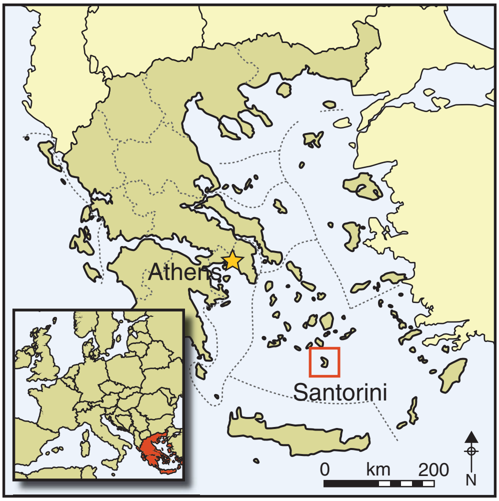
Dating the Thera (Santorini) eruption: archaeological and scientific evidence supporting a high chronology

Sturt W. Manning[1], Felix Höflmayer[2], Nadine Moeller[2], Michael W. Dee[3], Christopher Bronk Ramsey[3], Dominik Fleitmann[4], Thomas Higham[3], Walter Kutschera[5] & Eva Maria Wild[5]



The date of the Late Bronze Age Minoan eruption of the Thera volcano has provoked much debate among archaeologists, not least in a recent issue of Antiquity *('Bronze Age catastrophe and modern controversy: dating the Santorini eruption', March 2014). Here, the authors respond to those recent contributions, citing evidence that closes the gap between the conclusions offered by previous typological, stratigraphic and radiometric dating techniques. They reject the need to choose between alternative approaches to the problem and make a case for the synchronisation of eastern Mediterranean and Egyptian chronologies with agreement on a 'high' date in the late seventeenth century BC for the Thera eruption.*

Keywords: Santorini, Thera, Late Bronze Age, Minoan eruption, radiocarbon dating, chronology

Introduction

For several decades there has been a debate over the date of the Late Bronze Age Minoan eruption of Thera and the associated synchronisation of eastern Mediterranean civilisations: principally between a 'high' date in the later seventeenth century BC (radiocarbon (^{14}C) based), and a 'low' (or conventional) date in the late sixteenth to early fifteenth century

1 *Department of Classics and Cornell Institute of Archaeology and Material Studies, Cornell University, Goldwin Smith Hall, Ithaca, NY 14853-3201, USA (Email: sm456@cornell.edu)*
2 *The Oriental Institute, University of Chicago, 1155 East 58th Street, Chicago, IL 60637, USA*
3 *Research Laboratory for Archaeology and the History of Art, University of Oxford, Dyson Perrins Building, South Parks Road, Oxford OX1 3QY, UK*
4 *Department of Archaeology, University of Reading, Whiteknights, PO Box 227, Reading RG6 6AB, UK*
5 *Vienna Environmental Research Accelerator (VERA) Laboratory, Faculty of Physics, University of Vienna, Währinger Strasse 17, A-1090 Vienna, Austria*

BC (Warburton 2009). The 'low' position claims it is based on archaeological evidence and simply ignores the large body of contrary ^{14}C data and other contradictory scientific information (e.g. Bietak 2003, 2013; Warren 2010a & b; Wiener 2010). Some scholars thus characterise this divide as an antagonistic science *versus* archaeology struggle (Bietak 2003, 2013). *Antiquity* recently published a paper (Cherubini *et al.* 2014) and some comments (Bietak 2014; MacGillivray 2014), which continue this divisive approach.

We write to reject arguments that there are alternative choices of 'archaeology' *or* 'science'. Instead, there is a necessity for integrated analysis (Pollard & Bray 2007). Moreover, we highlight that critical examination of the historical, archaeological and scientific evidence shows that it does not support the Aegean 'low' chronology. In fact, recent work across the full scholarly gamut of textual analysis, archaeology and science supports the 'high' chronology for the Thera eruption and the beginning of the Aegean Late Bronze Age (e.g. Höflmayer 2012a; Badertscher *et al.* 2014; Manning 2014; Ritner & Moeller 2014). The synchronisation of eastern Mediterranean civilisations in the second millennium BC is taking shape around a chronology consistent with the ^{14}C timescale for both Egypt (Bronk Ramsey *et al.* 2010; Quiles *et al.* 2012; Manning *et al.* 2013) and the Aegean (Friedrich *et al.* 2006; Manning *et al.* 2006; Bruins *et al.* 2009; Wild *et al.* 2010; Lindblom & Manning 2011; Höflmayer 2012a; Höflmayer *et al.* 2013; Manning 2014)—and with the Middle (or a near-Middle) chronology for Mesopotamia (e.g. Barjamovic *et al.* 2012; Roaf 2012; de Jong 2013)—with Babylonian records perhaps even preserving a trace of the Thera eruption's atmospheric effects (de Jong & Foertmeyer 2010). The notable exception is the archaeological chronology for the site of Tell el-Dab'a (see below), which is at odds with the ^{14}C timescale from this site (Kutschera *et al.* 2012).

Critique of Cherubini *et al.* (2014)

We agree that the accurate recognition of annual growth increments in most olive wood is problematic (Cherubini *et al.* 2013). Nonetheless, even if there were no tree-ring information available, the sequence of ^{14}C dates on the Thera olive branch buried by the eruption clearly supports a late seventeenth century BC date for the outer edge of the olive branch (Figure 1A) (see also Friedrich *et al.* 2014). Indeed, consideration of the timespan indicated by the segments dated from the Thera olive branch in such a sequence analysis using OxCal, *versus* the scale of the sample, allows a reasonable estimate for the extant outside edge as *before c.* 1600 BC (Figure 1B & C). The olive branch—if the death of the tree was caused by the eruption (see below)—thus remains both relevant and in clear support of a 'high' chronology. Cherubini *et al.* (2014) otherwise mislead concerning archaeology and ^{14}C.

Archaeology

Cherubini *et al.* (2014: 268) write that the 'low' "dating appears to be strongly supported by the presence and sequence of Egyptian artefacts found in the Aegean as well as by large amounts of Cypriot pottery of various phases found both in Egypt and in one notable case also in the Theran volcanic destruction layer". However, chronologically useful Egyptian items are, in fact, very rare in the Aegean in the relevant period (mature–late Late Minoan

