Chronology Going Forward (with a Query about 1525/4 B.C.)

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I like to be particular in dates,
Not only of the age, and year, but moon;
They are a sort of post house, where the Fates
Change horses, making history change its tune,
Then spur away o'er empires and o'er states,
Leaving at last not much besides chronology,
Excepting the post-obits of theology.

Lord Byron, *Don Juan:* Canto I (1818–1819)

It is an honor and a pleasure to present this paper on future directions in chronology to Manfred Bietak, whose contribution to the study of the chronology of the ancient world through scholarship, excavation and the creation of the Austrian Academy SCIEM Project will have a lasting impact on our understanding of the history of humanity.

It has been said that progress in science comes largely through discrediting false hypotheses. Accordingly, it is worth noting that prior claims that the eruption of Thera could be dated either c. 1645 B.C. on the basis of the chemical composition of glass shards in Greenland ice cores or c. 1650 B.C. on the basis of growth anomalies in tree rings (replacing previous support for 1628 B.C.) have now largely been abandoned, even by some who had been leading proponents of these dates (*e.g.*, Manning *et al.* 2002b; corrected by Manning 2004b. For recent discussions of the issues, see Bronk Ramsey *et al.* 2004b; Hammer *et al.* 2003; Keenan 2003; forthcoming; Pearce *et al.* 2004; Wiener 2003a; SCIEM 2nd EuroConference 2003 forthcoming). Pearce and Keenan independently reconsidered and rejected the chemical and statistical analysis performed by Hoppe at Mainz of the microscopic glass shards from the Greenland ice-core laminations dated to 1645 ±4 B.C. by Hammer; additional glass shards adjacent to those previously analyzed have been provided by Hammer to Fischer for examination utilizing state-of-the-art equipment and techniques available in Stockholm. The preliminary report supports the proposition that the eruption of Thera can be excluded as a source of the Greenland shards dated to 1645 ±4 B.C. (Fischer, pers. comm.) and opens a path to analysis of possible traces of major volcanic eruptions in other datable ice-core laminations (see below). Recognition should be given, however, to the fact that isotopic analysis of glass shards in ice cores is likely to produce information that is at least somewhat noisy, given the fact that the shards, often less than a tenth the width of a human hair, have traveled thousands of miles through the atmosphere and stratosphere and that variation may exist in particles from the same volcanic eruption (George *et al.* 2004. I thank N. Pearce for calling this article to my attention; Pearce 2004).

In the field of dendrochronology also, a number of false starts have been corrected and significant progress achieved. With respect to tree-ring growth anomalies, it is now clear that many factors affect tree-ring growth besides eruptions, and similarly that many factors affect whether a volcanic eruption, even if massive, will be reflected in a particular set of tree rings (Warren 1984; 1998, 324; Wiener 2003a, 379; SCIEM 2nd EuroConference 2003 forthcoming). The proposal that a growth anomaly in the Anatolian sequence could be dated to 1159 B.C. and the years following, thus providing not only a possible sign of a climatic disturbance capable of affecting events at the end of the Bronze Age, but also part of an anchor for the Anatolian "floating chronology" because of indications of a significant event at that time in trees of known date in the British Isles, is no longer considered valid (Kuniholm *et al.* 1996; Manning *et al.* 2001). (The more significant anchor for the floating chronology, based on the then-proposed link at 1628 B.C. between indications of an event in the trees in the British Isles and at Porsuk in Turkey in that year, has been similarly superseded.) Previously proposed dates for the floating chronology, together with all dendro-derived dates dependent on it, have been revised upward by 22 +4/−7 years, as noted below. Dates for the firewood or dunnage carried aboard the Uluburun ship (Manning *et al.* 2001, 2535 n. 38; Wiener 1998, 313–314; 2003b) were among those affected by the revision, but whether the wood in question, presumably gathered in Syria, the Levant or Cyprus, can be dated by comparison with the Gordion sequence is also being reconsidered. Revised hypothesized dendro dates for the Uluburun branches may be published shortly (Kuniholm *et al.* 2005; Newton, pers. comm. of 19 August 2004).

