AA111458 72-2 Inner”,U(0,25));
```

The models used for Figures 8 and 9 employ the same model structure as below but after deleting the line of code: `Delta_R(“test”,10,0);` and then changing the ^{14}C values (not the errors) for each of the Therasia samples based on IntCal20 values for the assumed calendar years (variously for the 100% or 50% interval length models) – see main text for years used – and adjusting the Difference query constraints (as above between the 100% and 50% models) as appropriate. To enhance run efficiency users can change the initial Boundary for each sample Phase from `Boundary();` to `Boundary(U(-1700,-1450));` This constraint for the start Boundary of the Phase at uniform probability to anywhere between 1700 BCE and 1450 BCE is neutral for the model results and the topic being investigated.

```
Options()
 {
  Resolution=1;
  Curve=”intcal20.14c”;
  kIterations=3000;
 };
 Plot()
 {
  Delta_R(“test”,10,0);
  Sequence(“Therasia olive sample 88-3”)
  {
   Boundary();
   Sequence()
   {
    R_Date(“AA111457 88-3 Inner”,3314,23);
    R_Date(“AA110275 88-3 Outer”,3297,23);
   };
   Boundary();
  };
  Sequence(“Therasia olive sample 88-2”)
  {
   Boundary();
   Sequence()
   {
    R_Date(“AA110272 88-2 Inner”,3361,21);
    R_Date(“AA110273 88-2 Outer”,3341,23);
    R_Date(“AA110274 88-2 Bark”,3301,23);
   };
   Boundary();
  };
  Sequence(“Therasia olive sample 88-1”)
  {
   Boundary();
   Sequence()
   {
    R_Date(“AA111456 88-1 Inner”,3398,21);
    R_Date(“AA110271 88-1 Outer”,3320,22);
   };
   Boundary();
  };
  Sequence(“Therasia olive sample 72-2”)
```

```
 {
  Boundary();
  Sequence()
  {
   R_Date(“AA111458 72-2 Inner”,3358,23);
   R_Date(“AA111459 72-2 Outer”,3342,24);
  };
  Boundary();
 };
 Sequence()
 {
  Tau_Boundary(“T”);
  Phase(“End Boundary/Outer/Bark Dates for Thera Eruption”)
  {
   Date(“=AA110275 88-3 Outer”);
   Date(“=AA110274 88-2 Bark”);
   Date(“=AA110271 88-1 Outer”);
   Date(“=AA111459 72-2 Outer”);
  };
  Boundary(“Eruption”);
 };
 Difference(“D1”,”AA110275 88-3 Outer”,”AA111457 88-3 Inner”,U(0,10));
 Difference(“D2”,”AA110274 88-2 Bark”,”AA110272 88-2 Inner”,U(0,79));
 Difference(“D3”,”AA110271 88-1 Outer”,”AA111456 88-1 Inner”,U(0,37));
 Difference(“D4”,”AA111459 72-2 Outer”,”AA111458 72-2 Inner”,U(0,50));
 Tau=(Eruption-T);
 Tau&=U(0,10);
};
```

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