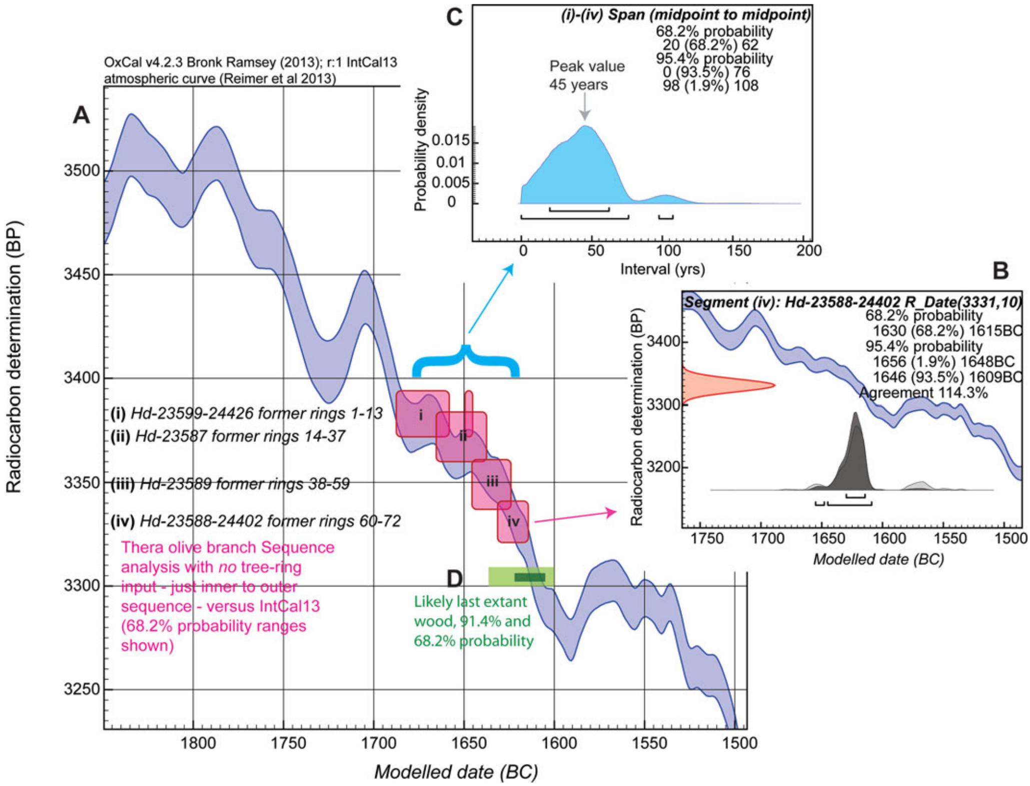


Figure 1. ***A)*** *Thera olive branch sequence from innermost to outermost dated segments, (i) to (iv), with no supposed tree-ring information, against IntCal13 (Reimer* et al. *2013) showing the most likely 68.2% probability ranges (from OxCal—Bronk Ramsey 2009a— with curve resolution = 1).* ***B)*** *Details for segment (iv) from A.* ***C)*** *The period in calendar years from the midpoints of (i) to (iv) in A. From the image of the olive branch in Warburton (2009: frontispiece), the distance between these mid-points represents* c. *85% of the total branch radius, and the distance from the midpoint of (iv) to the outside edge is* c. *7.5%. The allometry of tree/branch growth means we may expect more time to be represented in less distance towards the outer part of the sample.* ***D)*** *Nonetheless, given that 85% of the sample probably encompasses no more than 0–76 years (93.5% probability) and most likely no more than 20–62 years (see C), with a value somewhere centred around* c. *45 years (see C), it seems that even a very generous allowance could not place the last extant wood of the branch more than* c. *10 years after the midpoint of segment (iv). Thus, we find a last extant wood date no later than about 1622–1605 BC (68.2% probability) or 1636–1600 BC (most likely, 91.4%, range of the 95.4% probability range).*

IA). Presumably, Cherubini *et al*. refer to the few (just three) proposed Egyptian stone vessels discussed by Warren (2009: figs. 2a–c). Even these three are not clear-cut examples. Only two of the vessels have Egyptian parallels (for the vessel illustrated in Warren 2009: fig. 2c, Warren 2009: 184 writes "no twin can be produced from Egypt"). Others regard these objects as Levantine (see Manning 2014: 37–38 and literature cited). Even if they are Egyptian, it is not clear whether they are necessarily New Kingdom (Eighteenth Dynasty) as they could be Second Intermediate Period (SIP) in date (Höflmayer 2012a: 440–41); even Warren (2010a: 68) allows late SIP for one. 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.

Cherubini *et al.* (2014: 268) refer to "large amounts of Cypriot pottery. . .in Egypt". Detailed examination shows that the chronologically relevant items are quite a small subset. Nearly all items come from Tell el-Dab‘a, and from redeposited (secondary and tertiary) contexts. There are only a handful of relevant clear Late Cypriot I items of the Thera eruption period, and not one from Egypt derives from a primary context. Furthermore, the publications on Tell el-Dab‘a are equivocal about whether two Cypriot White Slip I sherds and one Cypriot Base Ring sherd might actually come from pre-New Kingdom (Stratum D) contexts (DAB 378, 383, 388: Maguire 2009) undermining the (only) New Kingdom date claim (Höflmayer 2012a: 442–43; Manning 2014: 39–41, 105). On critical review, this small body of archaeological material is very weak chronological evidence (Höflmayer 2011; 2012a; 2012b: 125–87; Manning 2014: 34–42).

Cherubini *et al.* (2014: 268) further state that an eruption date during the early New Kingdom "is also supported by the presence of pumice sourced to the Theran eruption in archaeological contexts in Egypt, the Near East and Cyprus (Doumas 2010), whereas all pumice found in earlier contexts has been sourced to other, earlier eruptions in the Dodecanese (Manning *et al.* 2006, 2009; Friedrich & Heinemeier 2009; Friedrich *et al.* 2009; Heinemeier *et al.* 2009)". This is an odd assertion as Doumas (2010) does not discuss pumice. Neither do Manning *et al.* (2006, 2009), Friedrich and Heinemeier (2009), Friedrich *et al.* (2009) or Heinemeier *et al.* (2009) address this subject, and so none of the references support the claim. In fact, the pumice data are inconclusive. Although more than 350 samples have been analysed, the overwhelming majority come from New Kingdom contexts, and only a few samples derive from the SIP. As Sterba *et al.* (2009: 1738) conclude: "the pumice data are still not conclusive". For a recent summary and critique of the pumice issue, and why it at best sets only a *terminus ante quem* for the Thera eruption, see Höflmayer (2012a: 441–42) and Manning (2014: 31, 198).

Radiocarbon

Cherubini *et al.* (2014: 271–72) finish by asserting "the date range of 1525–1490 BC proposed for the [Thera] eruption from numerous other ^{14}C studies". No references are given, and no studies support this statement. This date range is the 'low' archaeological position, which ignores or discounts the ^{14}C evidence. Cherubini *et al.* (2014: 271) also state that 'low' chronology 1525–1490 BC "interconnections with the well-established Egyptian historical chronology are now confirmed by 211 radiocarbon measurements (Bietak & Höflmayer 2007; Bronk Ramsey *et al.* 2010;

Warren 2010[b]; Wiener 2010)". Of these citations, only Bronk Ramsey *et al.* (2010) cover the Bayesian modelling study of a large set of ^{14}C dates on Egyptian samples, and that did not even discuss Aegean chronology. The other three citations criticise the use of ^{14}C in this region. Bronk Ramsey *et al.* (2010) do demonstrate that ^{14}C offers a detailed timeframe compatible with the historical Egyptian chronology—something previous scholarship sometimes questioned (e.g. Bietak 2003)—and so their work suggests that, as ^{14}C results are consistent with historical chronologies of Egypt, ^{14}C may reasonably be assumed to work elsewhere in the eastern Mediterranean (volcanic effects aside). In turn, we may assume that ^{14}C can offer the correct and independent timeframe to enable the synchronisation of the various archaeological sequences across the region.

Cherubini *et al.* (2014: 269) claim "the oscillating nature of the radiocarbon calibration curve over the relevant period. . .makes it impossible to distinguish on radiocarbon grounds alone between an event around 1610 BC and one around 1525 BC". This is incorrect. First, recent work employs Bayesian chronological modelling (Bayliss 2009; Bronk Ramsey 2009a) with a *sequence* of ^{14}C dates in order to overcome the single-case potential dating ambiguity (as, e.g., Manning *et al.* 2006), or considers the relevant Akrotiri volcanic destruction level (VDL) data set on short-lived samples as a weighted average (Manning & Kromer 2012), or as a group of events assumed to be distributed exponentially towards the end of the final pre-volcanic eruption phase at Akrotiri using a Tau_Boundary paired with a Boundary in OxCal (Bronk Ramsey 2009a) as in Höflmayer (2012a: fig. 2) (see Figure 2). In each case, a later seventeenth century BC date range is clearly most probable (Manning 2014: 60–74, 169–75, 191–95). The exponential (Tau_Boundary) model is particularly relevant to the discussion because it assumes that all the ^{14}C-dated samples are older than the eruption, even by a significant margin, ensuring that dates on individual residual samples or individual samples older for some other reason will not cause us to overestimate the age of the eruption. Cherubini *et al.* (2014) do not cite the detailed reappraisal of the evidence produced by Höflmayer (2012a), or any other relevant publication after 2010.

Second, even in the case of a single date calibration, things are not as alleged. Figure 3 shows the calibrated calendar age range of the weighted average ^{14}C date for the most appropriate 25 dates from the Akrotiri VDL on short-lived plant matter with a combined estimate (mean) of 3345$\pm$8 ^{14}C years BP (the 28-date set in Manning *et al.* 2006, but excluding the 3 Heidelberg dates: see Manning 2014: 45–46 and no. 38) with arbitrarily larger measurement errors of $\pm$15, $\pm$20, $\pm$25 and $\pm$30 ^{14}C years (the last at the level of a single modern ^{14}C date, ignoring the fact that 25 dates are available to narrow the precision in this case). In every case, the most likely 68.2% range lies solely in the seventeenth century BC. Only when the error is more than double the (actual) calculated one does a very small sixteenth century BC range become possible at 95.4% probability, and of course 88.4% of the probability (including the most likely 68.2%) still lies in the seventeenth century BC. Even with uncertainties allowed for, the most likely 68.2% range remains solely seventeenth century BC, and the sixteenth century BC range remains under 20% probability (and ends *before* 1530 BC). Contra Cherubini *et al.* (2014), ^{14}C does have the resolution to show that a later sixteenth century BC date is very unlikely.