A new anchor has been proposed for the Anatolian floating chronology, with a stated range at two sigma (95.4% statistical confidence, presupposing a Gaussian bell curve distribution) of +4/–7 years initially and now believed likely to be accurate to within 0–3 years (KUNIHOLM *et al.* 2005; NEWTON and KUNIHOLM 2004, 171). Decadal radiocarbon determinations at over fifty points in the Anatolian sequence have been compared to radiocarbon determinations from points at known dates in the continuous calibration curve sequence and the "wiggles" in the two sequences matched. The revised placement for the floating chronology finds confirmation in the dating of logs used to construct a temple at Ayanis in Urartu dedicated in the reign of Rusa II, a ruler whose regnal dates are known within a circumscribed range through independent historical sources. Rusa II's dates fit well with the last preserved rings of logs from the temple in Ayanis in 677–73 B.C. and a final floating chronology ring date of c. 649 B.C. Moreover, this chronology has now been extended to cover a 2009-year span from c. 2657 to 649 B.C. (subject to a slight degree of uncertainty regarding one area of putative overlap in the EBA), a major achievement (NEWTON and KUNIHOLM 2004).

The historical significance is already clear. Dendro analysis utilizing the new placement of the Anatolian floating chronology has supplied dates for Karum II and Karum Ib levels at sites in Anatolia, including construction dates for well-known buildings at these sites; clarified the sequence of events at Iron Age Gordion (DEVRIES *et al.* 2003; MANNING *et al.* 2001; MANNING *et al.* 2003); and provided some provisional support for a low, but not ultra-low, Babylonian chronology (KUNIHOLM *et al.* 1996, 782; see also note 6 below). Of potential major future significance is the fact that access to Egyptian wood has been obtained at last, thanks to the initiative of Manfred Bietak. Egyptian samples are currently under study by Cichocki.

Recent developments in radiocarbon dating also provide both grounds for optimism and reasons for caution in the interpretation of data, in general and in particular with respect to proposed dates for the eruption of Thera. Greater precision in measurement, recognition of the importance of measurement duration in the case of AMS dating or number of repetitions in the case of laser-based spectrometry dating, narrowing of inter-lab differences in measurements, increasing awareness of problems inherent in pre-treatment procedures, a greater appreciation of intra- and inter-year variation, efforts to address the problem of regional variation in ^{14}C absorption, and increased numbers of improved calibration curve determinations on decadal samples of wood of known date have in general produced more reliable and accurate date ranges, while also clarifying the problems which remain (BRONK RAMSEY *et al.* 2004a; MANNING 2004a; REIMER 2001; WIENER 2003a, 380–387; SCIEM 2nd EuroConference 2003 forthcoming).[1]

Simultaneously (and in large part due to these advances), claims have appeared with regard to the accuracy and reliability of ^{14}C dates that are sometimes difficult to sustain in light of the relative paucity of data from high-precision laboratories employing current pre-treatment regimes compared to the inherent uncertainties of measurement. In particular, problems relating to determinations from Thera which fall within the period of the oscillating calibration curve of the seventeenth–sixteenth centuries B.C. require special consideration respecting matters scientific, statistical, stratigraphic and contextual (BRONK RAMSEY *et al.* 2004a; GILBOA and SHARON 2003, 58–60; KEENAN 2002, 225; VAN DER PLICHT and BRUINS 2001; WARREN 1998; WIENER 2003a; SCIEM 2nd EuroConference 2003 forthcoming). The basic problem remains as stated in 1988 by Aitken, then the Director of the Oxford Radiocarbon Accelerator Unit:

> Samples grown anytime within the span of calendar years 1620–1530 B.C. will have radiocarbon ages that are the same to within ±20 years and hence be indistinguishable even if measured in a high precision laboratory. It would be necessary for the date to be as early as c. 1650 B.C. in

[1] For example, the Oxford AMS laboratory has reported the results of a test on decadal segments of known-age wood supplied by Queens University at Belfast and calibrated to the INTCAL98 calibration curve. Ninety-six samples measured showed an overall bias of 8.9 ±3.3 years toward earlier dates (BRONK RAMSEY *et al.* 2004a, 22). In special cases where a steeply sloped segment of the calibration curve meets an oscillating range (as in the seventeenth–sixteenth centuries B.C.), an 8.9 ±3.3 year difference can result in a major extension of the calibrated date range. BRONK RAMSEY *et al.* (2004a, 24) identify pre-treatment as "the critical link in the measurement chain, both in terms of the removal of contaminants and the bias introduced in the processes themselves".

order for the radiocarbon age to be distinguishable from that corresponding to 1620–1530 B.C.; this is a fact of nature—of the radiocarbon content of the atmosphere (AITKEN 1988, 21–22).