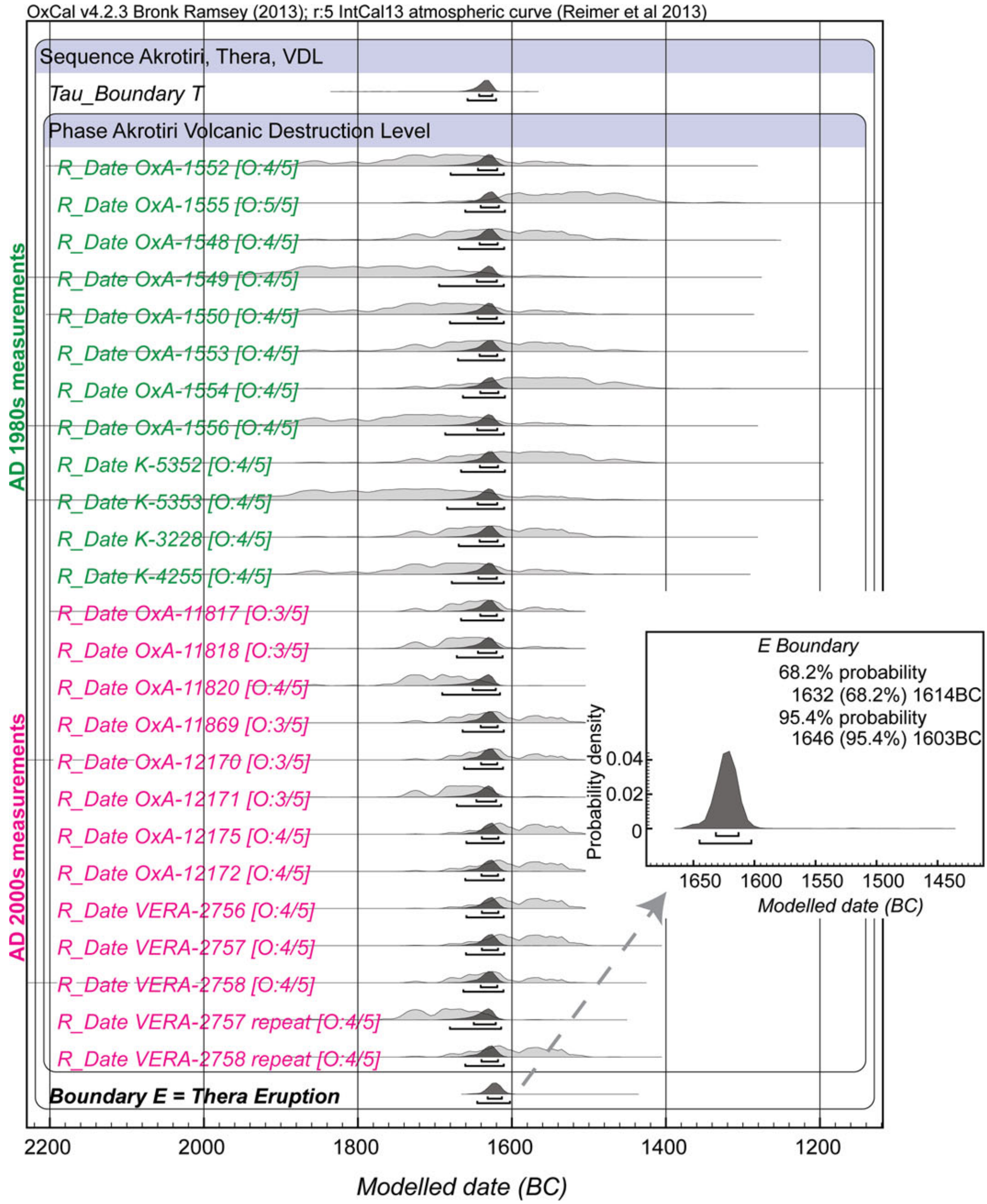


Figure 2. Modelled end of settlement (Boundary "E" = Thera eruption date) range based on 25 ^{14}C measurements of short-lived samples from Akrotiri in Manning et al. *(2006) excluding the three Heidelberg dates (see Manning 2014: 45–46 and no.38) when grouped as a Phase with a Tau_Boundary as the start ("T") and a Boundary ("E") as the end (Bronk Ramsey 2009a). There are no outliers, applying the General Outlier model of Bronk Ramsey (2009b). Calibrated ranges at 68.2% and 95.4% probability shown, from IntCal13 (Reimer* et al. *2013) employing OxCal (Bronk Ramsey 2009a) with curve resolution set at 5.*

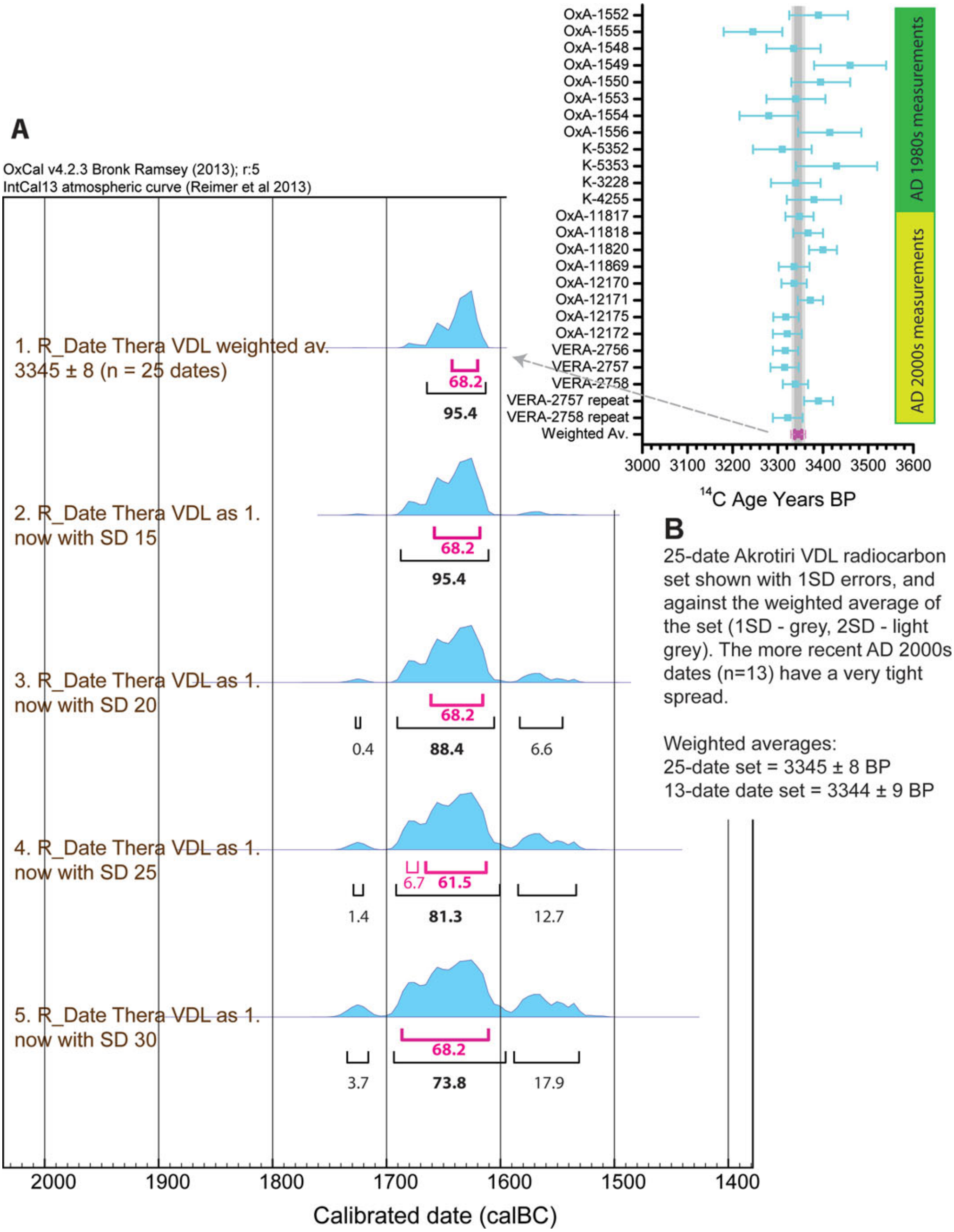


Figure 3. ***A)*** *The weighted average ^{14}C date for the set of 25 short-lived samples from the Akrotiri volcanic destruction layer (VDL) (see inset, B) = 3345±8 ^{14}C years BP, first as calculated with standard deviation of ±8 ^{14}C years, and then, arbitrarily, with larger errors of ±15, ±20, ±25 and ±30 ^{14}C years. Calibrated ranges at 68.2% and 95.4% probability shown (and sub-ranges where applicable), from IntCal13 (Reimer* et al. *2013) employing OxCal (Bronk Ramsey 2009a) with curve resolution set at 5.* ***B)*** *25-date ^{14}C set—see text—from the Akrotiri VDL on short-lived plant samples, 1σ errors, shown* versus *the weighted average of the set.*

Volcanic CO_2 has been raised as a possible issue for decades. But, as Bruins & van der Plicht (2014: 283–84) note, Cherubini *et al.* (2014) cite inappropriate volcanic analogies and offer no actual positive evidence. Furthermore, analysis of Aegean ^{14}C dates for the period not from Thera, and so clearly not affected by any possible volcanic CO_2 effect, nonetheless offer very similar age ranges for the time period of the Thera eruption—see Figure 4—contrary to the assertions of Cherubini *et al.* (2014: 271). This also addresses the question about whether the olive branch was alive at the time of the Thera eruption (Cherubini *et al.* 2014: 271). This is a possible complication; olive trees can carry dead branches. However, the ^{14}C dates on the olive branch offer conspicuously similar date ranges to the large set of ^{14}C ages from short-lived plant material from the VDL on Thera and from several other contemporary Aegean sites linked to the time of the Thera eruption (compare Figures 1–4). Cherubini *et al.* ignore the reasonable circumstantial case that this was *not* in fact a long-dead branch (Bruins & van der Plicht 2014: 284–86). There are also a number of other arguments for why it seems very unlikely that any substantive volcanic CO_2 effect applies with regard either to the dating of the olive branch or to the Akrotiri VDL (e.g. Friedrich *et al.* 2009; Heinemeier *et al.* 2009; Manning *et al.* 2009: 300–304; Manning & Kromer 2012; Manning 2014: 50–60).

Key recent evidence supporting the 'high' chronology

Khayan

The Hyksos king Khayan comprises a key element in the chronology of Tell el-Dab'a (he is purportedly linked to a palace complex of late Stratum E/1 and early Stratum D/3) and the 'low' Aegean chronology (e.g. Wiener 2010: 374–75; Bietak 2013: 84–86). Khayan is dated *c.* 1600–1580 BC by Bietak and usually placed towards the end of the Fifteenth (Hyksos) Dynasty. However, recent finds of a number of sealings of Khayan at Tell Edfu in Egypt, in near association with those of the Thirteenth Dynasty king Sobekhotep IV, indicate that this king instead dates some 80 years earlier (Moeller & Marouard 2011)—and a recent report from Tell el-Dab'a also indicates his place in the early Fifteenth Dynasty (Forstner-Müller & Rose 2012–2013). If the dates for Khayan are moved back, then the dates for the Tell el-Dab'a stratigraphy would match the ^{14}C dates from the site (Kutschera *et al.* 2012) (see Figure 5). However, such a significant revision of the Tell el-Dab'a chronology would also impact on inferences drawn from the 'low' Tell el-Dab'a chronology (Bietak 2013)—such as the arguments for dating Hazor via Tell el-Dab'a to lend support for the low Mesopotamian chronology (Bietak 2013: 81–84). Conversely, given the strong recent evidence for a solution in favour of a Middle or near-Middle Mesopotamian Chronology (see above), the find of a cuneiform letter fragment of later Old Babylonian type from the Khayan palace context at Tell el-Dab'a (Bietak & Forstner-Müller 2009: 115–18; Bietak 2013: 84) supports revision of the Tell el-Dab'a chronology in line with the site's ^{14}C evidence.

The new information about Khayan has key relevance to the Aegean chronology. A vessel lid with Khayan's cartouche was found at Knossos in a (most likely) Middle Minoan IIIB context (Macdonald 2005: 134; Höflmayer 2012b: 172–75). Instead of being an argument for the 'low' chronology (above), this now becomes further evidence supporting the 'high' chronology, as Khayan is (now) to be dated around 80 years earlier.