Both the fundamental physical processes causing oscillations in the amounts of ^{14}C reaching the earth and the causes of regional variation in radiocarbon measurements which themselves vary over time are imperfectly known, with various explanations of the latter phenomenon proposed (KEENAN forthcoming; KROMER *et al.* 2001; 2004; MCCORMAC *et al.* 2002; WIENER SCIEM 2nd EuroConference 2003 forthcoming). Questions pertaining to the particular properties of Thera itself and of thermal faults in the Aegean with respect to the possible presence of old carbon require further investigation (KEENAN 2002; MANNING *et al.* 2002a; WIENER SCIEM 2nd EuroConference 2003 forthcoming).[2] Preliminary reports of ^{14}C studies of material from Egypt and from Kerma suggest dates, particularly in the Second Intermediate Period, which appear somewhat older than the dates suggested by the archaeological material in the strata in question (STADLER *et al.* forthcoming; BONNET and VALBELLE forthcoming); accordingly, further attention to radiocarbon issues relating to delta and riverine environments is indicated, together with analysis of the intra-year effect of the calendrical difference in growing season between Nile plants and the European trees on which the calibration curve is based. (MARÉE forthcoming contains the most recent archaeological analyses of the history of the Second Intermediate Period.)

Finally, methods of presentation of radiocarbon data, and especially data relating to the dating of the Theran eruption, have sometimes resulted in misunderstandings, even among readers with long experience in this area. In particular, explicit acknowledgment should be made that the term "probability" as generally used in the presentation of radiocarbon dates refers to postulated *measurement* accuracy, not *date* accuracy. For example, neither the possible presence of old carbon in the sample nor the potential effects of regional variation in radiocarbon absorption in relation to the trees measured in the particular calibration curve utilized are incorporated in statements of measurement probability (although investigators sometimes state separately why they discount any likelihood of such effects).[3] Efforts now underway look toward the clarification and standardization of reports and discussions of radiocarbon dating (see endnote).

Significant progress may also be at hand in the field of Egyptian astronomy. Krauss contends that further analysis of Egyptian lunar observations establishes 1479 B.C. as the date of the accession of Tuthmosis III beyond reasonable doubt (KRAUSS SCIEM 2nd EuroConference 2003 forthcoming; see also KITCHEN 1987, 40; 1992; 1996, 6–7; 2000; 2002; contra WELLS 1992; 2002; SPALINGER 1992). If so, 1479 B.C. will supplant 911 B.C., the earliest year available from the continuous Assyrian records, as the earliest definite year in human history.

Of course archaeology continues to provide important new evidence. In the Near East, a recently discovered text at Assur contains correspondence between Meli-shipak of Babylon and an Assyrian ruler believed to be Ninurta-apil-Ekur, thus providing confirmation of the overlap in the reigns of these rulers proposed thirty years ago by BRINKMAN (1976) on the basis of his analysis of the chronologies of Assur and Babylon, with the overlap occurring at 1186–1179 B.C. Pfälzner now believes Near Eastern chronology after c. 1450 B.C. to be accurate to within a very few years, with the fall of Babylon occurring c. 1531 B.C. in accordance with the Babylonian low (but not ultra-low) chronology (PFÄLZNER 2004). Finally, the excavation at Tell el-Dabᶜa by

[2] One recent study suggests that a short release of carbon at the height of a plant's growing season can have a significant effect, given that "more than 5% of a plant's leaf carbon content may be replaced over a day" (MILTON *et al.* 1995, 492–493). Unless plants reach a somewhat uniform saturation point with respect to the absorption of old carbon, however, such uptake should result in widely varying measurements, dismissible as "outliers".

[3] An example of the difference between measurement and date probability may be useful. Radiocarbon determinations from present-day plants growing at distances of five and ten meters from the current volcanic emission source at Palea Kameni on Thera produced ages of 1000 and 1400 years respectively (BRUNS *et al.* 1980, 535). There is no reason to doubt the accuracy of the ^{14}C measurements in question, but the dates obtained for the contemporary plants were far off the mark. (Discrepancies of this magnitude would of course cause the dates obtained to be rejected as outliers in any analysis.) Whether seeds may be subject to small and hence unrecognized systemic errors is unclear, although arguably somewhat unlikely. Old carbon effects at distances up to 15 km from vents have been reported in Italy (ALLARD *et al.* 1991; WIENER SCIEM 2nd EuroConference 2003 forthcoming).

Manfred Bietak, and his magisterial publications analyzing the finds there with regard to Near Eastern, Cypriot and Aegean evidence, have greatly advanced our knowledge of chronological interconnections and revealed the limits of the possible with regard to Aegean mid-second millennium B.C. dates (BIETAK 2004; see also BIETAK 2003a; BIETAK and HEIN 2001; BIETAK *et al.* 2002).

FUTURE DIRECTIONS: A QUERY ABOUT 1525 B.C.