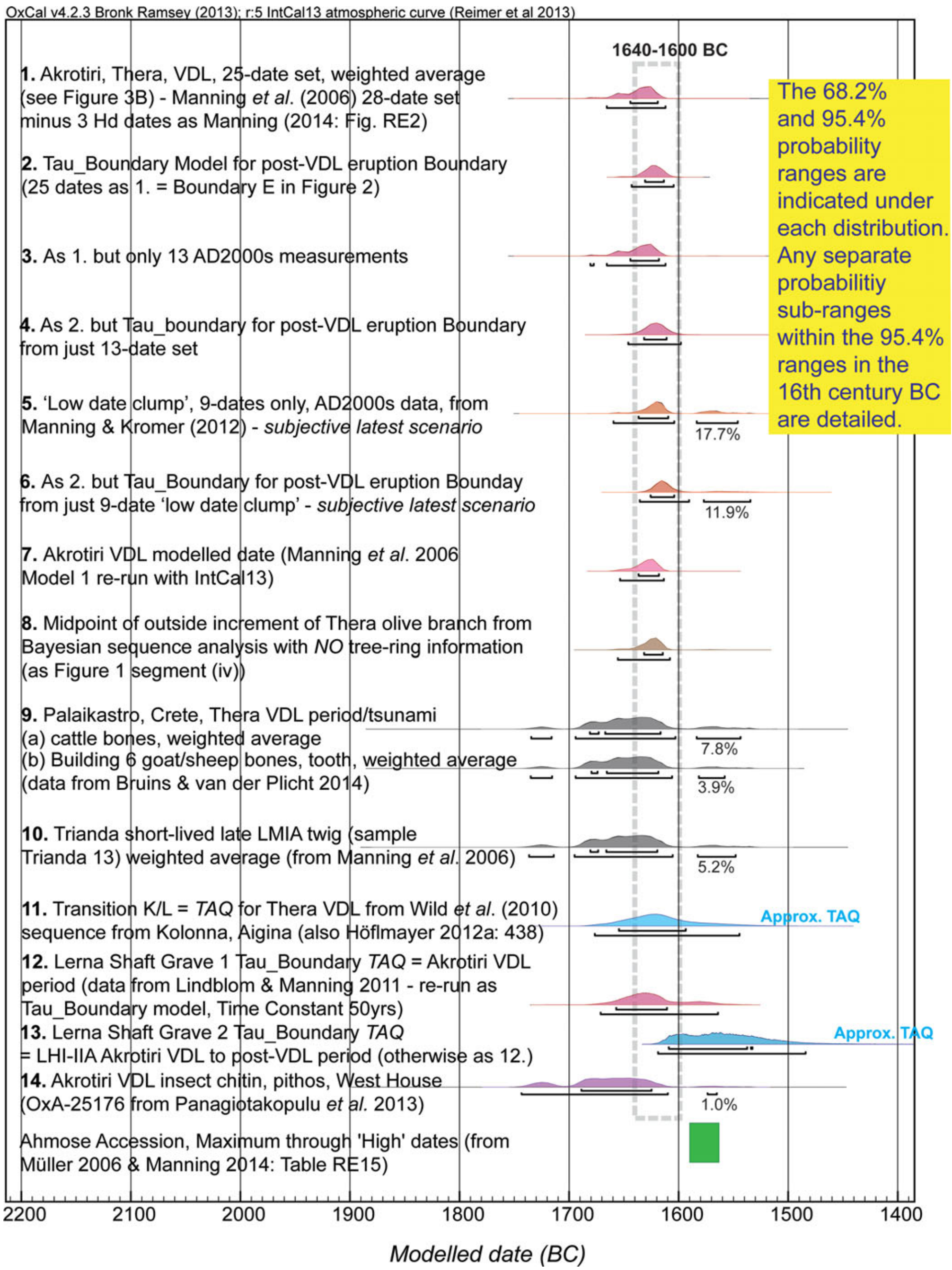


Figure 4. Calibrated calendar date ranges for the VDL at Akrotiri on Thera, or the immediately subsequent eruption, from short-lived plant samples (different approaches) and comparisons with the calibrated calendar date ranges for several other samples and contexts of approximately the same period from Thera, Crete, Rhodes and mainland Greece, and two approximate terminus ante quem *(TAQ) ranges for the Thera VDL period (from Aigina and mainland Greece). The earliest possible date (TPQ) for the accession of Ahmose is also shown. Data from OxCal (Bronk Ramsey 2009a) and IntCal13 (Reimer* et al. *2013) with curve resolution set at 5.*

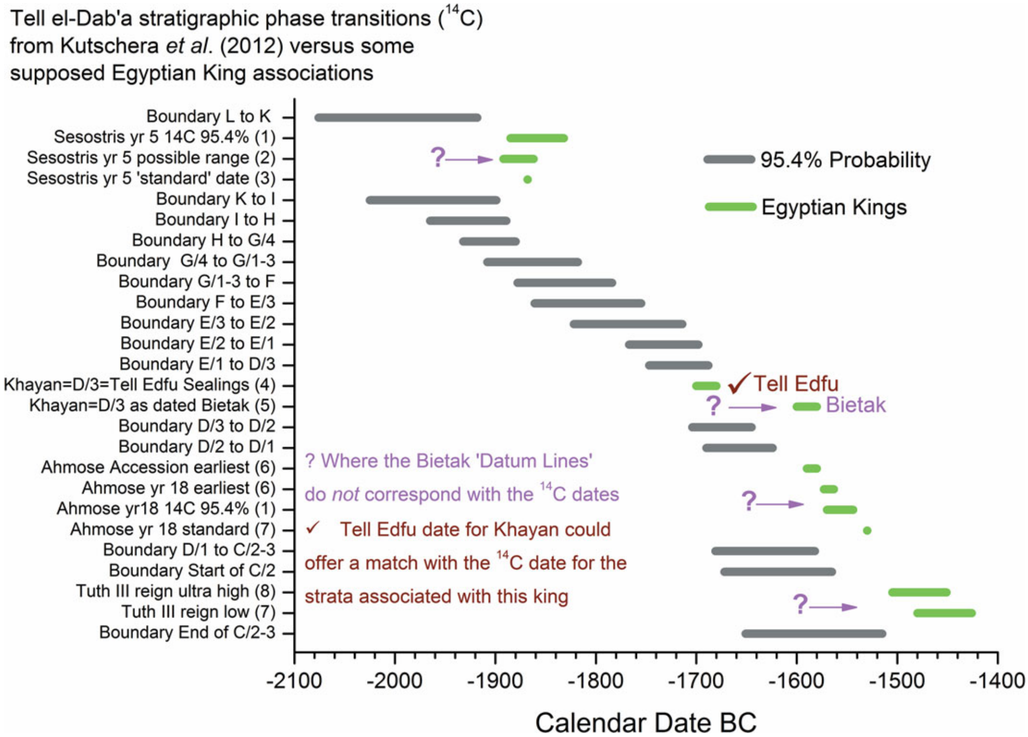


Figure 5. Comparison of the Bayesian modelled date ranges for the transitions between the stratigraphic phases (strata) from L to C/2–3 at Tell el-Dab'a after Kutschera et al. *(2012)* versus *the proposed dates for Egyptian kings linked to the Tell el-Dab'a sequence (Kutschera* et al. *2012: fig. 3; Bietak 2013) from historical and/or astronomical and/or ^{14}C dating. Sources: 1) Bronk Ramsey* et al. *2010; 2) Schneider 2008; 3) Gautschy 2011; 4) Moeller & Marouard 2011; 5) Bietak 2013: 86; 6) Müller 2006; 7) Schneider 2010; 8) Huber 2011, Aston 2012–2013, Gautschy 2013.*

Egyptian chronology

The start of the New Kingdom of Egypt has usually been placed at *c.* 1550 BC or 1540 BC in conventional scholarly assessments over the past three decades (e.g. *c.* 1548 BC in Schneider's thorough review of 2010). Recent historical, astronomical and ^{14}C work indicates either similar or slightly earlier dates (e.g. a 95.4% probability range of 1570–1544 BC: Bronk Ramsey *et al.* 2010: tab. 1) and highlights that a couple of decades of error/flexibility remain (Bronk Ramsey *et al.* 2010; Huber 2011; Quiles *et al.* 2012; Aston 2012–2013; Gautschy 2013; Manning 2014: 20–23, 116–33, 181–83). The very latest work indicates likely adjustments to some of the reign lengths employed by the Bronk Ramsey *et al.* (2010) analysis (especially Tuthmosis IV) (Aston 2012–2013). If the Bronk Ramsey *et al.* (2010) model is re-run, employing the subsequent IntCal13 calibration dataset (Reimer *et al.* 2013) and revised with a combination of Aston's (2012–2013) 'high' critical historical assessment of Eighteenth Dynasty internal chronology and otherwise Schneider's (2010) standard New Kingdom historical chronology, this suggests a 95.4% range for the accession of the first king, Ahmose, as early as 1585–1563 BC (Manning 2014: 184). Such dates are only a couple of decades earlier than the previous standard dates, but make a big difference. Higher dates for Ahmose remove much of the previous apparent 'gap' between a late seventeenth century BC date for the Thera eruption, *versus* the 'low' archaeological synthesis. Since claims for exclusive Eighteenth Dynasty associations for Cypriot White Slip I and some stone vessels are not sound—discussed above—a higher date for Ahmose permits most evidence to be consistent with the 'high' Aegean chronology.

The higher date for Ahmose has another important aspect: there is an unusual text from his reign (the Tempest Stela of Ahmose). This inscription suggests a possible association with the Thera eruption and its regional impacts (Ritner & Moeller 2014). Previously, with the accession of Ahmose *c.* 1550 BC or 1540 BC, the account in the Ahmose Tempest Stela seemed *c.* 50–75 years younger than the ^{14}C date for Thera. Now, with the date of Ahmose raised, and the eruption of Thera placed in the *late* seventeenth century BC, it is much more reasonable to consider an association of the Ahmose Tempest stela with the effects of the eruption, whether with Ahmose as a direct witness at the start of his reign or life, or as including a dramatic event from a little before.

Tell el-Dab'a

We have noted the discrepancy between the historical and archaeological chronology and the ^{14}C dates from the site (Kutschera *et al.* 2012). A critical review of the literature reveals additional issues. In particular, it is argued that four links ('datum lines') between Tell el-Dab'a and Egyptian kings structure the site's chronology (e.g. Bietak 2013: 80): a) stela mentioning the fifth year of Sesostris III for the start of Stratum K; b) palace of Khayan from late Stratum E/1 and early Stratum D/3; c) conquest (abandonment) by Ahmose at the end of Stratum D/2; and d) from Stratum C/2 "numerous scarabs from the Eighteenth Dynasty with the latest from Tuthmosis III and Amenhotep II" (Bietak 2013: 80). None of these datum lines seems, however, to be secure.

a) It is unclear whether the stela mentioning the fifth year of Sesostris III relates to the original building of the temple (Stratum K), or to an enlargement only, nor whether the stela was brought to the site from elsewhere, or that it necessarily belongs to this temple and not another proximate structure, or even that it is an original Sesostris III document (Czerny 2012: 61).

b) Assuming that the Khayan association is correct for the late Stratum E/1 and early Stratum D/3 palace—the link is less than certain as the key sealings come from a secondary context in a large offering pit (Bietak *et al.* 2012–2013: 25)—we have already discussed the recent finds which require a radical earlier re-dating of Khayan (compatible with the ^{14}C evidence).

c) There is no positive evidence for the supposed Ahmose link with the end of Stratum D/2—it is just an assumption based on the dramatic change in occupation in the area of Ezbet Helmi from a citadel to a large storage facility. The name of Ahmose is not attested.

d) The find contexts of the New Kingdom scarabs are from *after* the supposed Tuthmosid palace structures—thus, the association and dating of these buildings as Tuthmosid is questionable, and the older ^{14}C dates from these strata indicate that a rethink is necessary (Figure 5). These scarabs, some 30 of them inscribed with royal names from Ahmose to Amenhotep II, were retrieved from a small building compound, "the walls of which abutted on the eroded eastern ramp attached to Palace (F)" (Bietak *et al.* 2007: 27). The so-called Tuthmosid Palaces are not associated with any kings' names. The excavator then goes on: "[t]his was one of the reasons why, at the inception of the excavation, Palace (F), which was built before the supposed workshop, was dated pre-Ahmose" (Bietak *et al.* 2007: 27). The ^{14}C evidence suggests that this initial diagnosis was in fact perhaps correct (Figure 5).

Given these complications, and the evident problems in the interpretation of the archaeological chronology of Tell el-Dab'a, this site should not be used as a firm chronological foundation or as a basis for arguments against ^{14}C, or for (re-)interpretation of other archaeological evidence (*contra* Bietak 2013; Porter 2013).

White Slip I

Bietak (2014: 281) repeats claims that Manning (1999) argued that White Slip I started in northern Cyprus 150 years before the south of the island. This is not the case. There is certainly a regional pattern on Cyprus, with eastern Cyprus adopting some of the new Late Cypriot I package later than the north-west (and this may even reflect separate political entities (Brown 2013: 130–31), but the chronological gap Bietak refers to is a product only of his low dating of residual material at Tell el-Dab'a. As discussed above, evidence at Tell el-Dab'a may even suggest that White Slip I ante-dates the New Kingdom—thus, on current evidence, a date *before* perhaps *c*. 1564 BC (Gautschy 2013: 67) or *before c*. 1585–1563 BC from ^{14}C (95.4% range: Manning 2014: 184). The White Slip I bowl from pre-eruption Thera in the later seventeenth century BC is, therefore, not 150 years earlier, as observed by Höflmayer (2012a) (for a brief re-statement of the White Slip I issue, see Manning 2014: 39–41).

Sofular speleothem

Geochemical analysis of the Sofular Cave speleothem (northern Turkey) offers a coherent package of changes in specific trace elements (bromine, molybdenum, sulphur) very likely indicating a major volcanic impact (Badertscher *et al.* 2014). It is argued that bromine may be the most sensitive indicator, offering a clear, short-lived peak at 1621±25 BC, with molybdenum following at 1617±25 BC and sulphur later at 1589±25 BC—the observed sequence (Br, Mo, S) in the speleothem relates to differences in retention rates in the soil above the Sofular Cave. It is important to note that there are no such indications in the trace elements in the later sixteenth to early fifteenth centuries BC (Badertscher *et al.* 2014: fig. 5). Given the pattern of, and dates for, these changes, and the geographic situation with just one very large volcanic eruption in the proximate region around this time, the enormous Thera eruption (Johnston *et al.* 2014) seems the obvious (but not proven) candidate.

Radiocarbon

At present, the only direct dating evidence for the Thera eruption and the associated Aegean periods comes from ^{14}C. Since the demonstration that ^{14}C analysis can achieve a coherent chronology consistent with the approximate historical Egyptian chronology for the second and earlier first millennia BC (Bronk Ramsey *et al.* 2010), there is every reason to expect ^{14}C to provide a valid chronology for Aegean prehistory (independent of the step-wise logic transfers inherent in the archaeological and art-historical modes of chronology building). ^{14}C dates from Thera, and from locations well away from Thera, offer the same chronology for the later Late Minoan IA period around the time of the eruption (Figure 4)—excluding any volcanic CO_2 or other 'offset' claim, while Bayesian analysis of an archaeologically defined time-series of ^{14}C dates overcomes any single-case dating ambiguities caused by the history of past atmospheric levels of ^{14}C (the wiggly shape of the calibration curve) (e.g. Manning *et al.* 2006; Wild *et al.* 2010; Manning 2014: 66–74, 191–95). Repeated measurements at different laboratories employing slightly different protocols have achieved very similar ^{14}C results for samples from the Aegean and from Egypt—notably as detailed in the studies of Manning *et al.* (2006) and Bronk Ramsey *et al.* (2010). Therefore, although a few Aegean 'low' chronology scholars have repeatedly suggested that there must be problems with ^{14}C dating (e.g. Wiener 2010, 2012), we dismiss such concerns and regard the ^{14}C-based chronology as sound.

The ^{14}C evidence from the VDL on Thera and other contemporary sites yields a clear and coherent timeframe indicating a probable date in the late seventeenth century BC (Figures 1–4). The sequence of ^{14}C dates (no tree-rings) on an olive branch found buried in the Minoan eruption pumice also indicates a late seventeenth century BC date (Figure 1). If we narrow our dataset down to the recent AD 2000s, ^{14}C measurements from Akrotiri on short-lived samples—13 dates on plant matter (Manning *et al.* 2006), one date on insect chitin (Panagiotakopulu *et al.* 2013)—the dataset clearly indicates a seventeenth century BC date (Figure 4 nos. 3–4 & 14). Even subjectively choosing to consider just the group of the nine latest dates from this set (very much biasing the situation to the latest possible date), as discussed in Manning & Kromer (2012), either a Tau_Boundary model or the weighted average still overwhelmingly indicate a seventeenth century BC date range—see Figure 4 nos. 5–6—and *not* a date range in the late sixteenth century BC as required by the 'low' chronology.

Conclusions

The Thera debate has come full circle. What began as a belated element of the (second) ^{14}C revolution in the Aegean in the 1970s and led to something of a divide between the approaches of conventional archaeology and archaeological science, now finds approximate resolution in a body of consistent information from recent archaeological finds, renewed textual and astronomical analysis, and science-based work. It is now time for the archaeology and history of the second millennium BC Aegean and eastern Mediterranean to be responsibly analysed, taking account of the increasingly coherent chronology based on ^{14}C and the latest archaeological and scientific research.

References

ASTON, D. 2012–2013. Radiocarbon, wine jars and New Kingdom chronology. *Ägypten und Levante* 22–23: 289–315.

BADERTSCHER, S., A. BORSATO, S. FRISIA, H. CHENG, R.L. EDWARDS, O. TÜYSÜZ & D. FLEITMANN. 2014. Speleothems as sensitive recorders of volcanic eruptions—the Bronze Age Minoan eruption recorded in a stalagmite from Turkey. *Earth and Planetary Science Letters* 392: 58–66. http://dx.doi.org/10.1016/j.epsl.2014.01.041

BARJAMOVIC, G., T. HERTEL & M.T. LARSEN. 2012. *Ups and downs at Kanesh—observations on chronology, history and society in the Old Assyrian period*. Leiden: Nederlands Instituut voor het Nabije Oosten.

BAYLISS, A. 2009. Rolling out revolution: using radiocarbon dating in archaeology. *Radiocarbon* 51: 123–47.

BIETAK, M. 2003. Science versus archaeology: problems and consequences of high Aegean chronology, in M. Bietak (ed.) *The synchronisation of civilisations in the eastern Mediterranean in the second millennium BC. II*: 23–33. Vienna: Austrian Academy of Sciences Press.

– 2013. Antagonisms in historical and radiocarbon chronology, in A.J. Shortland & C. Bronk Ramsey (ed.) *Radiocarbon and the chronologies of ancient Egypt*: 76–109. Oxford: Oxbow.

– 2014. Radiocarbon and the date of the Thera eruption. *Antiquity* 88: 277–82.

BIETAK, M. & I. FORSTNER-MÜLLER, WITH F. RADNER & F. VAN KOPPEN. 2009. Der Hyksospalast bei Tell el-Dab'a. Zweite und Dritte Grabungskampagne (Frühling 2008 und Frühling 2009). *Ägypten und Levante* 19: 91–119.