Dendro and ice-core based efforts to date the Theran eruption in the past have sought to link the eruption to the most significant tree-ring and ice-core indicators within the time frame considered possible by the investigator. This approach was animated partly by the fact that the Theran eruption was clearly massive in scale, and partly by past uncertainty about the archaeological evidence. The period examined was extended back as far as 1670 B.C. in light of radiocarbon dates which seemed to give sanction (and to some, strong support) to a seventeenth-century B.C. date. The increasing weight of the archaeological/textual evidence in support of an Aegean Short Chronology date, together with the realization that many factors other than the degree of explositivity of an eruption affect whether an eruption is likely to be represented in tree-ring and ice-core evidence (WIENER SCIEM 2nd EuroConference 2003 forthcoming), suggest that it may be appropriate to reverse the process and inquire whether scientific support can be found for dates within the period now apparently indicated by the archaeological evidence. A logical starting point is a research effort focused on the year 1525–1524 B.C.

(1) 1525 B.C. appears to be about the earliest date tenable on archaeological grounds. Indeed, a somewhat later date might appear preferable on solely archaeological grounds in light of the Tell el-Dab^ca evidence (BIETAK 2004). A date of 1530–1520 B.C. for the eruption was proposed in 1989 in WARREN and HANKEY on the basis of pottery and other interconnections between Egypt and the Aegean; c. 1520 B.C. is the current Warren preference (WARREN 1999). Somewhat earlier dates are still possible, but the earlier the date proposed prior to 1525 B.C., the more difficult it is to reconcile with the archaeological evidence.

(2) 1525 B.C. appears to be about the latest date consistent with the radiocarbon evidence from Thera and elsewhere (assuming that measurements were not affected by the presence of old carbon or some other distorting factor). In fact an earlier date may appear preferable on radiocarbon dating grounds alone (MANNING and RAMSEY 2003; but see also WIENER 2003a; SCIEM 2nd EuroConference 2003 forthcoming). After 1525 B.C., the calibration curve begins a steep decline which makes post-1525 B.C. dates for the eruption increasingly unlikely (WIENER 2003a, 391–392. The INTCAL04 correction [REIMER *et al.* 2004] to the INTCAL98 aberration resulting from measurement for the decade centered on 1515 B.C. noted by WIENER in SCIEM 2nd EuroConference 2003 forthcoming does not significantly change the picture).

(3) Tree-ring evidence indicates an event of worldwide impact, probably volcanic in origin, in rings of 1524 B.C. In 1525–1524 B.C., tree rings of bristlecone pine from two locations at the upper forest border in the White Mountains of California and from Mt. Washington in Nevada, collected and analyzed by the Laboratory of Tree-Ring Research at the University of Arizona, display indications consistent with a weather-forcing volcanic event (SALZER and HUGHES 2003). Potential indications of a volcanic event were noted in the years 1652, 1649, 1641, 1626, 1597, 1558, 1549, 1544, 1524, 1520 and 1486 B.C. (Averaging the three locations, each of these years displayed rings in the narrowest 5% of annual rings over the last 5000 years.) Other years which display very narrow rings at high elevations, such as 1571 and 1499 B.C., were discounted as volcano-linked because rings of these years also displayed very low growth in trees at low elevations, and were thus deemed more likely to have been drought years (SALZER, pers. comm. of 2 August 2004). (Indications at 1570 in the Siberian tree-ring sequence and at 1569 ±4 B.C. in the ice-core record, if caused by the same event as the 1571 B.C. indication in the bristlecone pines, may suggest a volcanic source for all, however.) Two of the years examined, 1652 and 1524 B.C., show extreme low growth at high elevation but not as much decline at low elevation, a pattern likely to result from decreased temperature rather than drought. Accordingly, these two years are deemed the most likely of all to reflect a volcanic event. In the early nineteenth-century A.D. (prior to the appearance in the atmosphere of the direct carbon dioxide fertilization effect resulting from the expansion of agriculture and the beginning of industrialization, which nullified future indicators), two known volcanic eruptions, Tambora in 1815 and Cosiguina in 1835, were followed by small growth rings at high elevations in the succeeding year. The event reflected in the ring of 1524 B.C. may have occurred in 1525 B.C. in similar fashion. Salzer estimates that the putative volcanic event responsible

for the narrow ring occurred between the summers of the two years (pers. comm. of 8 March 2004).[4]

An event in the year 1524 B.C. appears widely in the rings of larch trees from the Yamal Peninsula in northwestern Siberia, from a site at approximately 72° N (SALZER and HUGHES 2003; citing HANTEMIROV and SHIYATOV 2002; plus personal examination of the Yamal Peninsula data, SALZER pers. comm. of 31 July 2004).[5]