BIETAK, M. & F. HÖFLMAYER. 2007. Introduction: high and low chronology, in M. Bietak & E. Czerny (ed.) *The synchronisation of civilizations in the eastern Mediterranean in the second millennium B.C.—III*: 13–23. Vienna: Austrian Academy of Sciences Press.

BIETAK, M., N. MARINAROS & C. PALYVOU. 2007. *Taureador scenes in Tell el-Dab'a (Avaris) and Knossos*. Vienna: Austrian Academy of Sciences Press.

BIETAK, M., N. MATH, V. MÜLLER & C. JURMAN. 2012–2013. Report on the excavations of a Hyksos Palace at Tell el-Dab'a/Avaris (23rd August–15th November 2011). *Ägypten und Levante* 22–23: 17–54.

BRONK RAMSEY, C. 2009a. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51: 337–60.

– 2009b. Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51: 1023–45.

BRONK RAMSEY, C., M.W. DEE, J.M. ROWLAND, T.F.G. HIGHAM, S.A. HARRIS, F.A. BROCK, A. QUILES, E.M. WILD, E.S. MARCUS & A.J. SHORTLAND. 2010. Radiocarbon-based chronology for Dynastic Egypt. *Science* 328: 1554–57. http://dx.doi.org/10.1126/science.1189395

BROWN, M. 2013. Waterways and the political geography of south-east Cyprus in the second millennium BC. *Annual of the British School at Athens* 108: 121–36. http://dx.doi.org/10.1017/S006824541300004X

BRUINS, H.J. & J. VAN DER PLICHT. 2014. The Thera olive branch, Akrotiri (Thera) and Palaikastro (Crete): comparing radiocarbon results of the Santorini eruption. *Antiquity* 88: 282–87.

BRUINS, H.J., J. VAN DER PLICHT & J.A. MACGILLIVRAY. 2009. The Minoan Santorini eruption and tsunami deposits in Palaikastro (Crete): dating by geology, archaeology, ^{14}C and Egyptian chronology. *Radiocarbon* 51: 397–411.

CARTER, H. 1916. Report on the tomb of Zeser-Ka-Ra Amenhetep I, discovered by the Earl of Carnarvon in 1914. *Journal of Egyptian Archaeology* 3: 147–54. http://dx.doi.org/10.2307/3853752

CHERUBINI, P., T. HUMBEL, H. BEECKMAN, H. GÄRTNER, D. MANNES, C. PEARSON, W. SCHOCH, R. TOGNETTI, & S. LEV-YADUN. 2013. Olive tree-ring problematic dating: a comparative analysis on Santorini (Greece). *PLoS ONE* 8(1): e54730. http://dx.doi.org/10.1371/journal.pone.0054730

– 2014. The olive-branch dating of the Santorini eruption. *Antiquity* 88: 267–73.

CZERNY, E. 2012. 'Ezbet Rushdi: glimpses of a 12th Dynasty town- and temple site, in R. Schiestl & A. Seiler (ed.) *Handbook of pottery of the Egyptian Middle Kingdom. Volume* II*: the regional volume*: 61–72. Vienna: Austrian Academy of Sciences Press.

DE JONG, T. 2013. Astronomical fine-tuning of the chronology of the Hammurabi Age. *Jaarbericht van het Vooraziatisch-Egyptisch Genootschap "*Ex Oriente Lux*"* 44: 147–67.

DE JONG, T. & V. FOERTMEYER. 2010. A new look at the Venus observations of Ammisaduqa: traces of the Santorini eruption in the atmosphere of Babylon? *Jaarbericht van het Vooraziatisch-Egyptisch Genootschap* "Ex Oriente Lux" 42: 143–59.

DOUMAS, C. 2010. Akrotiri, in E.H. Cline (ed.) *The Oxford handbook of the Bronze Age Aegean (ca.* 3000–1000*BC)*: 752–61. Oxford: Oxford University Press.

FORSTNER-MÜLLER, I. & P. ROSE. 2012–2013. Grabungen des Österreichischen Archäologischen Instituts Kairo in Tell el-Dab'a/Avaris: Das Areal R/III. 1. Vorbericht (Herbst 2010 bis Frühjahr 2011). *Ägypten und Levante* 22–23: 55–73.

FRIEDRICH, W.L. & J. HEINEMEIER. 2009. The Minoan eruption of Santorini radiocarbon dated to 1613±13 BC—geological and stratigraphic considerations, in D.A. Warburton (ed.) *Time's up! Dating the Minoan eruption of Santorini*: 56–63. Athens: Danish Institute at Athens.

FRIEDRICH, W., B. KROMER, M. FRIEDRICH, J. HEINEMEIER, T. PFEIFFER & S. TALAMO. 2006. Santorini eruption radiocarbon dated to 1627–1600 BC. *Science* 312: 548. http://dx.doi.org/10.1126/science.1125087

– 2009. Santorini eruption radiocarbon dated to 1627–1600 BC: further discussion, in S.W. Manning & M.J. Bruce (ed.) *Tree-rings, kings and Old World archaeology and environment: papers presented in honor of Peter Ian Kuniholm*: 293–98, 327. Oxford: Oxbow.

– 2014. The olive branch chronology stands irrespective of tree-ring counting. *Antiquity* 88: 274–77.

GAUTSCHY, R. 2011. Monddaten aus dem Archiv von Illahun: Chronologie des Mittleren Reiches. *Zeitschrift für Ägyptische Sprache und Altertumskunde* 138: 1–19. http://dx.doi.org/10.1524/zaes.2011.0002

– 2013. Chronology of the Egyptian New Kingdom revisited, in C. Graves, G. Heffernan, L. McGarrity, E. Millward & M. Sfakianou Bealby (ed.) *Current research in Egyptology 2012. Proceedings of the Thirteenth Annual Symposium, University of Birmingham 2012*: 55–69. Oxford: Oxbow.

HEINEMEIER, J., W.L. FRIEDRICH, B. KROMER, & C. BRONK RAMSEY. 2009. The Minoan eruption of Santorini radiocarbon dated by an olive tree buried by the eruption, in D.A. Warburton (ed.) *Time's up! Dating the Minoan eruption of Santorini*: 285–93. Athens: Danish Institute at Athens.

HÖFLMAYER, F. 2011. Egyptian pots, Aegean chronology and radiocarbon dating: recent research on Egypt and the Aegean early Late Bronze Age, in M. Horn, J. Kramer, D. Soliman, N. Staring, C. van den Hoven & L. Weiss (ed.) *Current research in Egyptology 2010. Proceedings of the Eleventh Annual Symposium which took place at Leiden University, the Netherlands, January 2010*: 62–70. Oxford: Oxbow.

– 2012a. The date of the Minoan Santorini eruption: quantifying the "offset". *Radiocarbon* 54: 435–48.

– 2012b. *Die Synchronisierung der minoischen Alt- und Neupalastzeit mit der ägyptischen Chronologie*. Wien: Verlag der Österreichischen Akademie der Wissenschaften.

HÖFLMAYER, F., A. HASSLER, W. KUTSCHERA & E.M. WILD. 2013. Radiocarbon data for Aegean pottery in Egypt: new evidence from Saqqara (Lepsius) Tomb 16 and its importance for LMIB/LHIIA, in A.J. Shortland & C. Bronk Ramsey (ed.) *Radiocarbon and the chronologies of ancient Egypt*: 110–20. Oxford: Oxbow.

HUBER, P.J. 2011. The astronomical basis of Egyptian chronology of the second millennium BC. *Journal of Egyptian History* 4: 172–227. http://dx.doi.org/10.1163/187416611X618721

JOHNSTON, E.N., R.S.J. SPARKS, J.C. PHILLIPS & S. CAREY. 2014. Revised estimates for the volume of the Late Bronze Age Minoan eruption, Santorini, Greece. *Journal of the Geological Society, London* 171: 583–90. http://dx.doi.org/10.1144/jgs2013-113

KUTSCHERA, W., M. BIETAK, E.M. WILD, C. BRONK RAMSEY, M. DEE, R. GOLSER, K. KOPETZKY, P. STADLER, P. STEIER, U. THANHEISER & F. WENINGER. 2012. The chronology of Tell el-Daba: a crucial meeting point of ^{14}C dating, archaeology, and Egyptology in the 2^{nd} millennium BC. *Radiocarbon* 54: 407–22.