The Gordion Anatolian sequence also has a somewhat narrow ring at 1524 ±3 B.C.[6] 1524 B.C. is in addition one of the many years represented by a narrow ring in the Irish records (*e.g.*, 1540, 1539, 1527, 1524, 1510, 1498 and 1495 B.C.) but there is no reason to believe that any of them was caused by a volcanic eruption (BAILLIE, pers. comm. of 18 March 2000), at least not when considered in isolation. Narrow rings occurring at various places around the world in the same year suggest a major world-scale event, however, and may well result from a major volcanic eruption. Recent analysis of the Theran eruption (MCCOY and HEIKEN 2000) indicates an event even more massive (at an estimated 7.0 on the Richter Scale) than earlier calculations. Whether even a massive eruption will be reflected in a particular tree-ring record depends, however, not only on proximity and wind direction at the time of the eruption, but also critically on whether the eruption occurs during the primary growing season of the trees.

(4) An examination of the case for a Theran eruption in 1525–4 B.C. reintroduces the questions surrounding the Ahmose Tempest Stela. Ahmose, the founder of the New Kingdom in Egypt who reigned between c. 1539 and 1515 B.C. (KITCHEN 1996, 6; 2000, 44; KRAUSS SCIEM 2nd EuroConference 2003 forthcoming), erected a stela at Thebes describing a great storm and his efforts to restore order in Egypt, including the refounding of Egyptian temples which had been left to decay. Several distinguished scholars, including VANDERSLEYEN (1967; 1968), DAVIS (1990), GOEDICKE (1992), and most recently FOSTER and RITNER (1996) have sought to connect the storm described in the stela to the Theran eruption.

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4 Forty-seven separate logs or dead trees from higher elevations at different places on Sheep Mountain were collected in the study, of which thirty-seven produced readable rings, a significantly greater database than that originally sampled by LaMarche, when two trees apparently provided the ring dates for 1628 B.C. (SALZER and HUGHES 2003; LAMARCHE and HIRSCHBOECK 1984; and subsequent personal discussions with Christine Hallman of the Arizona laboratory, for which I am most grateful).

5 It should be noted that other years familiar from the tree-ring literature in connection with discussions of the Theran eruption are well represented in the Yamal Peninsula larch trees, *i.e.*, 1653, 1627–1625, and 1570 B.C. (HANTEMIROV and SHIYATOV 2002). The years 1628–1626 B.C. are of course already known from the White Mountain bristlecone pines and the Irish and British oaks, but are not represented at Porsuk near the Cilician Gates in the revised Anatolian floating chronology sequence.

If the 1653 B.C. ring event in the Yamal Peninsula trees and the 1652 B.C. ring event in the bristlecone pines of the White Mountains and Mt. Washington are related and have the same origin as the major growth spurt at Porsuk placed at 1650 ±3 B.C. in the Anatolian floating chronology, then the Near Eastern dates proposed in accordance with the latter would move higher by two to three years, the ±3 range would disappear, and the floating chronology would at last be fixed. This hypothesis requires that the stunted tree growth caused by a drop in temperatures at very high altitudes resulting from a volcanic eruption be matched by a growth spurt caused by eruption-induced heavy rains at ground level in a somewhat arid climate at Porsuk in Turkey. (At Gordion, the single tree recovered that grew those years, from the Kızlarkaya Tumulus, shows no similar growth spurt, but there is no way to determine whether the Gordion tree came from a semi-arid zone. The tree was born 118 years before the putative event and lived for 800 years thereafter [NEWTON, pers. comm. of 18 August 2004], suggesting a hardiness not easily disturbed.) 1653 B.C. is also just outside the range indicated by Hammer *et al.* for their 1645 ±4 B.C. Greenland ice-core event. If, on the other hand, the somewhat narrow ring of 1524 ±3 B.C. at Gordion (see below) was caused by the same event represented in other narrow rings of that known date, then the Anatolian floating chronology would be fixed at its present location, again with the ±3 leeway no longer required.

Of course there is no way at present of establishing whether the 1650 ±3 B.C. event at Porsuk was volcano-driven and, if so, whether the eruption in question was the same event as that represented in the California and Siberia trees. Massive eruptions of both Hayes and Aniakchak in Alaska are believed to have occurred in or about the seventeenth-century B.C. (BEGÉT *et al.* 1992). Hantemirov and Shiyatov report evidence of double cooling events in the Yamal Peninsula trees in the seventeenth-century B.C. around 1652 and 1628 B.C., possibly caused by volcanic eruptions (HANTEMIROV and SHIYATOV 2002, 725–726).

1570 B.C. in the Siberian tree rings may match an ice-core event placed at 1569 ±4 B.C. Glass particles of that date in the ice core deserve careful examination with respect to the possibility of a Theran source.

6 It is conceivable that nutrients from a tephra deposit or major rains following an eruption could result in a growth spurt in one place in the same year that clouds caused by tephra in the atmosphere produced a year of low growth in another, particularly if moisture conditions in the two areas differ at the time of the eruption.

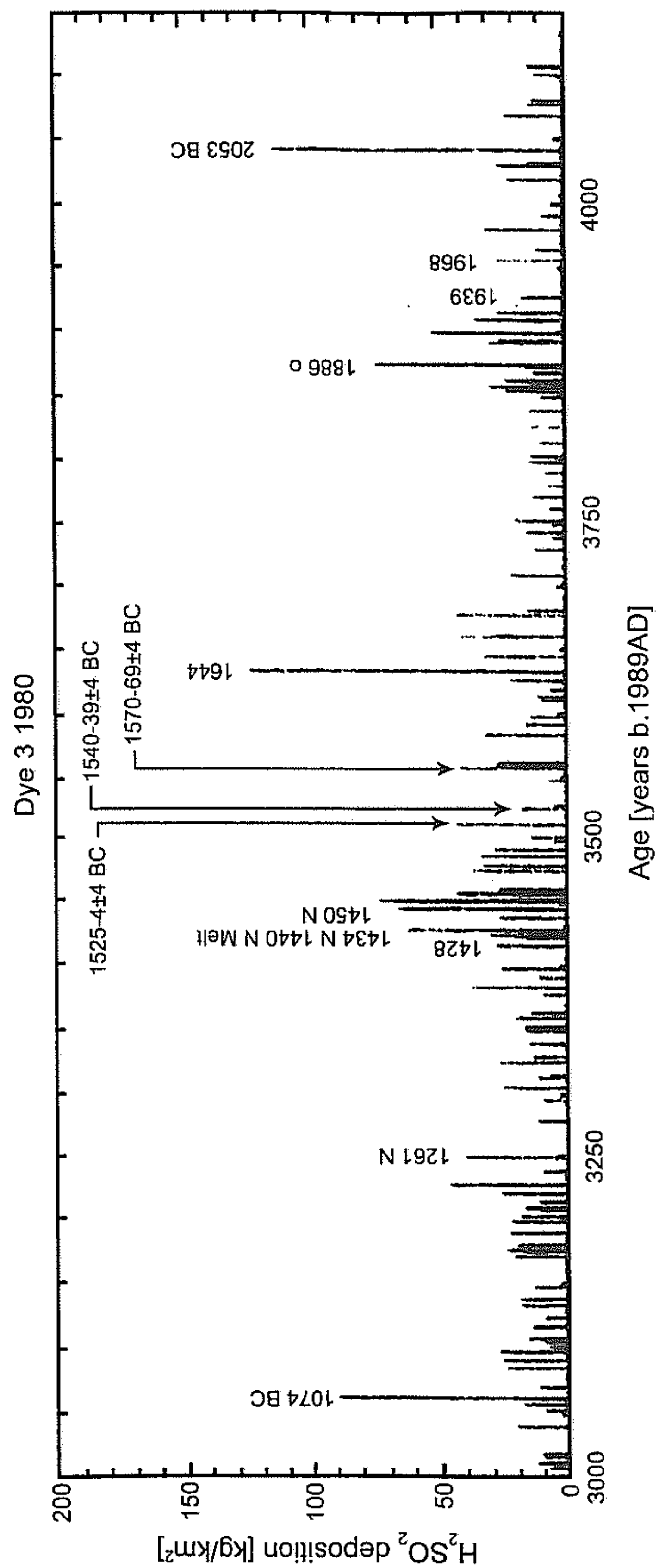

Fig. 1 Dye 3 Greenland ice-core profile (after CLAUSEN *et al.* 1997)

WIENER and ALLEN (1998) responded to Foster and Ritner in a paper challenging the bases of the proposed connection. They argued that the text of the stela was in general characteristic of a genre of texts describing the restoration of order by rulers. Allen further proposed that the terminology of the stela suggested willful human agency as the cause of the destruction of the tombs and mortuary monuments described and neglect as the cause of the damage to the temples. Wiener noted that the text spoke of a darkness appearing in the west whereas Thera lies 1300 km to the north-northwest of Thebes, and further that the great monsoons which originate in the Indian Ocean and sweep up the Nile at intervals bring darkened skies and noise such as the stela describes, together with devastating floods and landslides on occasion. He also pointed to the abundant evidence of tephra fallout from the eruption found in locations to the east of Thera, leaving no doubt as to the eastward direction of winds at the time of the eruption.