LILYQUIST, C. 1995. *Egyptian stone vessels. Khian through Tuthmosis IV.* New York: Metropolitan Museum of Art.

LINDBLOM, M. & S.W. MANNING. 2011. The chronology of the Lerna shaft graves, in W. Gauss, M. Lindblom, R.A.K. Smith & J.C. Wright (ed.) *Our cups are full: pottery and society in the Aegean Bronze Age. Papers presented to Jeremy B. Rutter on the occasion of his 65^{th} birthday* (British Archaeological Reports international series 2227): 140–53 Oxford: Archaeopress.

MACDONALD, C.F. 2005. *Knossos.* London: Folio Society.

MACGILLIVRAY, J.A. 2014. A disastrous date. *Antiquity* 88: 288–89.

MAGUIRE, L.C. 2009. *Tell el-Dab'a XXI. The Cypriot pottery and its circulation in the Levant*. Vienna: Austrian Academy of Sciences Press.

MANNING, S.W. 1999. *A test of time: the volcano of Thera and the chronology and history of the Aegean and east Mediterranean in the mid-second millennium BC.* Oxford: Oxbow.

– 2014. Revisit essay: the Thera/Santorini debate 13+ years on, in S.W. Manning *A Test of Time and A Test of Time Revisited*: *the volcano of Thera and the chronology and history of the Aegean and east Mediterranean in the mid-second millennium BC*: 1–198. Oxford: Oxbow.

MANNING, S.W. & B. KROMER. 2012. Considerations of the scale of radiocarbon offsets in the east Mediterranean, and considering a case for the latest (most recent) likely date for the Santorini eruption. *Radiocarbon* 54: 449–74.

MANNING, S.W., C. BRONK RAMSEY, W. KUTSCHERA, T. HIGHAM, B. KROMER, P. STEIER & E.M. WILD. 2006. Chronology for the Aegean Late Bronze Age 1700–1400 B.C. *Science* 312: 565–69. http://dx.doi.org/10.1126/science.1125682

– 2009. Dating the Santorini/Thera eruption by radiocarbon: further discussion (AD 2006–2007), in S.W. Manning & M.J. Bruce (ed.) *Tree-rings, kings and Old World archaeology and environment: papers presented in honor of Peter Ian Kuniholm*: 299–316, 327–28. Oxford: Oxbow.

MANNING, S.W., B. KROMER, M.W. DEE, M. FRIEDRICH, T.F.G. HIGHAM & C. BRONK RAMSEY. 2013. Radiocarbon calibration in the mid to later 14th century BC and radiocarbon dating Tell el-Amarna, Egypt, in A.J. Shortland & C. Bronk Ramsey (ed.) *Radiocarbon and the chronologies of ancient Egypt*: 121–45. Oxford: Oxbow.

MOELLER, N. & G. MAROUARD with a contribution by N. AYERS. 2011. Discussion of late Middle Kingdom and early Second Intermediate period history and chronology in relation to the Khayan sealings from Tell Edfu. *Ägypten und Levante* 21: 87–121.

MÜLLER, V. 2006. Wie gut fixiert ist die Chronologie des Neuen Reiches wirklich? *Ägypten und Levante* 16: 203–30.

PANAGIOTAKOPULU, E., T. HIGHAM, A. SARPAKI, P. BUCKLAND & C. DOUMAS. 2013. Ancient pests: the season of the Santorini Minoan volcanic eruption and a date from insect chitin. *Naturwissenschaften* 100: 683–89. http://dx.doi.org/10.1007/s00114-013-1068-8

POLLARD, A.M. & P. BRAY. 2007. A bicycle made for two? The integration of scientific techniques into archaeological interpretation. *Annual Review of Anthropology* 36: 245–59. http://dx.doi.org/10.1146/annurev.anthro.36.081406.094354

PORTER, R.M. 2013. The Second Intermediate period according to Edfu. *Göttinger Miszellen* 239: 75–80.

QUILES, A., E. AUBOURG, B. BERTHIER, E. DELQUE-KOLI, G. PIERRAT-BONNEFOIS, M.W. DEE, G. ANDREU-LANOË, C. BRONK RAMSEY & C. MOREAU. 2012. Bayesian modelling of an absolute chronology for Egypt's 18th Dynasty by astrophysical and radiocarbon methods. *Journal of Archaeological Science* 40: 423–32. http://dx.doi.org/10.1016/j.jas.2012.05.026

REIMER, P.J., E. BARD, A. BAYLISS, J.W. BECK, P.G. BLACKWELL, C. BRONK RAMSEY, C.E. BUCK, H. CHENG, R.L. EDWARDS, M. FRIEDRICH, P.M. GROOTES, T.P. GUILDERSON, H. HAFLIDASON, I. HAJDAS, C. HATTÉ, T.J. HEATON, D.L. HOFFMANN, A.G. HOGG, K.A. HUGHEN, K.F. KAISER, B. KROMER, S.W. MANNING, M. NIU, R.W. REIMER, D.A. RICHARDS, E.M. SCOTT, J.R. SOUTHON, R.A. STAFF, C.S.M. TURNEY & J. VAN DER PLICHT. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55: 1869–87. http://dx.doi.org/10.2458/azu_js_rc.55.16947

RITNER, R.K. & N. MOELLER. 2014. The Ahmose 'Tempest Stela', Thera and comparative chronology. *Journal of Near Eastern Studies* 73: 1–19. http://dx.doi.org/10.1086/675069

ROAF, M. 2012. The fall of Babylon in 1499 NC or 1595 MC. *Akkadica* 133: 147–74.

SCHNEIDER, T. 2008. Das Ende der kurzen Chronologie: eine kritische Bilanz der Debatte zur absoluten Datierung des Mittleren Reiches und der zweiten Zwischenzeit. *Ägypten und Levante* 18: 275–313.

– 2010. Contributions to the chronology of the New Kingdom and the Third Intermediate period. *Ägypten und Levante* 20: 373–403.

STERBA, J.H., K.P. FOSTER, G. STEINHAUSER & M. BICHLER. 2009. New light on old pumice: the origins of Mediterranean volcanic material from ancient Egypt. *Journal of Archaeological Science* 36: 1738–44. http://dx.doi.org/10.1016/j.jas.2009.03.031

WARBURTON, D.A. (ed.). 2009. *Time's up! Dating the Minoan eruption of Santorini*. Athens: Danish Institute at Athens.

WARREN, P. 2009. The date of the Late Bronze Age eruption of Santorini, in D.A. Warburton (ed.) *Time's up! Dating the Minoan eruption of Santorini*: 181–86. Athens: Danish Institute at Athens.

– 2010a. The date of the Late Bronze Age eruption of Santorini on the basis of the historical chronology. *Pasiphae* 4: 67–72.

– 2010b. The absolute chronology of the Aegean circa 2000 B.*C.–1400 B.C.* A summary, in W. Müller (ed.) *Corpus der minoischen und mykenischen Siegel. Beiheft 8: Die Bedeutung der minoischen und mykenischen Glyptik*: 383–94. Mainz: von Zabern.

WIENER, M.H. 2010. A point in time, in O. Krzyszkowska (ed.) *Cretan offerings: studies in honour of Peter Warren*: 367–94. London: British School at Athens.

– 2012. Problems in the measurement, calibration, analysis, and communication of radiocarbon dates (with special reference to the prehistory of the Aegean world). *Radiocarbon* 54: 423–34.

WILD, E.M., W. GAUSS, G. FORSTENPOINTNER, M. LINDBLOM, R. SMETANA, P. STEIER, U. THANHEISER & F. WENINGER. 2010. ^{14}C dating of the Early to Late Bronze Age stratigraphic sequence of Aegina Kolonna, Greece. *Nuclear Instruments and Methods in Physics Research B* 268: 1013–21. http://dx.doi.org/10.1016/j.nimb.2009.10.086

Received: 11 April 2014; Accepted: 14 August 2014; Revised: 22 August 2014