Foster and Ritner contended that the stela was erected between the 11th/15th and 22nd year of Ahmose's reign. 1525–4 B.C. would fall in the 14th–15th regnal year if the reign began in 1539 B.C. Allen, however, argued that the text implied actions taken on behalf of Ahmose immediately upon his accession c. 1539 B.C., and hence incompatible with a storm caused by an eruption in 1525–4 B.C. Allen's date would match the narrow years appearing solely in the Irish tree-ring sequence at 1540 and 1539 B.C. and the slight indication of an event at or near that point in the Dye 3 ice core.

Foster and Ritner also argued that the presence at Tell el-Dabᶜa in the Nile Delta of sea-borne pumice identified isotopically with the Theran eruption in strata perhaps a generation after the reign of Ahmose (see now BIETAK 2004, 214–215) supported the proposed connection of the stela to the eruption. Wiener in reply argued that Theran pumice had appeared in the Aegean in post-eruption strata spanning more than a thousand years (WIENER 1998, 25–26), while agreeing that the absence of Theran pumice in earlier strata was significant, even as evidence *ex silentio*. He also noted that pumice frequently disappears through use as an abrasive, and that what remains is found mostly in workshop contexts from destruction deposits, often considerably later in time than the date of the eruption which produced the pumice. In sum, the purported connection between the pumice and the stela appeared to Wiener to be highly tenuous.

One Aegean deposit may be suggestive, however. Much Theran pumice was found on the island of Pseira off the north coast of Crete (BETANCOURT and DAVARAS 1988, 218; WIENER 1998, 26). Only about 10% of the pumice came from the LM IA eruption context itself, however, whereas around 90% came from the LM IB destruction context, perhaps about two generations later. On this analogy, pumice found in a stratum believed contemporaneous with the reign of Tuthmosis III could well be consistent with an Ahmoside date for the eruption. On balance, it would appear that the pumice evidence from Tell el-Dabᶜa neither supports nor contradicts an eruption date in the reign of Ahmose to any significant degree. While the purported origin of the tempest described in the stela of Ahmose in the Theran eruption still appears highly tenuous and the time of the erection of the stela within the reign of Ahmose uncertain, the possibility that the stela reflects the Theran eruption cannot be wholly excluded, nor can the further possibility that the stela refers to an event in 1525–4 B.C.

(5) Finally, 1525–4 B.C. brings us back full circle to the Greenland ice cores. In response to an inquiry as to whether a very small spike in the published Dye 3 ice-core profile (Figure 1) occurred in 1525–4 ±4 B.C., Claus Hammer, with customary generosity, replied that this was indeed the case. He kindly added that "it is probably a small volcanic signal, but we have not analyzed its chemical composition. The signal may be influenced by melt layers. Its peak only lasted a third of the year 1524 B.C. and has not a corresponding signal in the GRIP core; this indicates that the eruption did not occur in the Arctic and may barely have reached the stratosphere. Perhaps an eruption in America". Analyses to determine whether the chemical composition of the Dye 3 1570 B.C., 1540 B.C. or in particular the 1525 B.C. Dye 3 signal is consistent with the composition of tephra from Thera seems an obvious next step for chronology going forward.

On present evidence, the selection of the most likely of the dates depends on judgments concerning 1) whether the massive Theran eruption is likely to be represented in a number of tree-ring and/or ice-core sequences, and in major signals in some; 2) whether radiocarbon determinations to date are sufficient to suggest earlier dates and if so, how strongly and how many years earlier; and crucially 3) whether the archaeological/Egyptological evidence allows a date before c. 1525 B.C., and if so, how long before. The archaeological judgment in turn depends critically on how the Cypriot pottery evidence is assessed, how the apparent links between LM IB and the reign of Tuthmosis III are viewed, and how much separation in time can be accepted between the wall paintings of Thera and those of Tell el-Dab^ca brought to light by Manfred Bietak.

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Endnote

Protocols now in preparation for the presentation of (1) radiocarbon data and (2) contexts of samples may include the following recommendations:

(1) Duration of AMS measurements and number of repetitions of radiometric measurements on individual samples should be stated to enable readers to evaluate laboratory estimates of precision and accuracy of ^{14}C ages obtained. The size of the sample (*e.g.*, whether close to the minimum required or too small to be divided between labs), any problems noted by the laboratory technician performing the measurement (*e.g.*, unusual amount of humic acid of different date initially present), and any uncertainty regarding complete carbonization of the sample at the time of deposition should also be stated. If the radiocarbon determinations provide data that are internally inconsistent, thus requiring wide one and two sigma bands to contain the data (as in the case of a widely discussed piece of wood from Trianda in Rhodes with thirty years of rings, where adjacent decadal measurements provided dates eighty years apart and the outermost decade provided a ^{14}C determination earlier in date than the inner rings [Manning *et al.* 2002b, 740; Manning and Ramsey 2003, 118–122; Wiener 2003a, 388–389]), such inconsistencies should be clearly and conspicuously noted in the publication. The pre-treatment regime to which measured samples were subject should be noted as well. Because statements of calibrated radiocarbon date ranges may depend heavily on the discretion of the investigator (Manning 1995, 126–142; Wiener 2003a, 381–382), the grounds for such judgments should be set forth where possible, particularly when the judgment may well prove controversial, and particularly where the one and two standard deviation estimates provided are almost identical. Where decadal ^{14}C measures are presented as a stylized, smoothed succession of annual points, notwithstanding what is known concerning both intra- and inter-year variation, this should be made clear. The fact that the calibration curve determinations used to correct uncalibrated dates are themselves subject to many of the uncertainties affecting sample measurements should be stated. (Because of the uncertainty inherent in each decadal calibration measurement, the INTCAL04 restatement of the calibration curve incorporates information from several preceding and succeeding decadal measurements in order to mitigate the effects of errors in single decadal measurements and smooth the overall oscillations.) Where the growing season of seeds (*e.g.*, in Egypt) differs markedly from the main growing season of the trees (now generally European) used in calibration curve determinations, the possibility of significant intra-year variation in radiocarbon ages should be noted, as well as the likely direction of error (*e.g.*, older radiocarbon ages for the Egyptian seeds than for European tree rings of similar date). The archaeological correlates of all "Bayesian Boundaries" utilized in probabilistic analysis of radiocarbon measurements should be clearly stated where they are not self-evident (as in the case of a known accession date of a particular ruler or similar cases). In cases such as the frequently employed OxCal program where the term "boundary" is used in a special manner not necessarily consistent with general usage, the justification for the "boundaries" employed should be clearly stated.[i]

(2) All factors pertaining to the context and recovery of a measured sample should be stated, including whether the sample is recorded in the day-

[i] For example, the justification for the "Boundary 'Early LM IB to Late LM IB' " (Bronk Ramsey *et al.* 2004b, 344), also described as "the early/late LM IB transition which must pre-date 1520 B.C." (Bronk Ramsey *et al.* 2004b, 334), seems problematic. The "boundary" created is a program-generated construct to describe a point between the mature/final LM IA determinations from the Volcanic Destruction Level at Thera, which as a consequence of the oscillating calibration curve are consistent with dates encompassing 1525 B.C. at the low end, and the determinations from the LM IB destructions at Chania and Myrtos-Pyrgos, with dates encompassing c. 1485 B.C. at the low end.

book of the excavation (and if so, where and how). All relevant information regarding the stratigraphy and nature of the deposit from which the sample was obtained, whether the findspot appeared undisturbed by subsequent activity, anthropomorphic or geological, and whether the findspot was examined by a micromorphologist should also be stated. (There have been instances where an area has been described by a meticulous archaeologist as undisturbed, but by a micromorphologist as disturbed by natural processes.) Evidence of major grain storage at a site providing seed samples for testing should be noted,[ii] particularly when the dates obtained fall within a portion of the calibration curve where a decade or less difference in radiocarbon age can result in a difference of several decades in calibrated years.

Where space limitations do not permit the presentation of all information listed in (1) and (2) above, the information omitted should be provided on a website.

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[ii] The massive grain storage facilities at the citadel of Büyükkale in the Hittite capital of Hattusha provide an obvious example, further supported by texts pleading for emergency shipments of grain (SEEHER 2000, 295–299). A siege preventing the arrival of a harvest preceding a destruction level (in which radiocarbon dated samples are recovered) would provide a natural occasion for consumption of long-stored grain supplies. If no major grain storage areas have been excavated to date at a site, but the site in question is a capital of a significant polity containing other major structures and hence a place likely to have practiced social storage of grain (HALSTEAD 2000, 116–117), such information seems worth noting as well. (For example, it is not necessarily the case that the seeds found in the final LM IB destruction level at Chania were harvested in the year of the destruction [see MANNING *et al.* 2002b; WIENER 2003a, 391–393]).

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